The Impact of Disruptions along the I-95 Corridor on Congestion and Air Quality

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A report submitted to the University of Delaware University Transportation Center (UD-UTC)

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Overview

The following thesis "The Impact of I-95 Closures on Traffic and Air Quality." was submitted by Dung Ngo as partial requirements for the degree of Master of Civil Engineering. The thesis was completed under the supervision of Professor Earl (Rusty) Lee. The thesis serves as a final report for the University Transportation Center project "The Impact of Disruptions along the I-95 Corridor on Congestion and Air Quality."

THE IMPACTS OF I-95 CLOSURES

ON

TRAFFIC AND AIR QUALITY

by

Dung Ngo

A thesis submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Master of Civil Engineering

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ABSTRACT

Interstate 95 is a major corridor for vehicles and freight for the eastern United States. Extensive planning and review is needed to keep this corridor running as efficiently as possible, minimizing the impacts of construction or disruptions. The Delaware Department of Transportation (DelDOT) has established re-routing plans for portions of I-95 in Delaware. These plans provide guidance to system managers and law enforcement as to how to re-direct traffic in case sections of the interstate are closed. These plans are based on the knowledge and experience of the DelDOT Traffic Management Team. However, it is difficult to evaluate these plans since complete closures are thankfully rare events. There does exist a capability to evaluate these plans, without disrupting traffic, by using a simulation model. Using the DelDOT regional transportation planning model, which covers the entire DelMarVa Peninsula, a series of scenarios were developed and tested to evaluate the existing plans and suggest alternatives. Each scenario was compared to the un-disrupted condition and impact to drivers was measured by computing additional vehicle-miles travelled and vehicle-hours travelled and looking at the impact on the environment by the increased emissions. Recommendations and conclusions were developed as well as opportunities for future work.

Chapter 1

INTRODUCTION

Congestion is a problem in America's 439 urban areas, and continues to get worse. In 2007, congestion caused Americans to travel 4.2 billion hours more and to purchase an extra 2.8 billion gallons of fuel for a congestion cost of $87.2 billion – an increase of more than fifty percent over the previous decade (Schrank and Lomax 2009). Congestion is typically classified as recurring or non-recurring (Ju, Cook et al. 1987): recurring congestion is that which occurs during peak travel period and non-recurring is that which occurs at an irregulars frequency, such as crashes, disabled vehicles, work zones, adverse weather events, and planned special events. By divert traffic from the mainline to parallel freeway, arterials and streets, the alternate route plan help to minimize the effects of non-recurring congestion (Latoski, Dunn et al. 2003). This thesis will look at non-recurring delays that cause entire sections of I-95 to be closed, no matter the cause.

Interstate 95 is one of the most important routes along the East Coast of the United States, connecting Florida to Maine. In Delaware, I-95 runs 22 miles from the border of Maryland to the border of Pennsylvania. Interstate 95 is reported to contribute up to $4.7 trillion to the U.S. economy, or forty percent of U.S. gross domestic product to a region of about 110 million people (I-95 Corridor Coalition 2010). It was estimated that in 2040 the truck volume using I-95 could nearly double (Cambridge Systematics Inc. 2008).

The Delaware Department of Transportation has established re-routing plans for four closures areas of Interstate 95 (DelDOT 2010) are shown in Figure 1. While based on expert opinion and judgment, no evaluation had been done on the impact of these closures. This project will evaluate the impact on regional traffic and the emission effects from these proposed closures.

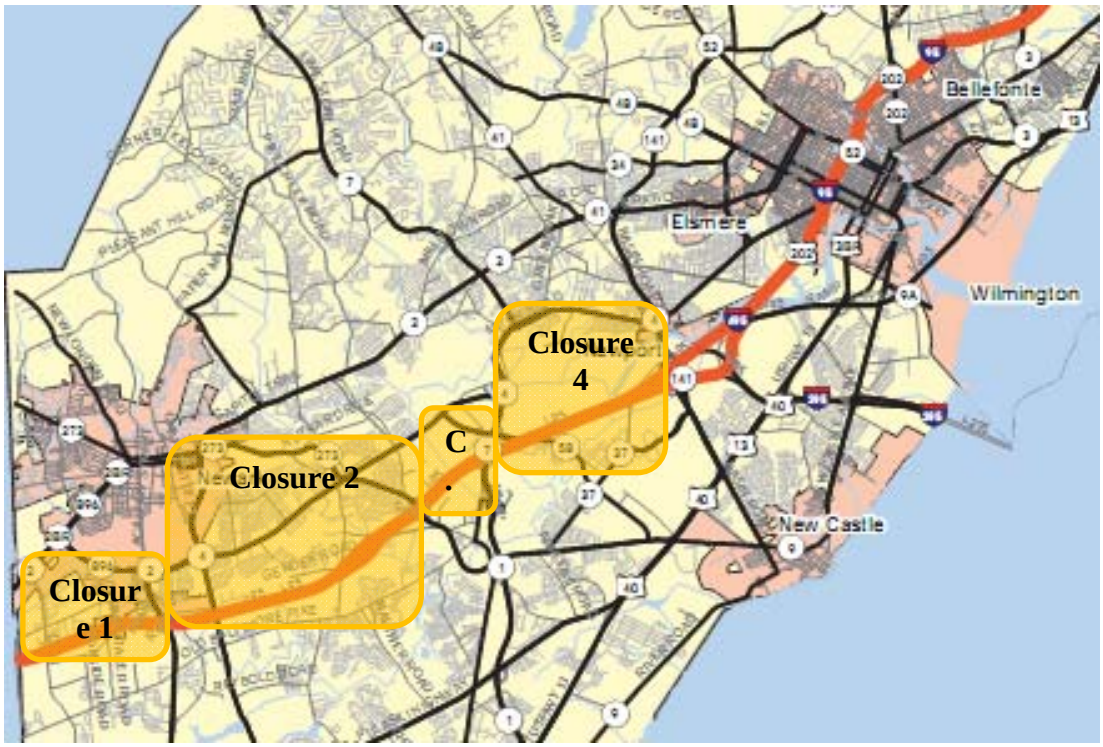

Figure 1 *Four closures of I-95 in the DelDOT plan*

Because the alternate routes accommodate both the traffic diverted from the interstate and its regular traffic load, the analysis must be examined carefully to minimize congestion of the overall network system and the adverse effects to the local road network.

The importance of advance planning of detour plans was to improve the on-scene traffic management capability of incident responders and managers from

multiple agencies (Dunn Engineering Associates 2006). Alternate route implementation provides improved safety and efficiency of the system under prolonged capacity restrictions and minimizes of adverse impacts on the surrounding zones.

Two approaches have been used for testing and evaluation of emergency scenarios. The first approach is the use of table-top exercises where emergency preparedness plans are tested using volunteers and participants from key agencies. The objectives of the drills were to test incident command structure, notification procedures, communications and coordination among agencies, as well as evacuation procedures and service restoration procedures. The ultimate goal was to understand possible vulnerabilities and weaknesses of the plan and revise it accordingly to better serve public safety interests. The second approach is through the use of simulation modeling. This is a good way to assess the impact of emergencies and response actions on the transportation network operations and test alternatives in a controlled environment without the need to disrupt traffic operations while testing (Sisiopiku, Jones et al. 2004).

Chapter 2

LITERATURE REVIEW

Major Disruptions to Traffic Systems

While large scale, long term disruptions to major transportation corridors are rare, they do occur. Examples include:

- The 1994 Northridge earthquake in California damaged the freeway network, including the Santa Monica Freeway (I-10) and the Antelope Valley Freeway (State Route 14)-Golden State Freeway (I-5) interchange.
- In 2002, a section of the Interstate 40 bridge over the Arkansas River in Oklahoma collapsed, after a barge crashed into bridge support pillars. It was estimated that approximate 20,000 vehicles per day were rerouted for about two months.
- In 2007, the I-35 bridge over the Mississippi River in Minneapolis, MN collapsed during repairs and resulted in the disruption of 140,000 daily vehicle trips.

Many of the past literature on traffic closures focused on policies and procedures, the roles and steps as well as the cooperation of related agencies and services to prevent, respond and recover from the closure when incidents happen.

Although there were number of projects were implemented to identify and evaluate of alternate routes, the use of travel demand model in large scale was limited.

Most of the simulation models focused on short-term closures and did not cover the emission effects.

Examples of Using Simulation to Aid Plan Development

CORSIM – a microscopic simulation model developed by the Federal Highway Administration was used by Cragg and Demetsky (1995) to analyze diversion strategies. To determine the effects to the network, the data required include incident types and durations, incident time and location. Several case studies were undertaken to test the application of the model to specific situation whose incident duration were given. CORSIM was also used to assess the impact of a planned closure of approximately seven miles of I-95 in Delaware (Allen, Duross et al. 2000). The paper concluded that a microscopic simulation was less useful than other options in analyzing traffic patterns at the system level. Although CORSIM has some advantages as a microscopic simulation, it also has limitations in modeling toll booths (ITT Industries and ATMS R&D and Systems Engineering Program Team 2006).

NETSIM , a microscopic simulation model developed by the Federal Highway Administration for simulating traffic operations on a surface street system, was chosen to examine the effectiveness of traffic diversions and signal timings on a street network (Taylor and Narupiti 1996). Three incident periods (5, 10, 15 minutes) and three types of incidents (a one-lane closure, a two-lane closure, and a reduction of the two-lane capacity to 15 percent of the original capacity) were considered. The results indicated that the traffic diversion with signal timing modification based solution can reduce congestion duration more effectively than when traffic metering and traffic diversion strategies are used separately.

Using The INTEGRATION simulation model for a case study of the I-29 corridor in Fargo, North Dakota, Birst and Smadi (1999) examined the feasibility of implementing an Incident Management System (IMS) in small/medium size urban areas. The potential benefits of an IMS which employs Advanced Traveler Information Systems (ATIS) and Advanced Traffic Management Systems (ATMS) were pointed out by the study, especially for incidents of less than 20 minute duration. To accommodate the diverted traffic from the freeway to the city arterials and to reduce the impact of incidents on the network, the ATMS is utilized incorporating optimized signal timing plans for the city arterials similar to Split Cycle Offset Optimization Techniques (SCOOT).

A methodology using SYNCHRO and CORSIM was presented to evaluate the effects of incident management and signal timing modifications on traffic operations along I-75 and alternative routes when a traffic incident happens on I-75, in Sarasota County, Florida (Zhou 2008). The simulation results showed that the percentage of diverted traffic volume had a great impact on the total delay of the entire network.

Son and N-Sang et al (2004) conducted an operational feasibility analysis of a diversion route for an urban freeway arterial in Springfield, Virginia. Timing plan optimization and lane assignment change strategies were considered. VISSIM, a stochastic and time-step behavior-based microscopic simulation model developed by PTV Inc. was used to estimate travel time and delay. The simulation results showed that current PM peak timing plan, a designated signal timing plan for freeway diversion, did not improve mobility of the arterial network during diversion.

Using adjacent arterials as a diversion route can be one feasible alternative (Son, N-Sang et al. 2004). However, in his work, Sisiopiku (2007) pointed out that most of the available studies in the literature focused on relatively small areas of consideration. This narrow focus could underestimate the effects of traffic diversions as well as the effectiveness of distributing the traffic diverted from incident link. In general, most prior studies did not consider.

Chapter 3

METHODOLOGY

The goal of this research was to evaluate the impacts of closures on Interstate 95 in Delaware. These impacts were measured as changes in travel time (induced delay) and total vehicle emissions from reduced speed and increased trip length. Also, the simulation model would indicate where the diverted traffic goes and the impact on regional traffic. The results of the model could also be compared to the existing closure plans developed by DelDOT. The measures of performance for this research are delay, vehicle miles traveled (VMT), vehicle hours traveled (VHT), level of service (LOS) performed by evaluating volume to capacity ratios (V/C) and emissions (volatile organic compounds (VOC), carbon monoxide (CO), nitrogen oxide (NOx), exhaust particulate matter (EXPM))

Three approaches for this analysis were considered:

Approach 1: The analysis could be implemented by manually diverting a specific volume of the existing traffic from the closed link to other links based on the experience of the system managers. The analysis would provide LOS and queues. This method would be relatively easy to explain. But the downside of this approach is that it can not achieve a system optimal since it is based on experience of the managers. Moreover, it is difficult to track impacts of local traffic diverting to avoid I-95, network travel time, especially for multiple alternative paths.

Approach 2: Computer based optimization using a travel demand model. With the aid of tools such as Cube Voyager, developed by Citilabs Inc., an optimum solution can be determined with outputs including LOS as well as system wide and user specific measures of performance (MOP's). This method also allows the evaluation of multiple alternatives. Processing time is lengthy for the approach but is satisfactory for developing plans, and wouldn't be suitable for real time management.

Approach 3: Travel demand/Micro-simulation with Dynamic Traffic Assignment. Using this method, the time interval step is reduced to provide higher levels of detail. Similar to approach 2, this method provides the optimum solution with the output of LOS and other user defined MOPs. But, this method requires more detailed data than approach 2.

Approach 2 was chosen for this project based upon available data and existing models. Specifically, using the DelDOT Planning Model built in Cube Voyager by Whitman, Requardt & Associates, LLP and DelDOT. This model is already in use by DelDOT for all planning studies, has been calibrated, and is current. The steps for the analysis are:

Step 1: Run the base scenario (using average annual daily traffic data for 2005)

Step 2: The DelDOT closure plans specify reroutes for eight locations along I95, four northbound and four southbound.

Scenario 1: The closure of I-95 northbound between exit 109 in Maryland and exit 1A in Delaware.

Scenario 2: The closure of I-95 southbound between exits 1B in Delaware and 109 in Maryland.

Scenario 3: The closure of I-95 northbound between exit 1A in Maryland and exit 3A in Delaware.

Scenario 4: The closure of I-95 southbound between exits 3B in Delaware and 1B in Delaware.

Scenario 5: The closure of I-95 northbound between exit 3A in Maryland and exit 4A in Delaware.

Scenario 6: The closure of I-95 southbound between exits 4B in Delaware and 3B in Delaware.

Scenario 7: The closure of I-95 northbound between exit 4A in Maryland and exit 5A in Delaware.

Scenario 8: The closure of I-95 southbound between exits 5B in Delaware and 4B in Delaware.

Each scenario was modeled and run. The Build and No-build Analysis Application in the State Model was used to trace what route the vehicles would take under each closure condition.

Step 3: Eight additional scenarios were developed which stop toll collection at the toll plaza during the closure. This would remove delays at the toll plaza and counteract the negative impacts of the closure.

Step 4: Running the emission model.

Step 5: The output from Cube included volume, volume/capacity ratio and vehicle volume tracking (where traffic currently using the analysis link goes when disruption happens). The comparison between other MOPs in each pair (with and without closure) including VMT, VHT, and emission attributes for all scenarios are made.

Chapter 4

RESULTS AND ANALYSES

Scenario 1: Closure 1 Northbound

This first scenario involved the closure of I-95 northbound between exit 109 in Maryland and exit 1A in Delaware. The majority of traffic was routed off I -95 at exit 109, proceeded north along Maryland route 279/ DE-2 (Elkton Rd), east along Delaware route 896/Route 4 (Christina Pkwy), then south along SR 896 (S.College Ave), and returned to I-95 northbound. Volume on northbound DE-2 increased from 15,500 to 38,500 and LOS dropped sharply from B (V/C=0.51) to F (V/C=1.24). Volume on eastbound DE 896 (Christina Pkwy) increased from 7,800 to 14,300. The LOS on this link was already at F before the event, so the closure would only further degrade the condition as the V/C increased from 1.21 to 2.02. The traffic on southbound S. College Ave increased from 16,900 (LOS A, V/C=0.58) to 31,700 (LOS F, V/C=1.04).

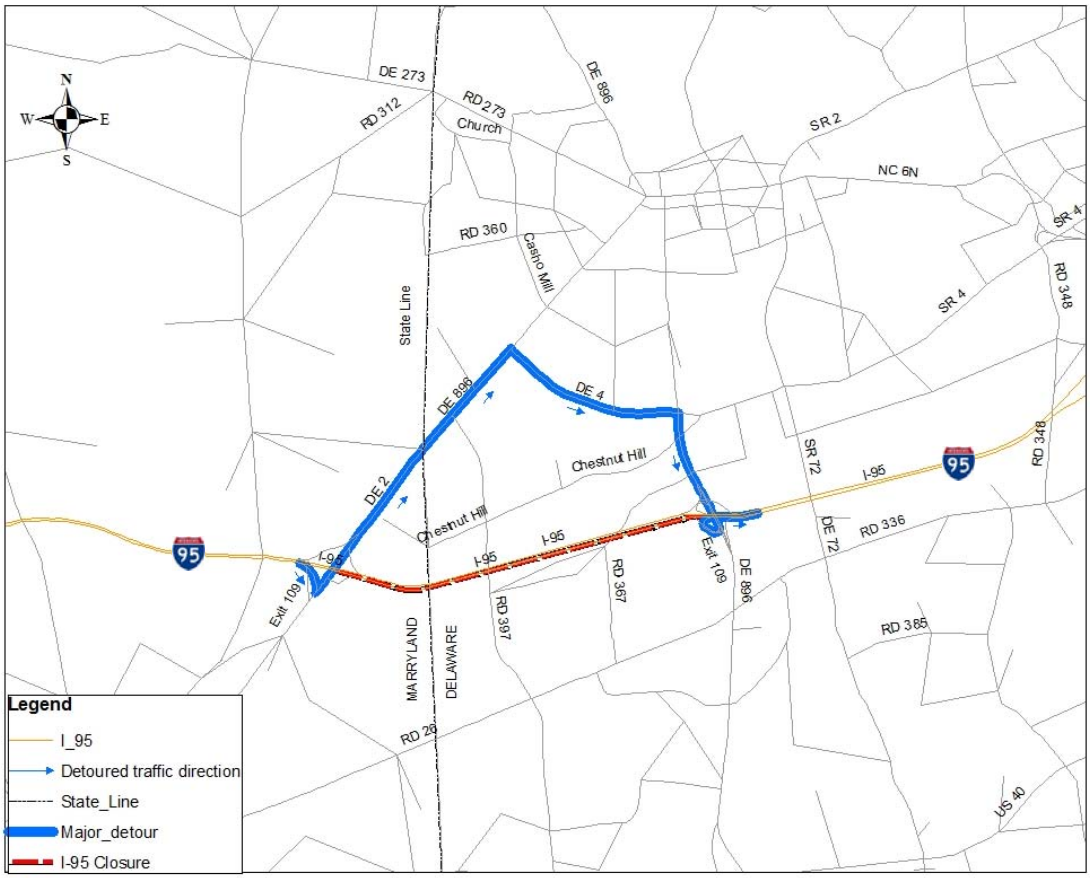

Figure 2 *Major traffic routed off I-95 (scenario 1)*

The largest percentage of the traffic follows the plan proposed by DelDOT (Figure 3). However, in this optimal solution, only 34% is directed along this path. The remaining 66% is diverted along several other routes. The use of these additional routes in addition to the primary route must be considered and could be included in the DelDOT plan. The single route shown in the DelDOT plan is not sufficient for all the volume of I-95.

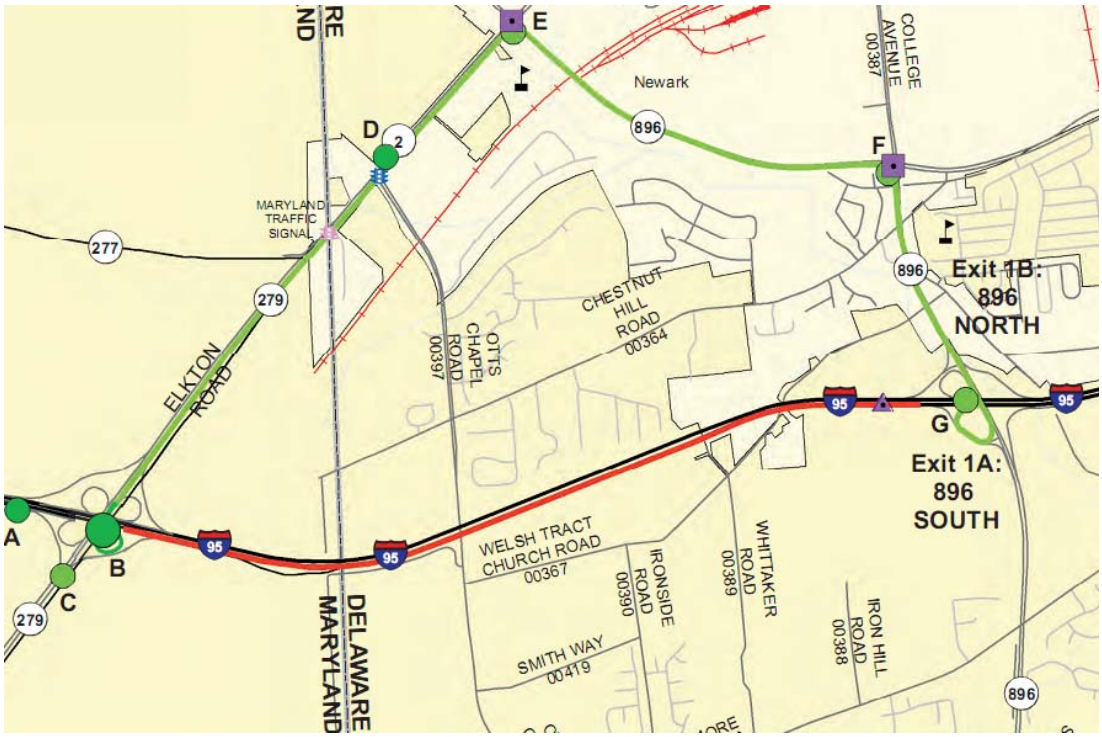

Figure 3 *The detour route plan by DelDOT (scenario 1)*

The model re-routed 4,400 vehicles that were headed to New Jersey to east US 40 at MD 222 and MD 272 to the Delaware Memorial Bridge. Also, four thousand five hundred vehicles originating in Maryland used US-40 to avoid the closure area and entered I-95 using DE 896 north. . The LOS of northbound S. College Ave (DE 896) fell from D (V/C=0.79) to E (V/C=0.99). These two re-routes would only be possible by information sharing between DelDOT and the Maryland State Highway Administration.

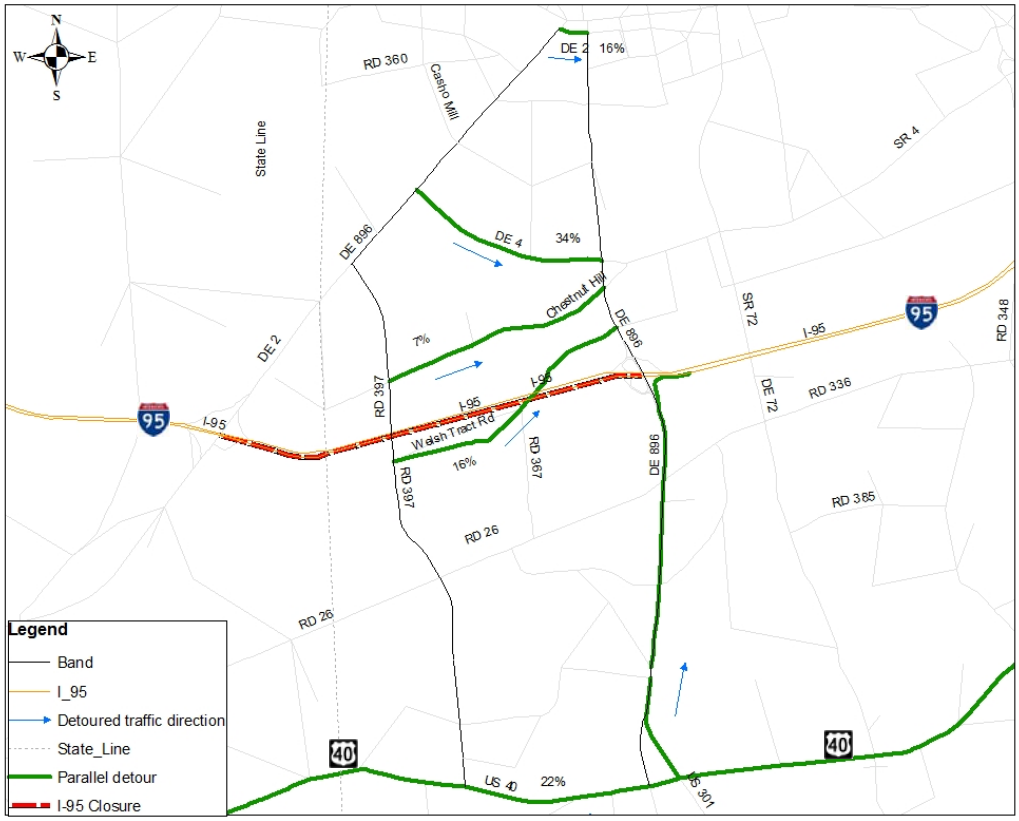

Figure 4 Traffic from closure link distribution (scenario 1)

The other routes used by the model in addition to the DelDOT detour are shown in Figure 4. The traffic diverted to US-40 was 22% of the total. The detour traffic using Elkton Rd mainly used DE-896/DE-4 (34%), partly used Chestnut Hill (7%) and Welsh Tract Rd (16%) to get back to I-95. Along Elkton Rd, 16% of the traffic used Delaware Avenue (along DE 273). The LOS of Delaware Avenue prior to the closure was F (V/C=1.25). As the result of the traffic increase, V/C of Delaware Avenue increased to 1.5.

The total re-route showed that the closure increased VHT by 10,238 hours and VMT by 72,698 miles a day.

In term of emissions, the change between the existing condition and post-incident condition attributes is shown in the Table 1:

Table 1 *Emission result (scenario 1)*

Attributes	**Increase (ton/day)**
VOC	0.06
CO	0.21
NOx	0.02
EXPM	0.27

Scenario 2: Closure 1 Southbound

This scenario involved the closure of I-95 Southbound between exits 1B in Delaware and 109 in Maryland. The model's output (figure 5) showed the major traffic was routed off I-95 at exit 1B, north along SR 896, west along DE 4, south on DE-2 and returned to I-95 southbound. The volume on northbound SR 896 (S. College Ave) increased from 19,300 to 31,900 and LOS decreased from B (V/C=0.76) to F (V/C=1.13). The diversion caused an increase of V/C on westbound DE-4 (Christina Pkwy) from 1.2 to 1.63. The traffic on southbound DE-2 (Elkton Rd) increased from 15,100 to 38,300 decreased the LOS from A (V/C=0.42) to F (V/C=1.03).

Figure 5 *Major traffic routed off I-95 (scenario 2)*

The largest percentage of the traffic follows the plan proposed by DelDOT (Figure 6). However, in this case, only 36% is directed along this path. The remaining 64% is diverted along several other routes.

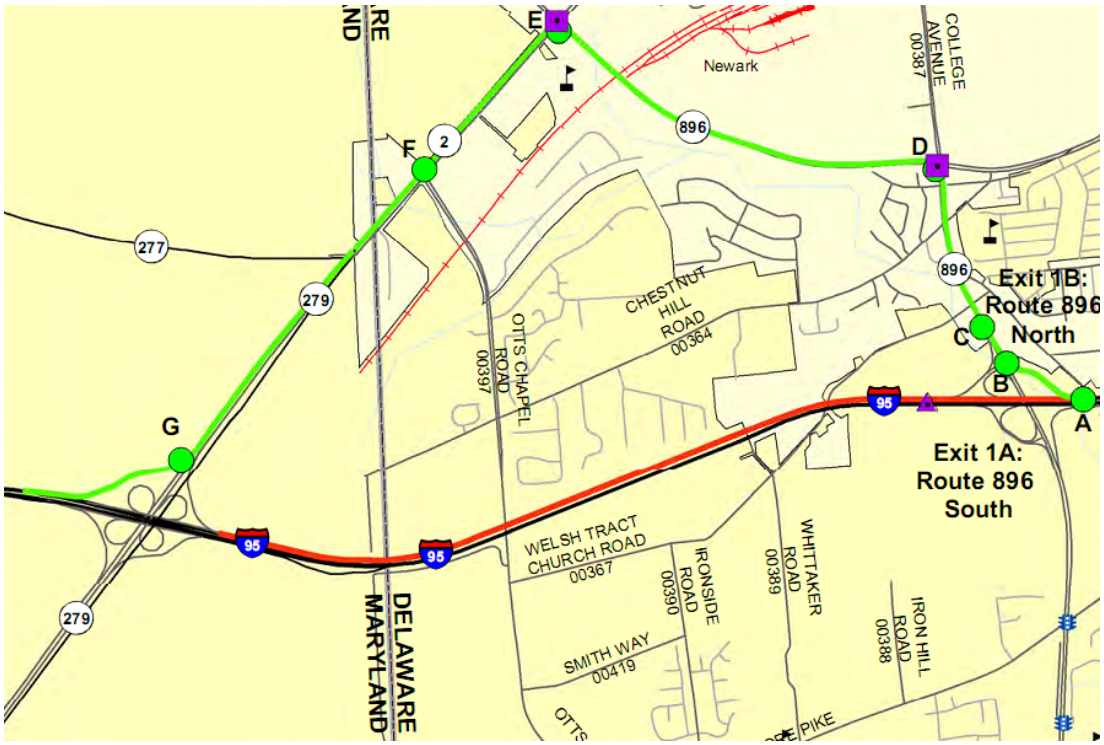

Figure 6 The detour route plan by DelDOT (scenario 2)

The distribution of the traffic from closed link diverted to new links is shown as in figure 7:

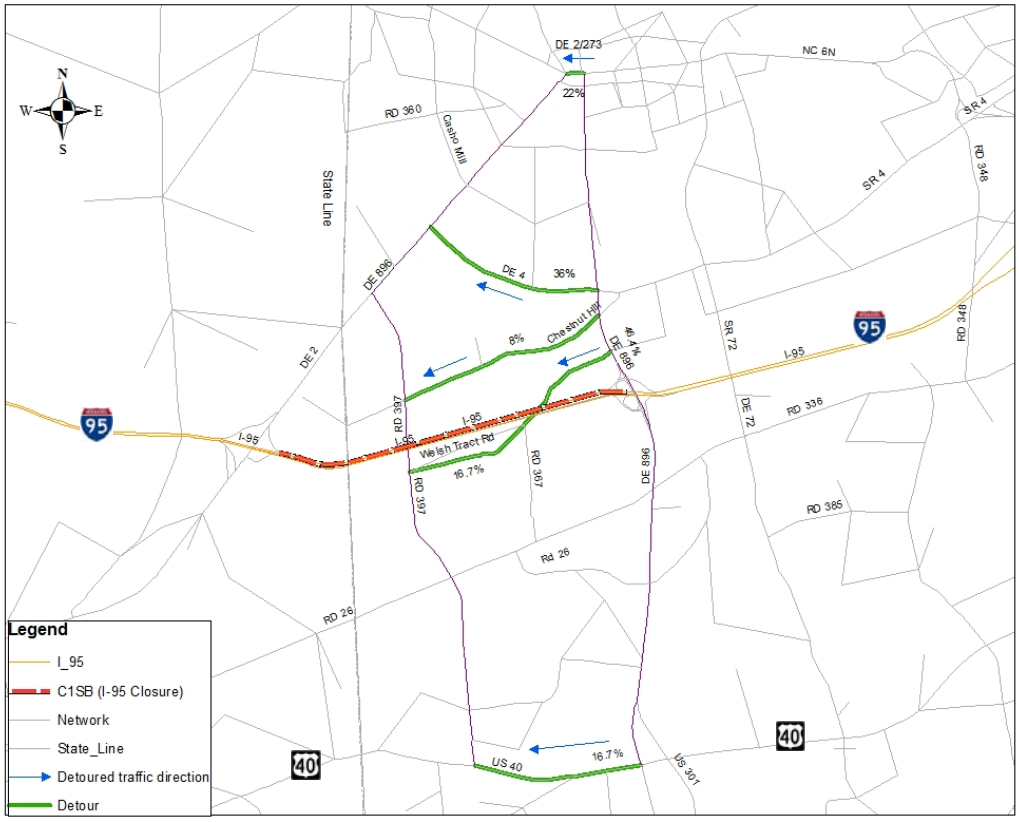

Figure 7 Traffic from closed link distribution (scenario 2)

In addition to the DelDOT proposed route, the diverted traffic used W. Chestnut Hill Rd (8%) and Welsh Tract Rd (16.7%) to get back to southbound I-95 via DE-2 (Elkton Rd). Traffic from New Jersey was diverted to US-40 and rejoined I 95 beyond the closure location.

The closure increased VHT by 10,360 hours and VMT of 44,134 miles a day.

The change between the existing condition and post-incident condition emissions is shown in Table 2:

Table 2 Emission result (scenario 2)

Attributes	Increase (ton/day)
VOC	0.05
CO	0.06
NOx	0.01
EXPM	0.2

Scenario 3: Closure 2 Northbound

This scenario modeled the closure of I-95 northbound between exits 1A and 3A in Delaware. Based on the model's output as in figure 8 below, the main traffic was routed off I -95 at exit 1A, headed north along DE-896 (S.College Ave), east along DE- 4, south on DE 273 and to I-95 northbound. Volume on Northbound S.College Ave rose from 16,100 to 28,300 and LOS fell from B (V/C=0.65) to F (V/C=1.01). Volume on eastbound DE-4 increased from 10,200 to 32,800, causing the LOS to drop from A (V/C=0.3) to F (V/C=1.03). Due to the traffic increase from 21,600 to 36,800 on DE 273, the LOS decreased from D (V/C=0.84) to F (V/C=1.18).

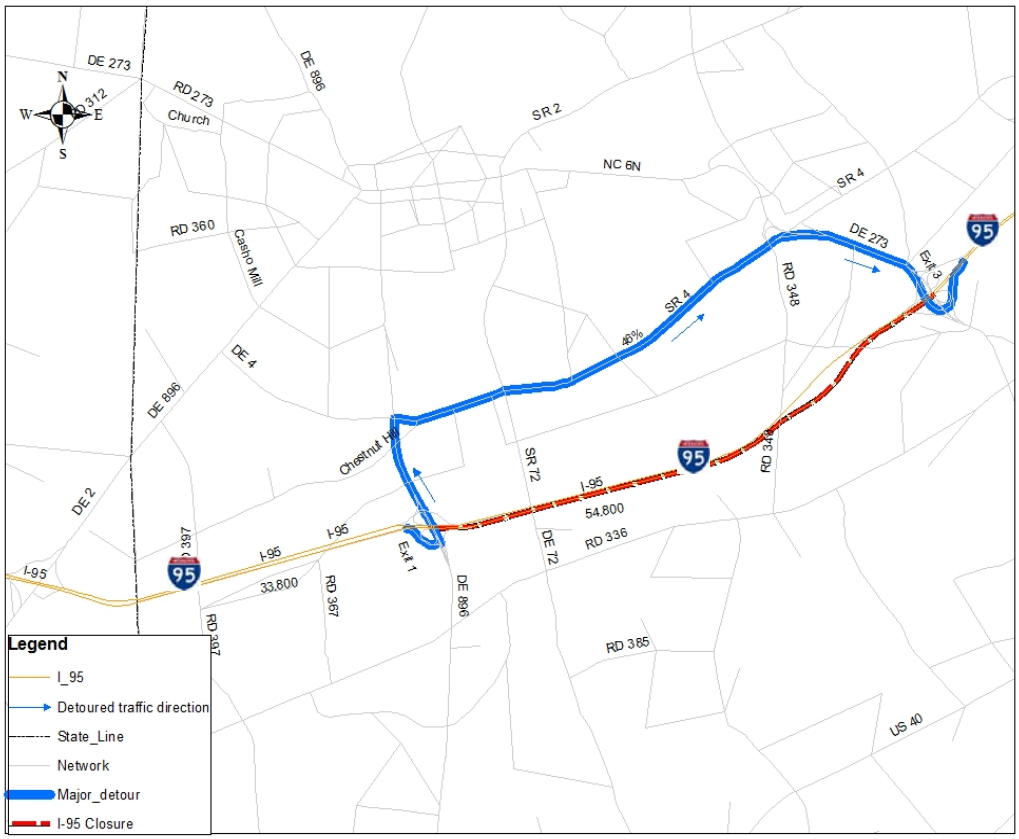

Figure 8 Major traffic routed off I-95 (scenario 3)

A total of 11,400 vehicles were diverted off I-95 at Elkton Rd, with a majority of them using DE-4 (Christina Pkwy), to DE-273 and returning to I-95. The remainder used Delaware Ave then splitting along DE-2 (Capital Trail) or DE 273 back to I-95. The detour traffic reduced the LOS of Elkton Rd from B (V/C=0.5) to D (V/C=0.83). The V/C of the Christina Pkwy segment connected to Elkton Rd increased from 1.2 to 1.37.

Figure 9 shows that the traffic shifted to DE-4 accounted for 46% of the total. This amount diverted to Old Baltimore Pike and US-40 was 13% and 21%, respectively. On Old Baltimore Pike, the V/C increased from 1.04 to 2.05. On US-40,

LOS fell from A (V/C=0.45) to D (V/C=0.87). Along US-40, of total traffic from closed link, 10% would use DE route 1 to return to I-95 and 11% would continue on to New Jersey via the Delaware Memorial Bridge.

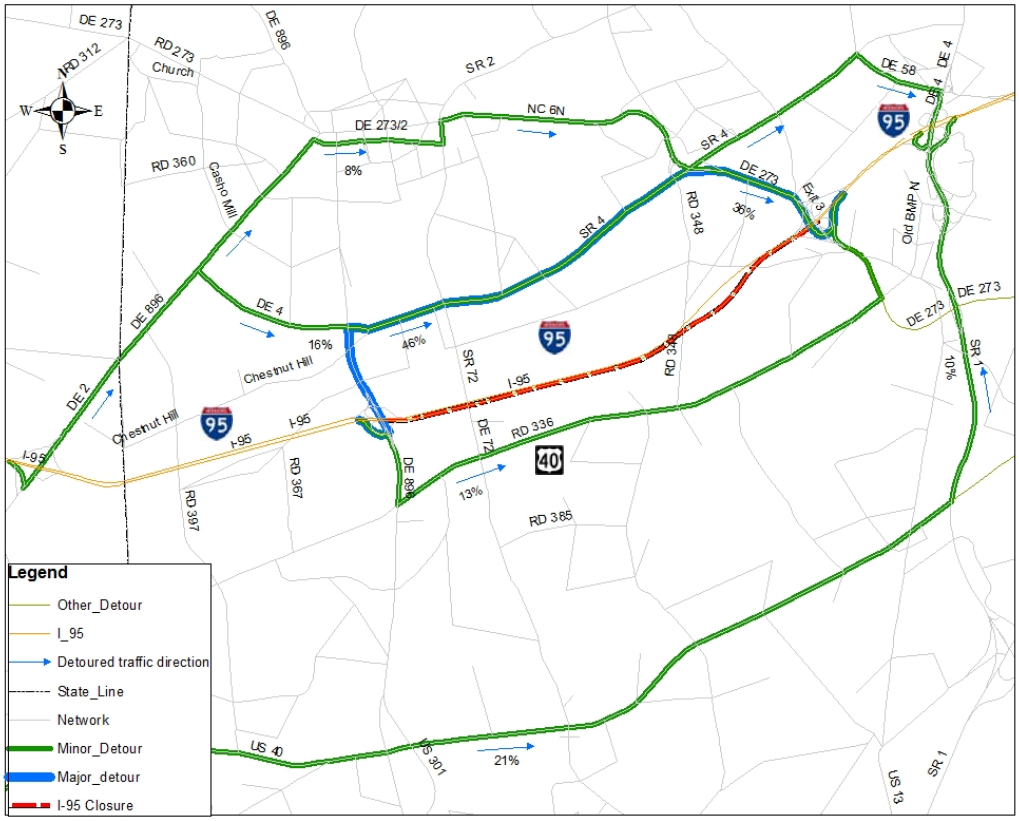

Figure 9 Traffic from closed link distribution (closure 3)

The output of the model is drastically different from the plan from DelDOT shown in Figure 10. Instead of using the DE-4 as the major alternative, DelDOT suggests the route DE-896/US-40/DE-1.

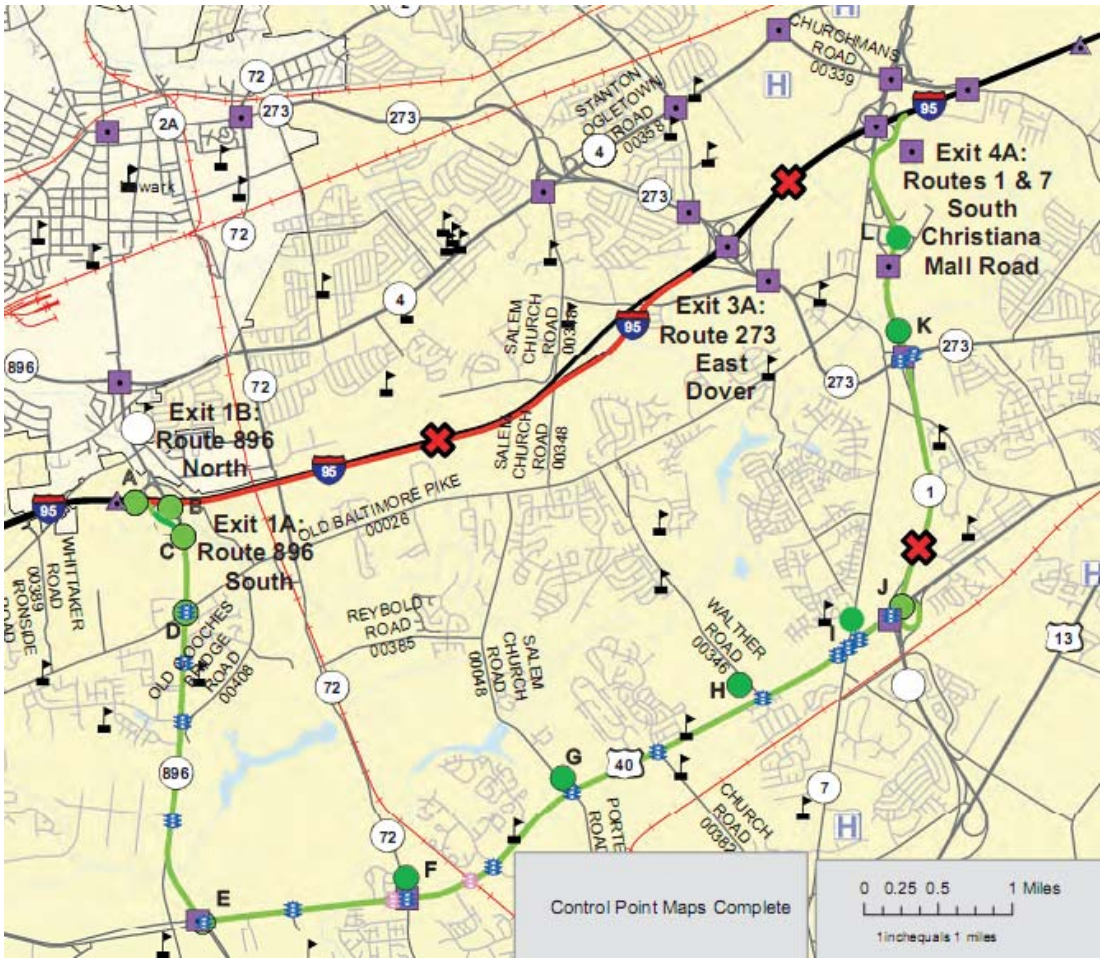

Figure 10 Detour route plan by DelDOT (scenario 3)

The option chosen by DelDOT as the major detour is not the best option because of several reasons. First, using DE-4 is much shorter than using US-40. Second, DE-4 has better LOS than US-40.

The closure increased VHT by 13,780 hours and VMT of 52,650 miles a day.

The comparison between the existing condition and post-incident condition emission is shown in Table 3:

Table 3 Emission result (scenario 3)

Attributes	Increase (ton/day)
VOC	0.07
CO	0.06
NOx	0.01
EXPM	0.24

Scenario 4: Closure 2 Southbound

By closing the Southbound of I-95 link between exit 3 in and exit 1 in Delaware, the majority of traffic was routed off I-95 at exit 3B, north on DE-273, west along DE-4, and south on DE-896 before returning to I-95 Southbound (Figure 11). The volume on the Northbound DE-273 rose to 36,500 from 24,300, which brought the LOS down to F (V/C=1.14) from C (V/C=0.76). On the Westbound DE-4, the total traffic increased from 10,000 to 35,100 and the LOS dropped from A (V/C=0.33) to F (V/C=1.1). The LOS on the southbound DE-896 fell from A (V/C=0.48) to E(V/C=0.95)

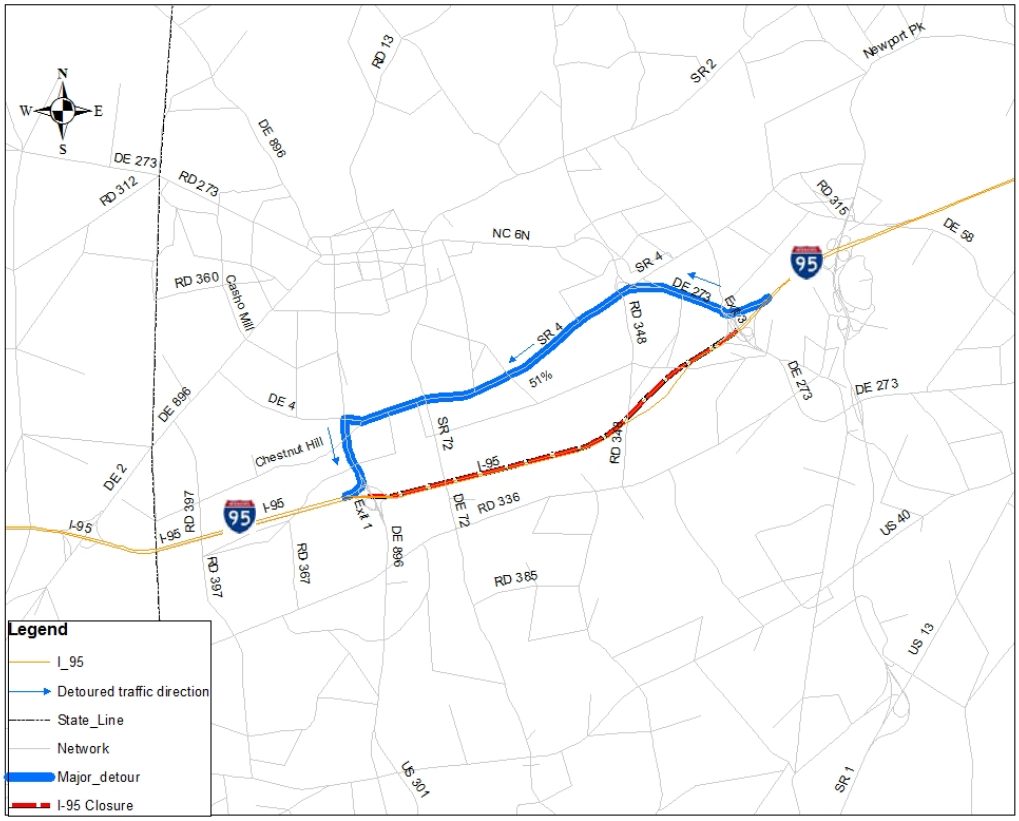

Figure 10 Major traffic routed off I-95 (scenario 4)

The model's output also showed that the traffic diverted to DE-273, US-40, SR 336 (Old Baltimore Pike) and DE-58. Eleven thousand vehicles diverted off I-95 at exit 4 to DE-58, along DE-4 to join with traffic from I-95 exiting at DE 273. Nearly ten percent of the diverted traffic used DE-4, then south on DE-2. A portion of the traffic used eastbound DE-273, East Main Street then turned onto Elkton Rd/DE-2. Of the total traffic from the closed link, the traffic shifted to DE-4, DE-273, SR-336 and US-40 were 51%, 6.7%, 10.5% and 10.5%, respectively (Figure 12). The LOS on these routes was F, F, F and E.

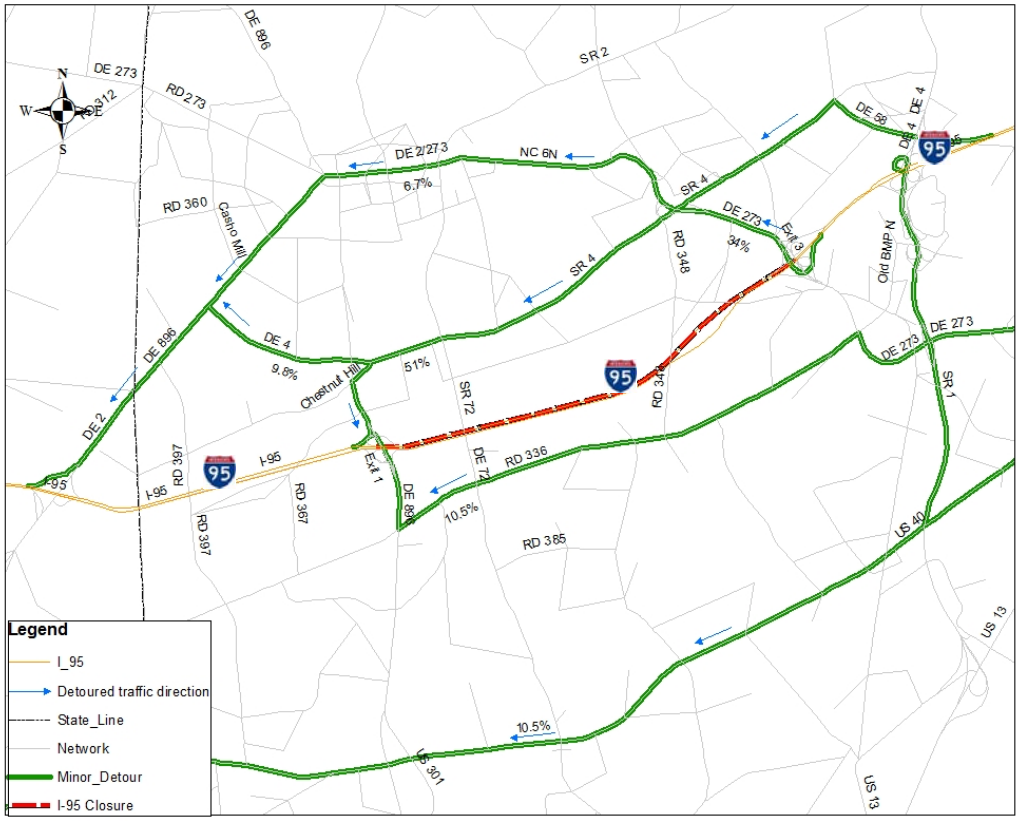

Figure 12 Traffic from closed link distribution (scenario 4)

Once again the DelDOT plan differs significantly from the suggestions of the model. Instead of using DE-4 as the major alternative, DelDOT suggests US-40 (Figure 13). For similar reasons mentioned in scenario 3, DE-4 is the better choice for the major traffic detour combined with the minor routes.

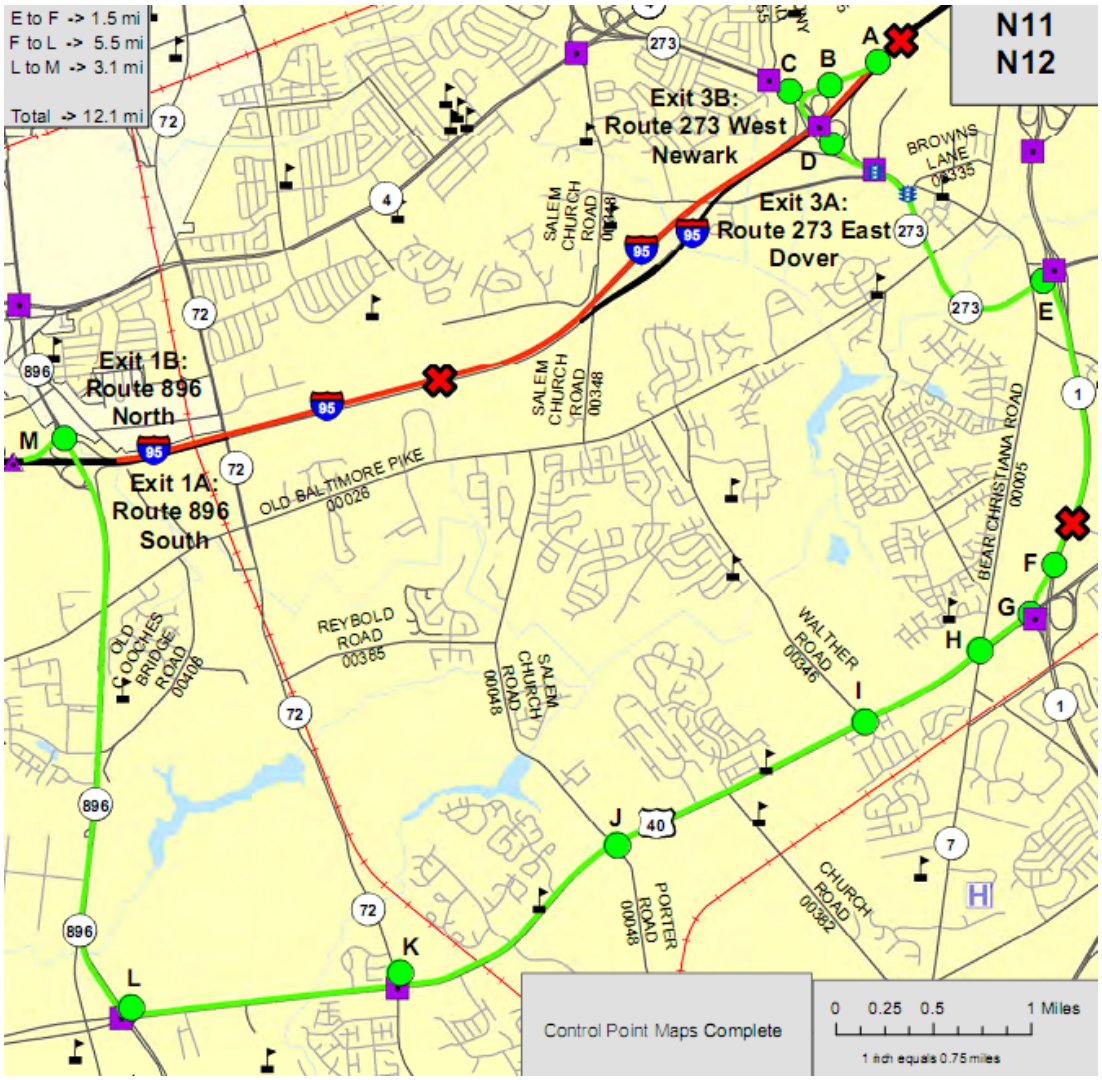

Figure 11 Detour route plan by DelDOT (scenario 4)

The closure increased VHT by 12,250 hours and VMT of 41,134 miles a day.

The comparison between the existing condition and post-incident condition emission is shown in the Table 4:

Table 4 Emission result (scenario 4)

Attributes	Increase (ton/day)
VOC	0.06
CO	0.05
NOx	0
EXPM	0.13

Scenario 5: Closure 3 Northbound

The scenario 5 considered the closure of I-95 northbound between exit 3A and exit 4A in Delaware. The major traffic from I-95 used exit 4A to southbound DE-273 (Christiana Bypass). Some traffic then used northbound DE-1 to return to I-95 northbound while the remainder continued eastbound along DE-273, turning east on US-40 heading to New Jersey via the Delaware Memorial Bridge (Figure 14). The traffic from closed link used DE-273 accounted for 36% of the total.

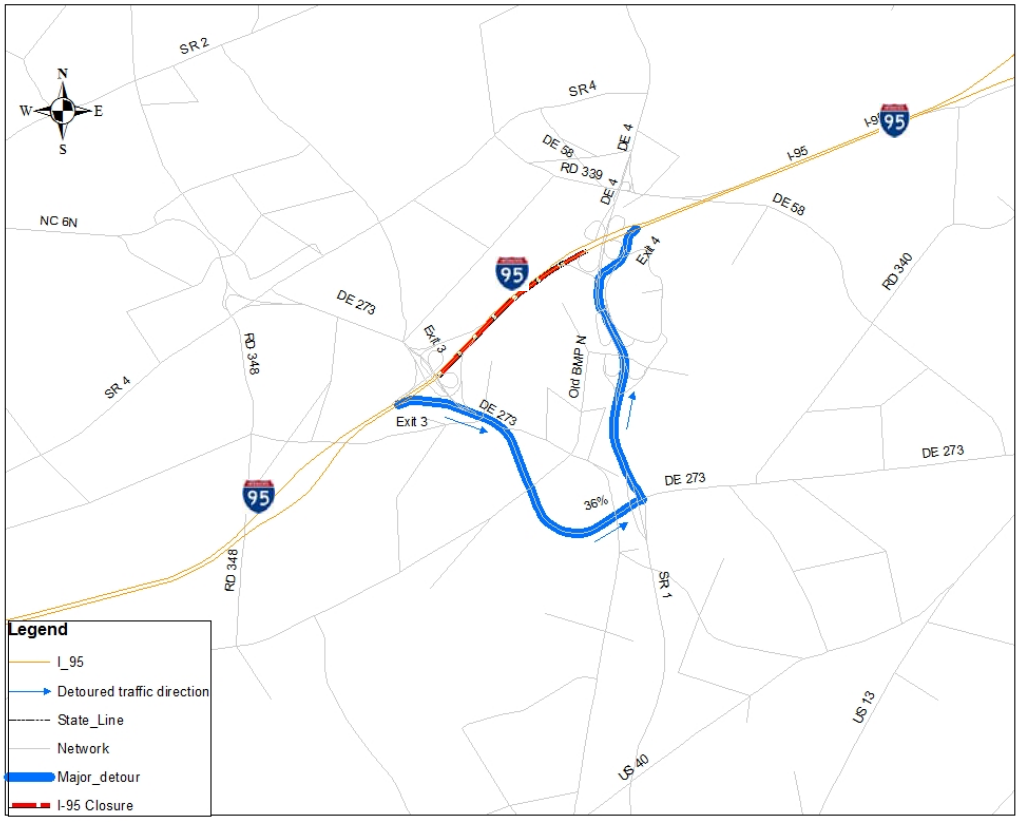

Figure 12 Major traffic routed off I-95 (scenario 5)

The traffic not using DE-273 used eastbound DE-4 being directed off I-95 at either exit 1 or exit 3A, following DE 339 and southbound DE-1 to return to I-95. Total traffic shifted to DE-4 accounted for 35% of the total. Consequently, the LOS fell sharply from A (V/C=0.42) to F (V/C=1.35). Sixteen percent of the diverted traffic was routed via US-40 to get back to I-95 or to New Jersey. The diversion to US-40 decreased LOS to F (Figure 15).

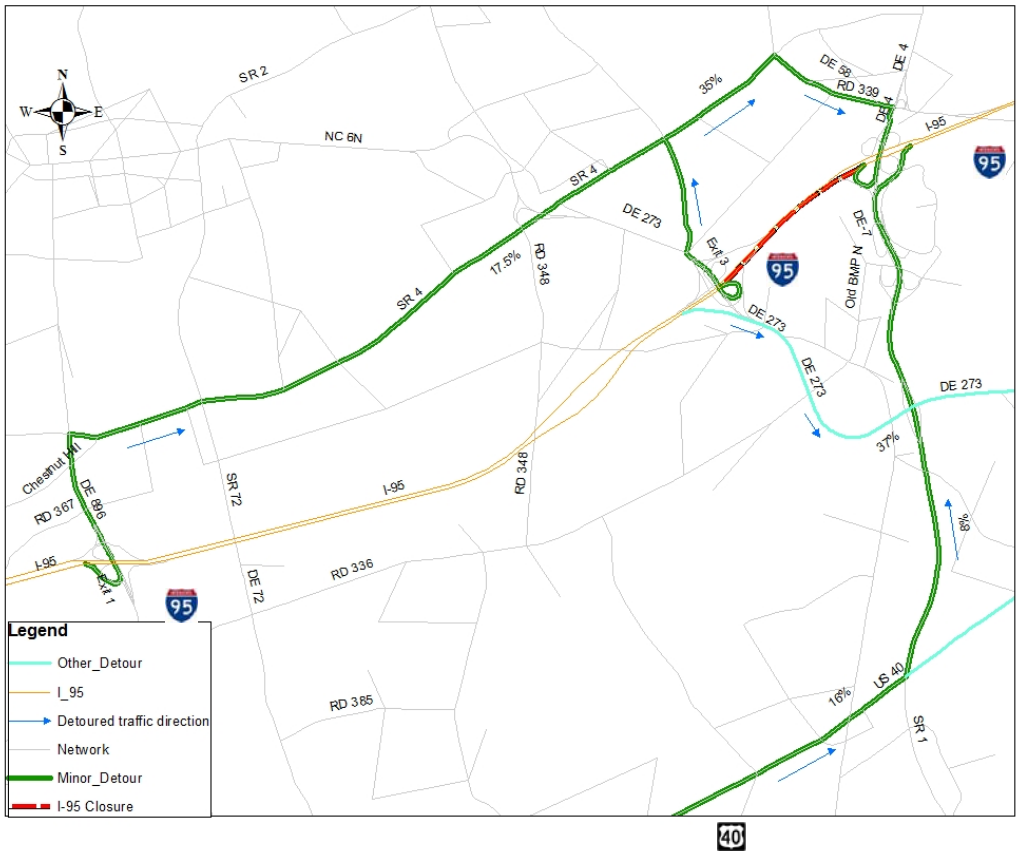

Figure 13 Traffic from closed link distribution (scenario 5)

The output of the model showed different detour options from the plan by DelDOT (Figure 16)

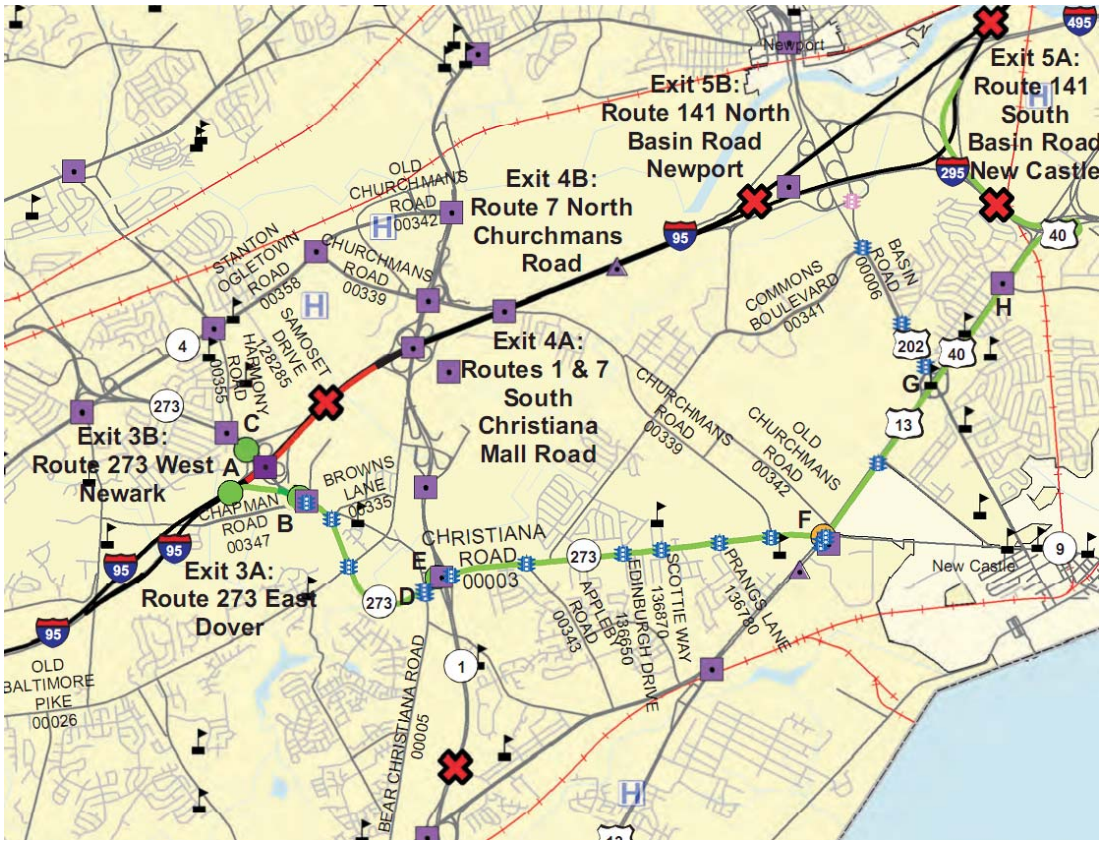

Figure 14 Detour route plan by DelDOT (scenario 5)

The closure increased VHT by about 12,478 hours and VMT of 69,600 miles a day.

The comparison between the existing condition and closure scenario emission is shown in Table 5:

Table 5 Emission result (scenario 5)

Attributes	Increase (ton/day)
VOC	0.07
CO	0.07
NOx	0.01
EXPM	0.27

Scenario 6: Closure 3 Southbound

Scenario 6 involved the closure of I-95 southbound between exit 3B and exit 4B in Delaware. The main traffic (41%) was routed off I-95 at exit 4B to westbound DE-58 (Churchman Rd), along westbound DE-4, partly turned to southbound DE-2 (Elkton Rd) and partly back to I-95 southbound (Figure 17). The volume from the closed link on westbound DE-58 was 23,400, which decreased LOS from E (V/C=0.99) to F (V/C=1.24). On westbound DE-4, the LOS fell from A (V/C=0.42) to F (V/C=1.17). Eleven thousand, eight hundred vehicles returned to I-95 at DE-273, while the remainder continued on DE-4, to DE-896 or DE-2 to return to I-95 southbound.

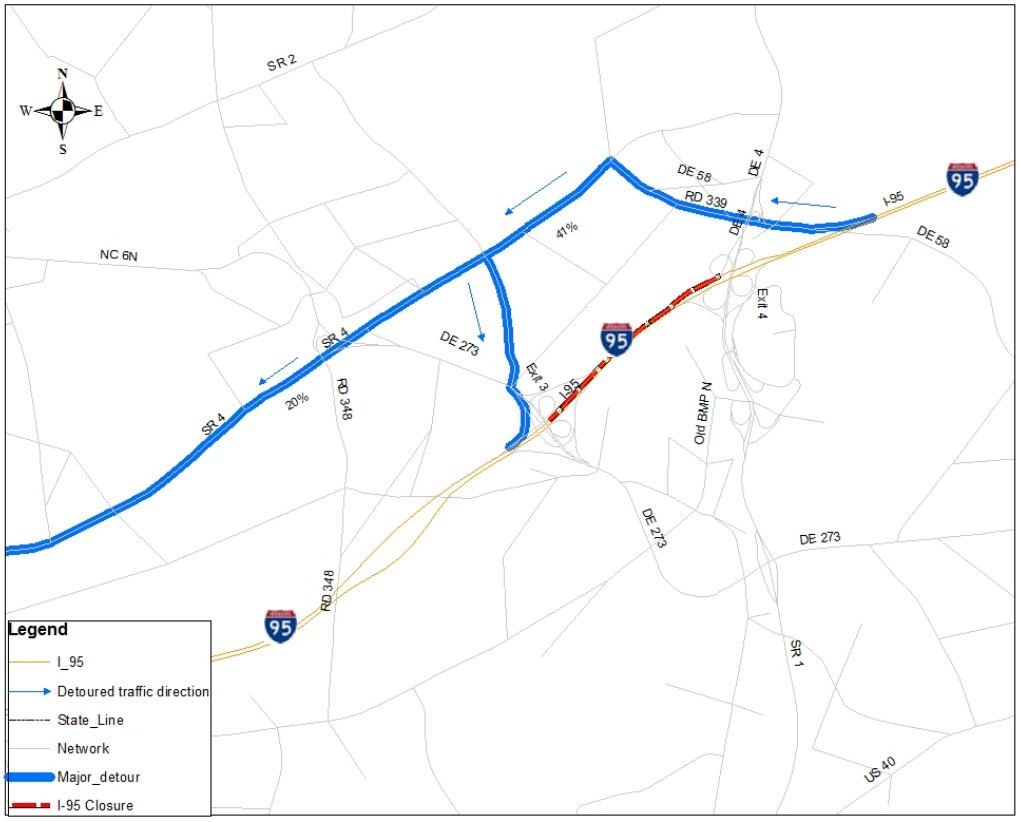

Figure 15 Major traffic routed off I-95 (scenario 6)

In addition to the detour described above, fifteen thousand five hundred vehicles from I-95 diverted to southbound DE-1 & 7 (Korean War Veterans Memorial Hwy) at exit 4A, then returned to I-95 along DE-273. Vehicles originating in New Jersey and using the Delaware Memorial Bridge (9,800 vehicles) were diverted along US-13 to US-40 to DE-273 and back onto I-95 south (Figure 18). On the DE-1/DE-7, LOS decreased from B (V/C=0.56) to F (V/C=1). On DE-273, the LOS fell from B (V/C=0.57) to F (V/C=1.07). The traffic diverted to US-40 (12%) came through

southbound DE-1 from I-95 and US-13/US-40 from New Jersey. The LOS on US-40 decreased from A (V/C=0.49) to C (V/C=0.7).

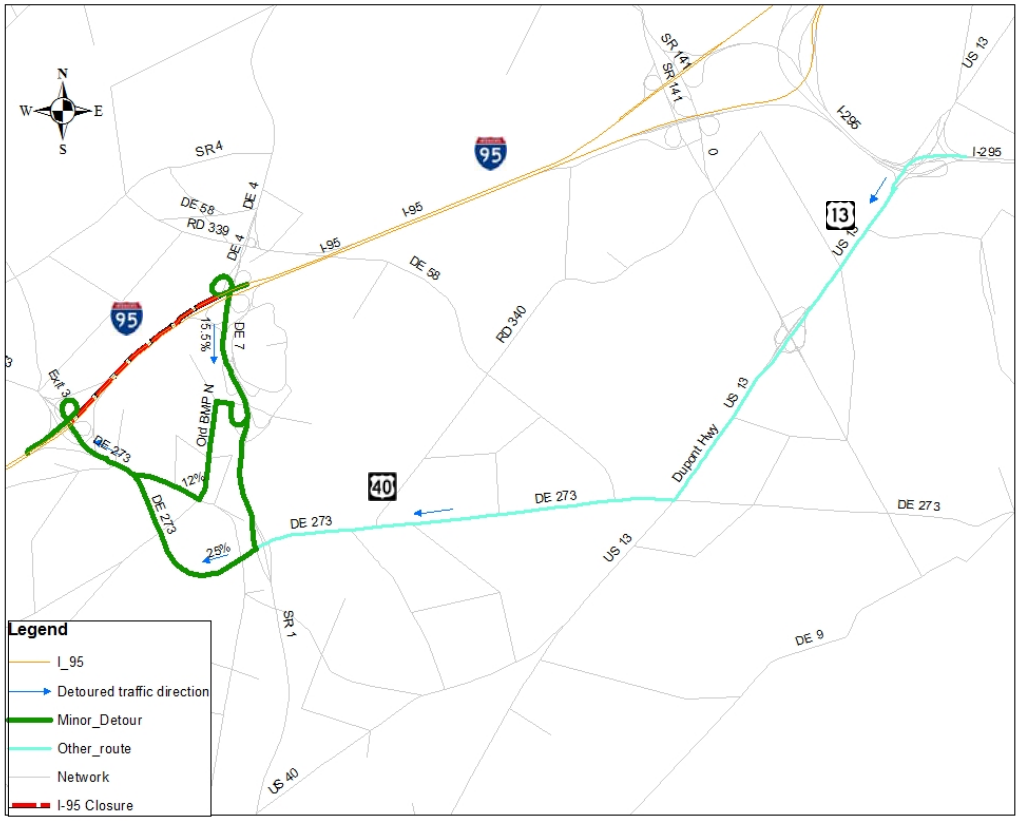

Figure 16 *Traffic from closure link distribution (closure 6)*

The plan proposed by DelDOT is one of the alternatives from the output of the model (Figure 19).

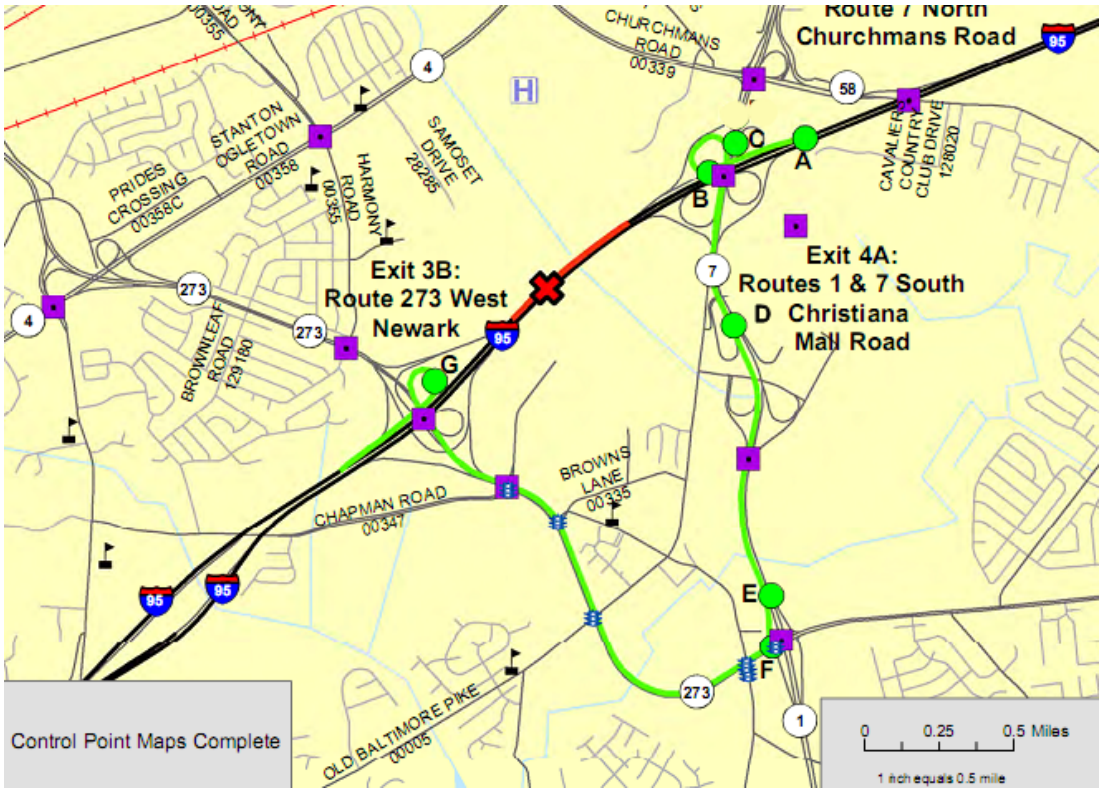

Figure 17 Detour route plan by DelDOT (scenario 6)

The closure increased VHT by about 12,600 hours and VMT of 44,100 miles a day

The comparison between the existing condition and closure scenario emission is shown in Table 6:

Table 6 Emission result (scenario 6)

Attributes	Increase (ton/day)
VOC	0.06
CO	0.01
NOx	0.01
EXPM	0.24

Scenario 7: Closure 4 Northbound

Scenario 7 modeled the closure of I-95 northbound between exit 4A and exit 5A in Delaware.

Twenty nine percent of the traffic from I-95 used exit 3A to get to eastbound DE-273 (Christiana Bypass), then to northbound along US-13. This traffic either returned to I-95, used I-495 to rejoin I-95 further north or used I-295 and the Delaware Memorial Bridge for New Jersey bound traffic. The LOS on DE-273 and US-13 were F (V/C=1.12) and D (V/C=0.81) (Figure 20).

Twenty five percent of traffic from I-95 used exit 4 to DE-4 and southbound DE-141, returning to northbound I-95. The detour dropped the LOS of DE-4 from C (V/C=0.73) to F (1.27) (Figure 20).

Figure 18 Major traffic routed off I-95 (closure 7)

The pattern of the remaining diverted traffic, with their distribution, are shown in Figure21. The traffic diverted to SR-2 and US-40 were 15% and 14%. The LOS on these routes were F(V/C=1.27) and F (V/C=1) after the diversion, respectively.

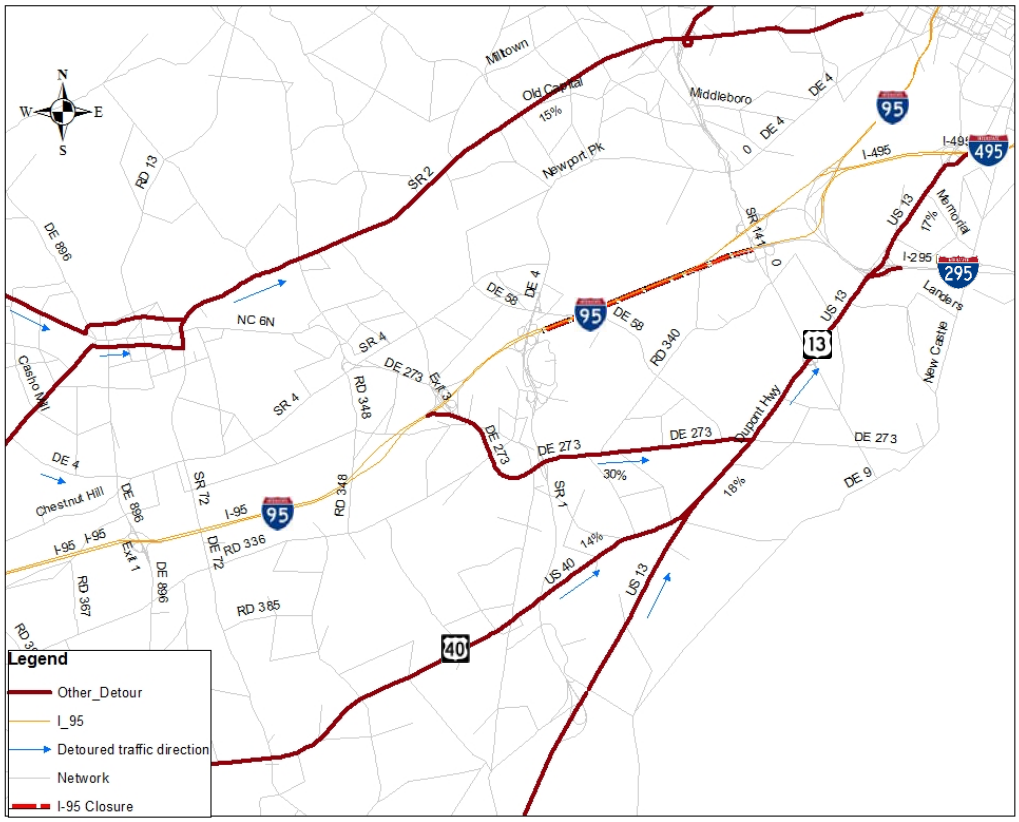

Figure 19 Traffic from closure link distribution (closure 7)

The model suggested different detour options from the plan by DelDOT. DelDOT suggested to use exit 4A to DE-1 and US-13, then I-295 (Figure 22). This may not be the best solution since the traffic has to take longer routes (11.5 miles) compared to using the two major detours from the output of the model.

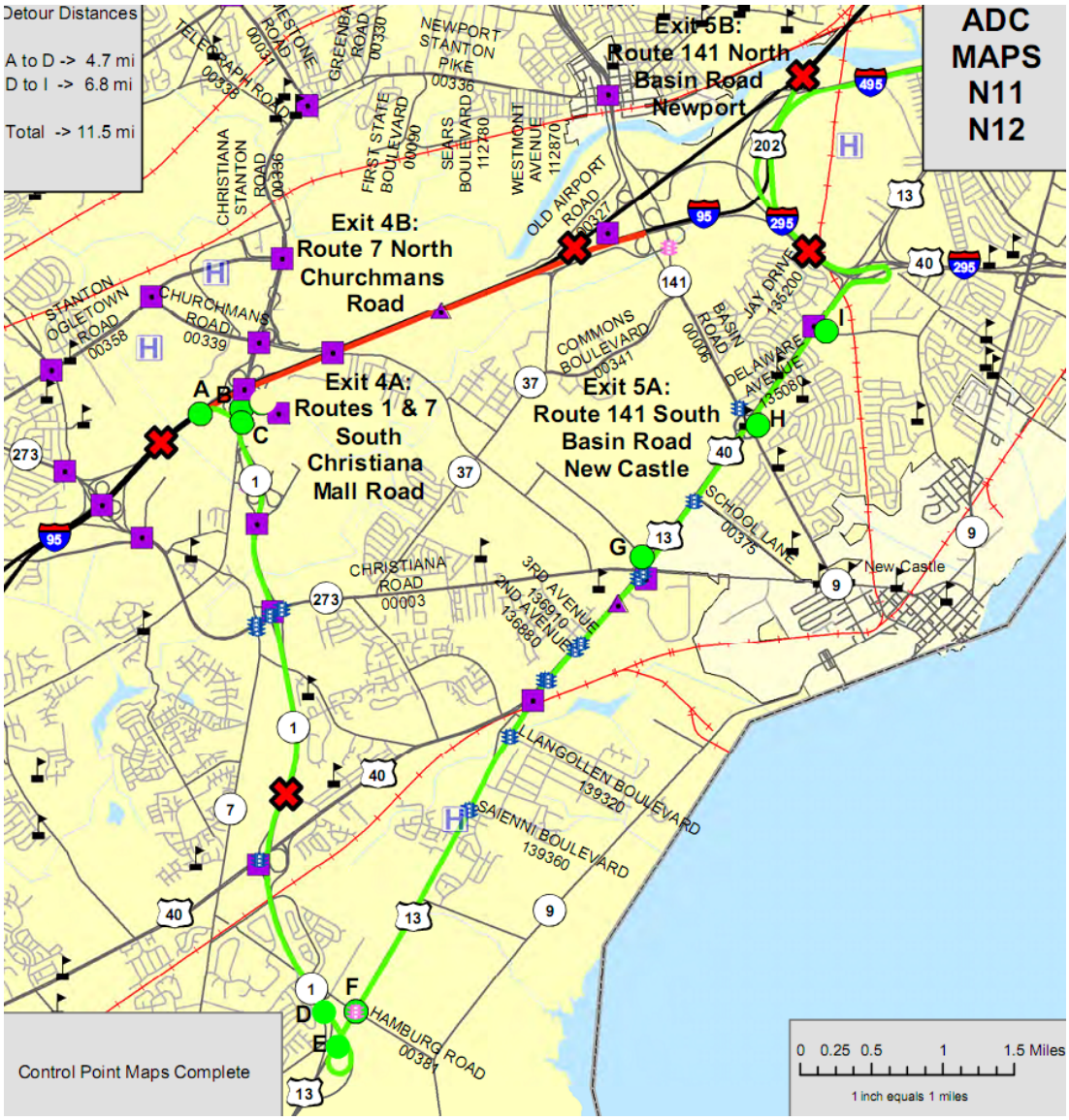

Figure 20 Detour route plan by DelDOT (scenario 7)

The closure increased VHT by about 24,700 hours and VMT of 71,600 miles a day.

Table 7 shows the change of emissions:

Table 7 Emission result (scenario 7)

Attributes	Increase (ton/day)
VOC	0.14
CO	0.08
NOx	0.02
EXPM	0.45

Scenario 8: Closure 4 Southbound

Scenario 8 involved the closure of I-95 southbound between exit 4 and exit 5 in Delaware. This section has the highest traffic volume of all I-95 southbound segments running through Delaware.

From I-95, the main traffic diverted to northbound SR-141 using exit 5A, westbound on Newport Pk (Main St), southbound on DE-7 (Stanton Christiana Rd) then returned to I-95 south. Some traffic was diverted to DE-4 south (Ogletown Stanton Rd) from DE-7 east. Thirty five percent of the diverted traffic was on Westbound Newport Pk, which caused its LOS to decline from A (V/C=0.49) to F(V/C=1.28). LOS on both northbound SR-141 and southbound DE-7 were F (Figure 23).

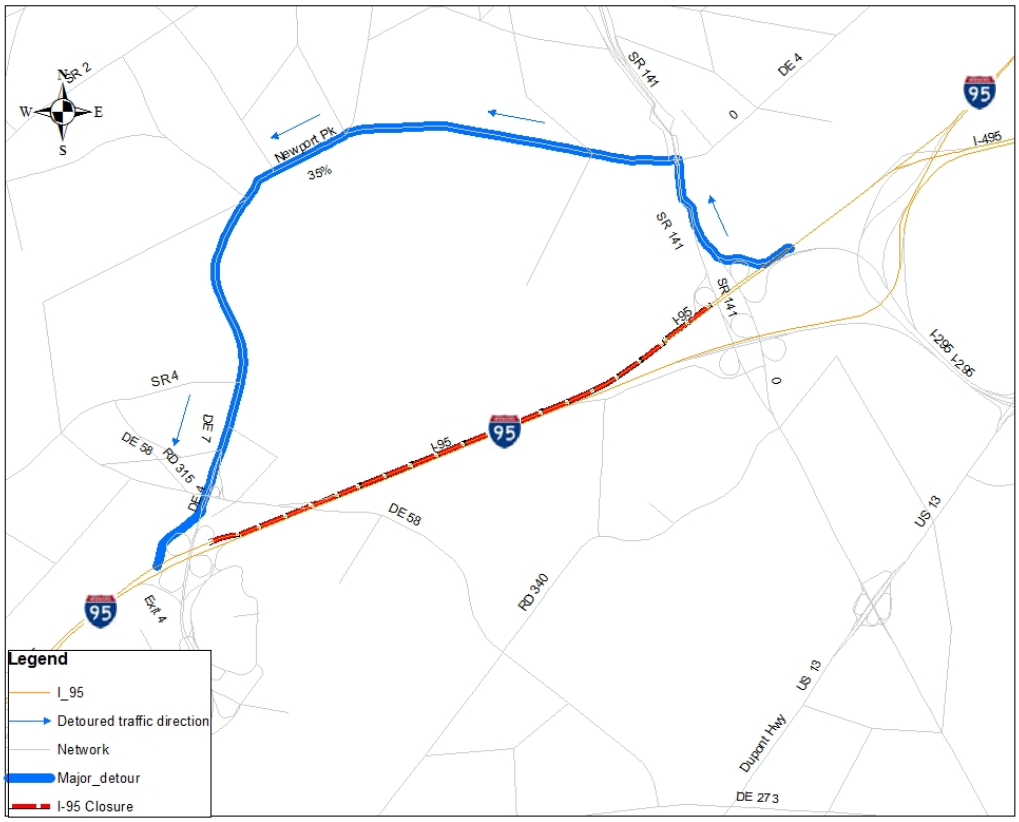

Figure 21 Major traffic routed off I-95 (scenario 8)

Fifteeen percent of traffic was diverted at exit 6, to westbound DE-9, along westbound DE-2 (SR-2), and back to I-95 southbound. At some segments, the LOS of westboud DE-2 was F.

Another re-route diverted traffic from New Jersey, from exit 5 along southbound SR141 and off I-495 tosouthbound US-13, DE-273 and back to I-95 using exits 3 and 4. US 13 (N. Dupont Hwy) absorbed 39% of total traffic from I-95 . Twenty five percent of the total traffic would used DE-273, with the remaining 14% staying on US 13 (Figure 24). The LOS of westbound DE-273 fell from A (V/C=0.43) to F (V/C=1.04).

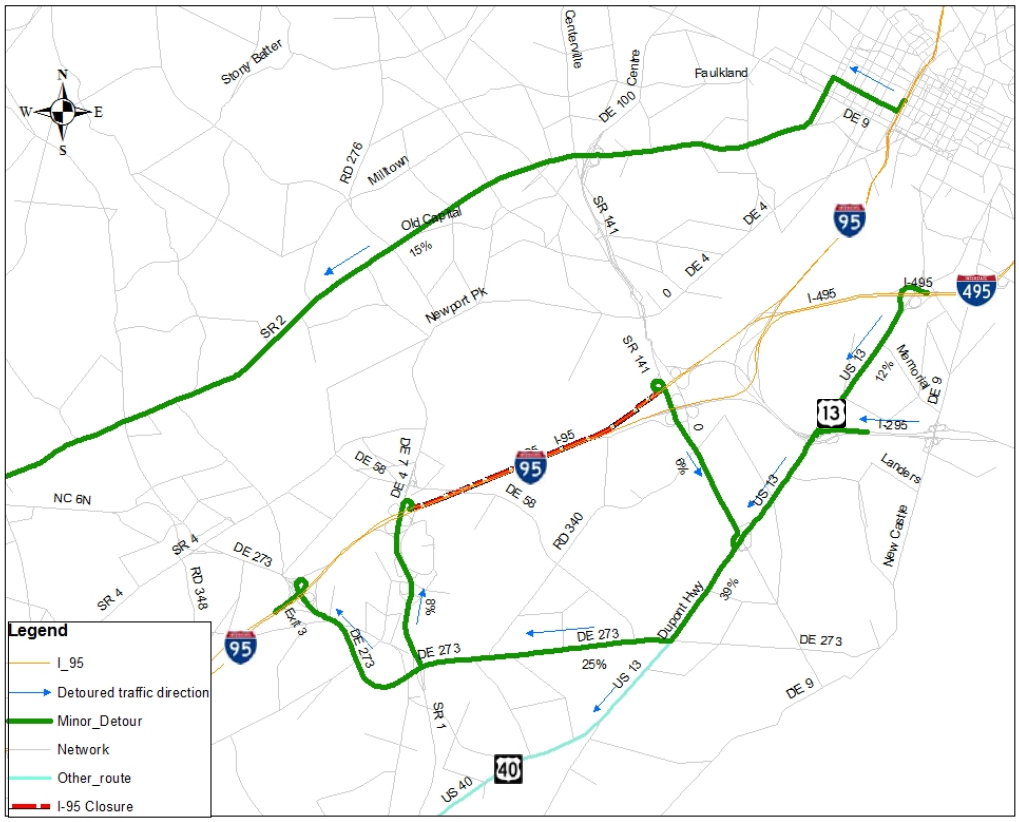

Figure 22 Traffic from closure link distribution (scenario 8)

The alternative of using US-13 as the detour in the model matches the plan by DelDOT (Figure 25).

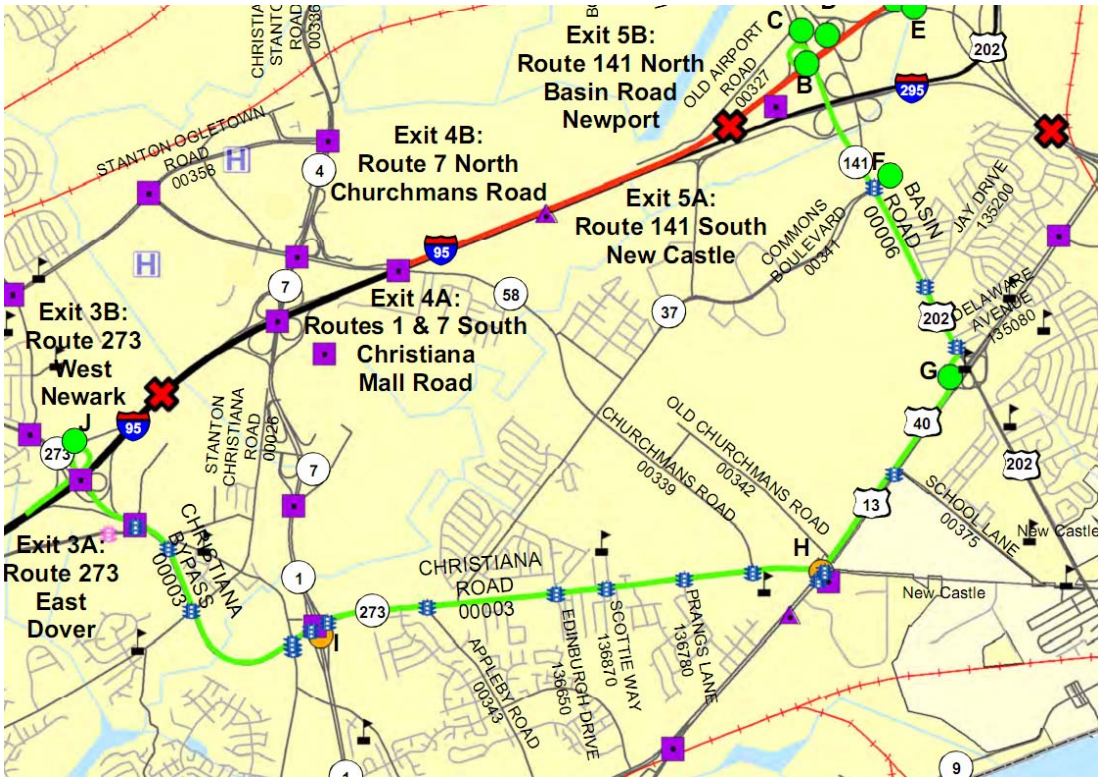

Figure 23 Detour route plan by DelDOT (scenario 8)

VHT of this scenario increased about 25,400 hours per day and VMT rose 92,800 miles a day.

Table 8 shows the change of emissions:

Table 8 Emission result (scenario 8)

Attributes	Increase (ton/day)
VOC	0.13
CO	0.23
NOx	0.03
EXPM	0.5

No Toll Scenarios:

For the closure 1 northbound and southbound without tolls: Since the links contain the toll booth, the result has no different from the closure with toll. For the other scenarions without tolls, there were minor changes in the pattern of traffic diverted, but in general they were insignificant.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

This research has shown that computer models can aid system managers and provide insight when dealing with traffic re-routing for non-recurring congestion. In most scenarios, the model's choice of route for the largest percentage of the traffic matches the DelDOT plan, in most cases this fraction was rarely above forty percent of the total traffic to be diverted. If the re-route plan is too strictly implemented, forcing all traffic to adhere to the proposed re-route, severe congestion will occur. System managers and those responsible to implement the plan must be aware that there are two constituencies involved in cases like this – those who are familiar with the region and route alternatives and those who are not. Those who are unfamiliar with the regional transportation network will need specific guidance to avoid the closure area and get back to their intended route and destination. Those familiar with the area will seem their own alternatives based on observations, judgment and knowledge of the system.

Although the optimization calculation based on the travel demand model answers the question of impacts of I-95 closures on traffic and air quality, there are some limitations which could be improved in future work:

- This project only focused on the disruption of links. An additional alternative would be to examine the closure of interchanges where both the

interstate and a major arterial which passes above or below the interstate would be closed.

- The existing model provided a snapshot of the system and volumes over an entire day. Using a dynamic traffic assignment methodology such as the one found in Cube Avenue would be useful in assessing the development of queues and provide better travel time estimates through the system

Scenarios involving partial closure scenarios could also be considered. These would be blockages of only some of the available lanes.

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