Truck Diversion Routing Using Geographic Information Systems

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Erin Kersh
Affiliation: Vanderbilt University
Address: VU Station B-35 1831
Nashville, TN 37235-1831
Phone: (615) 322-0430
Fax: (615) 322-3365
Email: erin.l.kersh@vanderbilt.edu
Corresponding Author

James P. Dobbins Ph.D.
Affiliation: Vanderbilt University
Address: VU Station B-35 1831
Nashville, TN 37235-1831
Phone: (615)322-0430
Fax: (615)322-3365
Email: j.dobbins@vanderbilt.edu

Mark D. Abkowitz Ph.D.
Affiliation: Vanderbilt University
Address: VU Station B-35 1831
Nashville, TN 37235-1831
Phone: (615)343-3436
Fax: (615)322-3365
Email: mark.abkowitz@vanderbilt.edu

ABSTRACT

The objective of this paper is to develop an analytical model in order to identify key interstate segments at which trucks are frequently diverted due to a disruption in service, and to determine an appropriate alternate route under such circumstances. Using a risk-based approach; segments of the Tennessee interstate system were selected based on histories of serious incidents, incidents with diversions, and high truck volumes. In selecting a preferred diversion route, the shortest alternate path may not be feasible for truck use based on varying size and performance characteristics. To address this consideration, a geographic information system (GIS) was utilized in which restrictions and costs were applied to candidate diversion routes to either eliminate or penalize routes undergoing evaluation. The alternate route assessment methodology illustrates the need for improvements in nationwide truck freight networks as well as the ability for GIS tools to address complex routing problems. A majority of the alternate routes studied as part of this project were impacted by these restrictions. Use of this methodology can lead to a reduction in congestion and an increase in travel time reliability for both trucks and other vehicular traffic.

INTRODUCTION

Keeping interstate corridors open is a crucial and demanding task for state departments of transportation. Alternate routes, as defined by the FHWA Alternate Route Handbook, “provide additional capacity to service primary route traffic” (*1*). Depending on the circumstances, the use of alternate routes can vary in timeframe from hours to weeks, and even months (as in the case of long-term construction, natural disasters, etc.). The public and freight providers are especially sensitive to congestion, both in terms of time (4.80 billion congestion hours in 2009) and cost ($114.8 billion in 2009), both of which continue to rise (*2*).

Planning for an alternate route must be comprehensive and thorough; simply finding the shortest path from the upstream and downstream exits may make conditions worse rather than alleviate the problem. Factors may be present on the alternate route that result in another closure and major cause of congestion, such as a low bridges, narrow lanes, lack of synchronized traffic signals, and/or an already-clogged arterial. In particular, trucks have special size (height and weight) and performance (e.g., turning radii, speed on grades) characteristics that warrant consideration.

Geographic information systems (GIS) refer to technology that represents reality in a series of digital geographic layers. These layers contain several like features with detailed attributes describing each feature. GIS platforms are typically capable of displaying vector (point, line, polygon) and raster (satellite images, aerial photography) features in a common geographic reference. Many GIS packages have functions that are particularly useful in transportation, such as linear referencing systems that enable location of events by route and milepost (e.g., an incident occurring at I-65, mile marker 62) or milepost ranges (e.g., traffic counts on I-65 between mile marker 61 and 63).

Additionally, GIS, since they provide a framework for comprehensive and consistent assignment of digital data, provide an analysis environment that takes into account multiple layers, criteria and attribute information. For example, shortest paths may be calculated that minimize travel time, subject to additional criteria such as restricting the path to certain types of roads and avoiding bridges with insufficient design loads and low vertical clearances.

This paper documents an effort undertaken to use a risk-based approach to identify segments of the Tennessee interstate system that have high truck volumes and are susceptible to freight diversions. Once these segments were identified and prioritized, GIS routines determined the most appropriate alternate routes for passenger vehicles and trucks.

LITERATURE REVIEW

Currently, there are several methods of navigation available for public use which allow for simple, automatic planning of routes. One such method is the Google Maps Navigation application, available to computer and smart phone users through the web at http://maps.google.com (*3*). This application takes real-time traffic into account when determining the quickest route. The computer view of this application displays a number of routes (where available), and users may manually override the pre-determined path by dragging any section of the route to “force” the route through a specified section. This application does not have routing options available for trucks as it does not treat trucks differently from other vehicle types, and the routing criteria are solely based on travel time, length and traffic conditions. There are several other free web-based methods for navigation (including MapQuest, Bing, Yahoo!) that operate similarly, but Google Maps is considered a leader as their platform is used for real-time navigation, is free, and has real-time traffic data integrated into their roadway network. Personal global positioning system (GPS) units are commonplace in passenger cars and trucks now, and most will sense when a vehicle is not moving, or is moving well below the speed limit, prompting a recommendation to consider making a detour. The suggested detour is based on calculating the shortest route according to speed limit and length.

There are navigation systems designed specifically for trucks. PTV Traffic Mobility Logistics (*4*) created a special satellite navigation system for trucks in the European Union (EU) to better plan their routes. Considered restrictions include weight, axle load, vehicle length, clearance height and width, and roads closed to trailers. Additionally, the system automatically diverts around residential areas. Another truck-specific EU application is the Renault NavTruck system (*5*). NavTruck chooses appropriate roads for trucks based on user-specified vehicle dimensions.

While both of these systems are highly useful and could be applied beyond just the need for individual truck routing, neither is developed for the United States nor do they include travel time minimization options. Truck routing systems which exist in the United States include PC Miler and Rand McNally; however, these systems fall short as well. PC Miler is a computer based software which does not allow for a quick determination of an alternate route. Rand McNally, on the other hand, while portable, makes no mentions of avoidance of features such as low-clearance bridges or weight restrictions, but rather focuses on truck stop information and other similar, useful features. The necessary nationwide roadway data for performing such truck routing in a broad sense in the United States is currently non-existent. The National Highway Planning Network (NHPN) and Highway Performance Management System (HPMS) both contain the number of through lanes for all roads, but neither has lane width, curvature, grade, bridge design load nor vertical clearances built into the network (*6*). The HPMS does contain a truck route field that identifies whether a section is on or off a designated truck route. However, as shown in Figure 1, the network is hardly routable (even some interstate segments are absent) and there are not enough non-interstate routes included in the dataset to form a suitable alternate route.

In terms of previous projects with similar ambitions, a few states and individual cities have developed their own rerouting techniques for trucks. The Traffic Diversion Plan for I-84 in Connecticut sought to develop emergency diversion plans for major expressways in a specific region (*7*). In order to accommodate truck traffic, the following criteria were considered: capacity, horizontal curve standards, bridge clearance, movement prohibitions, and size limitations for trucks. Diversion routes were determined from exit-to-exit and also within designated regions.

The Mobile (Alabama) Metropolitan Planning Organization (MPO) examined alternate routes for I-10, I-65, and I-165 using SYNCHRO, a traffic analysis and optimization software package (*8*). The following truck factors were considered when choosing the preferred route: bridge weight, vertical clearance and lane widths. With this framework, however, some proposed alternate routes were still found to be difficult for trucks to maneuver. While both of these studies considered diversion factors for trucks, each focused on a small region and the most at-risk areas of the interstate were not determined and given special interest.

The City of Seattle has attempted to improve freight mobility and safety through its Freight Mobility Program (*9*). Information is provided online relative to bridges with weight restrictions and truck-specific alternate routes around the Spokane Street Corridor. However, this requires that routes be extensively planned in advance for the everyday truck driver and the information is not provided in a form where it can be combined and examined at one time. Additionally, these alternate routes are not planned in anticipation of closures due to incidents; rather, the routes are intended to alleviate recurring congestion.

Stamatiadis and Culton evaluated alternate routes in Lexington, KY to be used in incident management based on minimizing traffic on local roads, ease of access and navigation, and reducing turning points to reduce driver confusion (*10*). While some potential geometric deficiencies were considered for truck traffic, the main thrust of this research was to evaluate a pre-determined alternate route using a combination of traffic flow and signalization software packages.

In 2007, Baird completed a Corridor Incident Management research project in Tennessee (*11*). This project developed a number of tools and an organizational framework that enabled rapid retrieval of alternate route information in a given county. While this effort was aimed at utilizing existing data and tools for overall incident management and did not specifically address alternate routes for trucks, some key findings resulted from the research. First, a spreadsheet was developed that showed the impact and queue build-up from a closed interstate segment. This methodology, once calibrated, could be used in alternate route decisions, specifically when to divert traffic versus the "quick clearance" decision.

Secondly, Baird identified the need for a comprehensive alternate route "playbook" for interstate segments (by county) which responders could refer to and take advantage of pre-planned alternate routes.

Upon completion of the literature review, it was clear that gaps existed in using a risk-based approach to prioritize interstate segments based on the likelihood of a complete interstate closure. Furthermore, there was a need for development of a GIS-based methodology that explicitly considered truck needs in designating alternate routes.

DATA

Several data sources were obtained in developing a methodology for determining the high-risk segments and truck-specific alternate routes. This section describes each respective data source:

TDOT SmartWay Information System (TSIS): As Tennessee Department of Transportation's (TDOT) primary travel information system, TSIS contains information on incidents, construction and maintenance projects, and weather-related road conditions (*13*). The system was designed in 2002, prototyped from 2003-2004 and went live at the end of 2004. TSIS was rolled out gradually, with Region 3 (middle Tennessee) being the first region to adopt it. Regions 1, 4, and 2 followed, and, as evident in Figure 2 (showing the number of incidents reported statewide), all regions had fully adopted the system for reporting events around December 2006. For this reason, only incidents occurring after 2006 were considered in the methodology. The upward trend in the number of incidents is a result of additional traffic detection cameras being deployed throughout Tennessee as well as increased user familiarity with the system.

An incident in TSIS can consist of anything from a traffic crash, large event (e.g., Tennessee Titans' NFL game, Bonnaroo Music Festival), vehicle or cargo fire, disabled vehicle, or gusty winds that make travel hazardous. Incidents in the TSIS database are primarily traffic crashes, however, as evident in the Table 1.

Key information attributes in the TSIS database include the incident location (using linear referencing by route and county logmile), impact (e.g., whether the roadway was completely or partially blocked), duration (time between incident start and clearance), direction in which the incident occurred, and whether or not traffic was diverted. There is also information withheld from the public contained in a field known as "current activities," which may provide useful information about the incident (e.g., fatality, injury, involved tractor-trailer, etc.).

Tennessee Highway Patrol (THP) Crash Data: This database contains information about traffic crashes investigated by THP officers. Relevant attributes include date, route and logmile and type of crash (property damage only, injury, fatality). Crashes in the database cover 1995 through 2008. Unfortunately, there is no direct linkage to the TSIS database and attempts to link records in the two databases by date/time and location were not successful.

TDOT GIS Datasets: The following describe relevant GIS datasets maintained by TDOT.

- Roadway Geometrics: considered the master line layer to which several tables (traffic, vertical alignment and horizontal alignment) can be attached via linear referencing. The layer itself contains information on right of way, access control, speed limit, school zone speed limit (if applicable), truck speed limit (if applicable) and number of through lanes.
- Traffic: contains traffic data for the year 2010. Attributes include route, beginning/ending county logmiles, average annual daily traffic (AADT), single and multi-unit truck percentages, passenger vehicle percentages, design hourly volume percentage, and directional distribution.
- Vertical alignment: records route, beginning/ending county logmiles, percent grade and direction of slope.
- Horizontal alignment: contains route, beginning/ending county logmiles, and degree of curvature of roadway segment. The storage of horizontal alignment data as roadway degrees of curvature, rather than turning radius when traveling from one segment to another, prohibited this data from being used in the analysis.

It should be noted that in order to have a complete and consistent geographic layer for analysis purposes, the traffic, vertical alignment and horizontal alignment tables have to be “attached” to the roadway geometrics layer via linear referencing. The GIS is able to interpolate and create new line features based on the roadway geometrics layer that contain attributes from all four datasets (geometrics, traffic, vertical and horizontal alignment) through a process known as dynamic segmentation. Figure 3 provides an example of how vertical alignment data is dynamically segmented with traffic data.

Interstate exits: This is a point geographic layer that was created manually by panning and zooming along Tennessee interstate corridors and adding point layers where interchanges are located. The exits layer was used to identify the ingress and egress alternate route locations.

National Bridge Inventory (NBI): The NBI is a point geographic layer describing more than 700,000 bridges in the United States. This inventory contains information about design loads, vertical clearances and appraisal statuses. The layer was downloaded from the Bureau of Transportation Statistics (BTS) National Transportation Atlas Database (NTAD) site (*13*).

School zones: The school layer originated from the data included with ESRI ArcMap. A one-half mile circular buffer was created to represent school zones.

METHODOLOGY

The Tennessee interstate system was divided into 2,245 half mile segments. For each segment, the following performance metrics were recorded:

1. number of THP-reported crashes, classified as fatality or injury (these are considered “severe” crashes that are more likely to result in a closure with alternate route diversions),
2. volume per lane - VPL (AADT/number of through lanes),
3. multi-unit truck percentage,
4. number of TSIS-reported incidents since 2006 (overall, and those resulting in a lane or total closure), and
5. average, total and maximum TSIS-reported incident duration (restricted to incidents lasting between 30 minutes and 24 hours).

Urban areas in the four major Tennessee cities (Chattanooga, Knoxville, Memphis and Nashville) were not considered since there are so many alternate route options and closely-spaced exits. These areas could feasibly be examined, but would require several alternative routes for those switching interstates or direction of travel. Segments near Chattanooga where Interstate 24 crosses into Georgia and then back to Tennessee were not considered since the network used for alternate route determination did not contain Georgia roads.

A correlation analysis (a measure of how dataset variables are related) was conducted on the first three metrics to ensure that none were closely related, thus “double-counting” and skewing the scoring system (see Table 2). The returned values indicate a slight positive correlation. Serious incidents are more likely to occur in segments with high volume per lane values, but the two metrics are not so closely related to warrant omitting one of the variables. For each metric, values representing the 25th, 50th, 75th and 100th percentiles were calculated. Each segment was assigned a number for each metric (i.e., 1 for 25th percentile, 2 for 50th percentile, etc.). These values were summed to determine the composite score across the 3 metrics. This resulted in half-mile segment scores ranging from 4 to 12. A higher composite score indicates that the segment has a greater likelihood of requiring an alternate route diversion with a significant percentage of trucks.

While each half-mile segment had an individual score, interstate exits occur much less frequently and the range of distances between exits varies greatly throughout the state. To take this effect into consideration, the average of half-mile segment scores between exits was calculated and the ten highest scores were selected to be evaluated. Figure 4 shows the locations of these segments by indicating at least one of the exits involved for each of the ten segments. The next step involved selecting locations along Tennessee Interstate corridors that experienced more than the usual amount of closures due to incidents. Locations along I-24, I-40 (between Memphis-Nashville and Nashville-Knoxville), I-65, and I-75 were selected to achieve a representative distribution of traffic, terrain and area type (i.e., rural, suburban, etc.). The selected locations are described below:

1. I-40 Exits 79-80, Score = 10.33
2. I-40 Exits 83-85, Score = 10.33
3. I-75 Exits 3-4, Score = 10
4. I-75 Exits 4-5, Score = 10
5. I-40 Exits 85-87, Score = 9.75
6. I-24 Exits 40-43, Score = 9.5
7. I-24 Exits 155-158, Score = 9.5
8. 1-40 Exits 238-239, Score = 9.5
9. I-40 Exits 192-196, Score = 9.38
10. I-40 Exits 133-137 (TN River Bridge), Score = 7.75

While Routes 1 through 9 were selected based on their average exit to exit segment scores, Route 10 (the I-40 bridge over the Tennessee River) was included for a different reason. This segment represents a unique type of critical infrastructure, for in the event of a bridge collapse or other long-term disabling event, the alternate route would be significantly longer than in other areas and result in up to an additional hour of travel time for trucks.

The next step was to develop criteria that enabled alternate routes to be evaluated and prioritized in terms of suitability for trucks. These criteria were incorporated into the network as either a restriction or scaled cost. Restrictions represent impassable and highly unfavorable conditions for trucks (bridge weight capacities, vertical clearances, lane widths, and over-capacity roads). Scaled cost roadway conditions result in longer travel times due to factors such as proximity to school zones, LOS E roads, and steep grades. Within the GIS, restrictions can be set so as to not allow trucks to be routed over the segment, while scaled costs are used to penalize the route by increasing the travel time by a specified factor (i.e., the scaled cost). Scaled costs were applied uniformly by criteria type and are subjective. The alternate route criteria for trucks are further described below:

1. **Bridge Weight Limits –** Bridges deemed to have insufficient live design loads for trucks were added as restrictions to the network, thus not allowing for undue stress to occur on those bridges. Bridges which met the following criteria were extracted from the National Bridge Inventory (NBI) and served as network restrictions:
    a. Bridges closed due to structural appraisal (NBI Field “Appraisal Rating” value of 0)
    b. “Intolerable” bridge appraisals at a high priority for replacement (NBI Field “Appraisal Rating” value of 2)
    c. Bridges rated for H10 and below (NBI Field “Design Load” value of 1)
2. **Bridge Clearance –** Bridges with vertical clearances of less than 4.2672 meters (14 feet) were selected from the NBI (field “Minimum Vertical Underclearance”) as restrictions.
3. **Lane Width –** Roads with lane widths of 9 feet and less were considered to not be wide enough for trucks to safety maneuver and were added as restrictions to the network.
4. **Over Capacity Roads –** Roads which were found to have more volume than capacity (LOS F) were added as restrictions to the network.
5. **LOS E Roads –** Roads operating near capacity (LOS E) were added to the network as a scaled cost restriction, with a value of two, indicating that these roads would take twice as long to travel than during free flow conditions.
6. **School Zones –** Areas surrounding schools become congested during the morning and afternoon hours and pose a danger to school children should heavy trucks be diverted through these locales. A one-half mile buffer was applied to the schools and overlaid on the network. Segments that intersected this polygon were assigned a scaled cost value of two.
7. **Grade –** Grades exceeding 7% were given a scaled cost of 2. This was chosen using the speed-

distance curves (Figure 47) contained in *NCHRP Report 505, Review of Truck Characteristics as Factors in Roadway Design* (*14*). Grade curves of 7% and greater, on a one-half mile length of grade, reduce entrance speed by 50%.

RESULTS

Once restrictions and scaled costs were added to the network, ArcGIS Network Analyst was utilized to characterize two sets of alternate routes. A baseline route was calculated, ignoring scaled costs and restrictions (this shortest path would likely be the route passenger cars would travel). A second route was computed, taking into account the scaled costs and restrictions. This represents the truck diversion route. As Network Analyst generates turn-by-turn directions, the routes were subsequently analyzed visually, inside the GIS and using Google Maps, before building a “playbook” to designate alternative routes for closures occurring on the high-risk Interstate segments. The playbook includes turn-by-turn directions, estimated travel time, obstacles of note (e.g., low clearance bridges, school zones that may not be a factor at certain times of the day) and the bottleneck index. The bottleneck index is defined as the minimum amount of excess capacity (capacity minus volume) for the diversion route. The bottleneck index and estimated travel time, along with the estimated closure duration, provide responders with additional information when determining whether to divert.

Interestingly, of the ten segments examined, six resulted in different alternative routes being specified if route restrictions are taken into account. Of these, the factors that affected the routing results are described in Table 3.

In some cases, the most desirable diversion route did not leave or rejoin the Interstate at the exits bounding the closed segment. Such was the case with Segment 6, which was located at I-24 (Exits 40-43). As shown in Figure 5, the route with no restrictions exits at Exit 40 and gets back on the interstate at Exit 43, for a total diversion distance of 5.5 miles taking approximately 11 minutes. However, the route with restrictions does not follow this pathway. Instead, the truck route is diverted to nearby I-65 due to capacity issues along potential alternate routes. From there, the truck route rejoins I-24 when I-65 and I-24 converge to one interstate. The diversion distance of this route is 7.2 miles.

In the case of segment 9, shown in Figure 6, the shortest path option was affected by a low bridge clearance and resulted in the need for an alternate truck route. Without this analysis, trucks needing a higher clearance would have become stuck under the bridge and caused further delays. Moreover, the route with no restrictions is 6.6 miles in length with a travel time of 12 minutes, while the truck route is a similar distance, with a travel time of only one minute longer.

CONCLUSIONS

The study report herein focused on two objectives: 1) developing a risk-based approach to identifying and prioritizing interstate segments for development of alternate route diversions for trucks, and 2) designing and implementing a method for selected preferred alternative truck routes when diversion is deemed necessary. The methodology utilized data from a travel information system, a state department of safety and a traditional state traffic reporting system to rank all Tennessee interstate segments based on their relative truck traffic, history of severe accidents and congestion levels. This approach offers the potential to develop contingency plans on highway systems when incidents arise, resulting in reduced congestion and increased travel time reliability.

Alternate routes were generated in a GIS environment that considered both trucks and passenger vehicles, taking into account varying criteria (grades, clearances, bridge design loads, school zones, capacity and demand). The entire state could have been analyzed using this approach; however, the scaled costs and restrictions used by the routing algorithms should be validated first. Modeling decisions of when and whether to divert trucks, or just passenger vehicles, requires a great deal of additional data (e.g., traffic signal synchronization) and was beyond the scope of this research. In addition, while only grades above 7% were considered in the rerouting decision, lower grades can also have an effect on truck handling. Further study could examine how routes change based on the selection of a lower grade. The same is true of traffic density. LOS E and LOS F were used to determine routes, but the incremental increases to move from LOS D, E, and F are smaller once LOS C is reached on roadway. Rerouting interstate traffic would help to further accentuate these increments and perhaps other service levels could also be considered in examining the alternate routes.

This effort demonstrated the challenge of gathering and using relevant truck routing data for just one state, let alone a region or the entire nation. There has been increased attention given to freight corridor analysis and intermodal connectivity recently. However, significant effort needs to be devoted to improving the current data structure and quality of nationwide networks, with special attention given to truck restrictions and parameters. GIS is particularly adept at managing the data involved in such analyses and the network analysis tools have outpaced the quality of data available, as was highlighted during the review of road network datasets.

ACKNOWLEDGMENT

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FIGURE 1 Tennessee HPMS Truck Routes

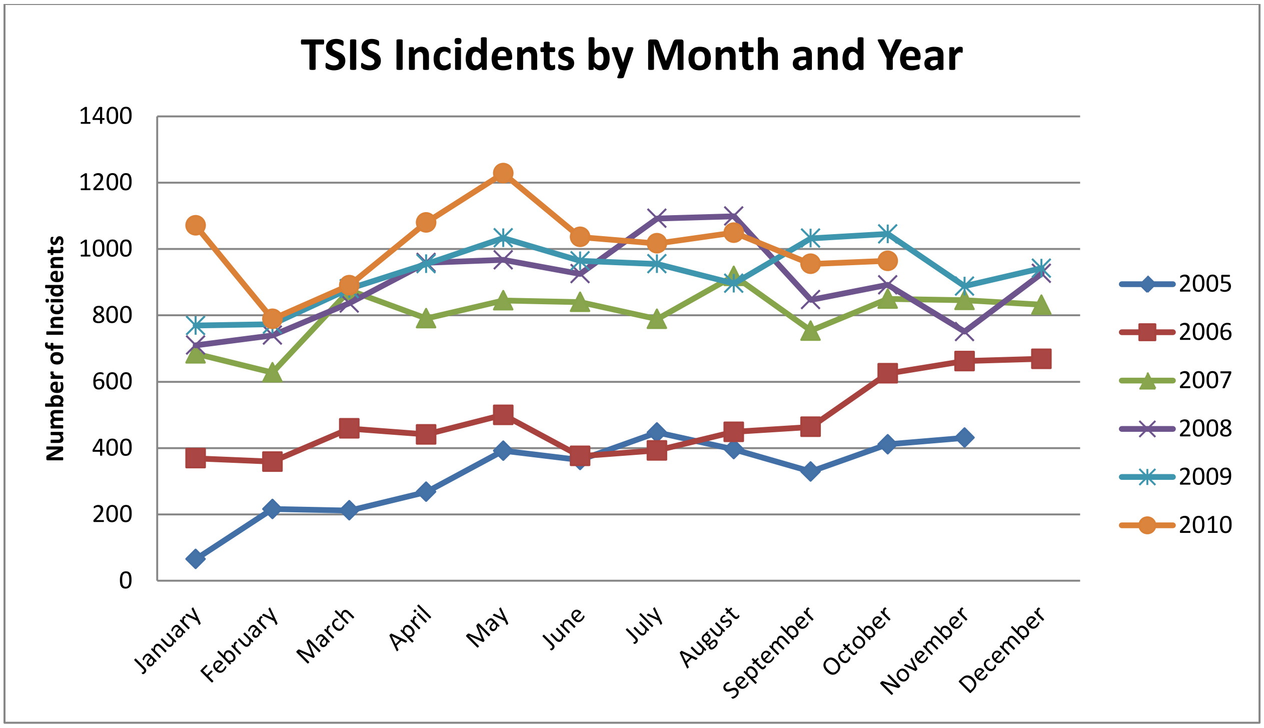

FIGURE 2 TSIS Incidents by Month and Year (2005-2010)

TABLE 1: Number of Tennessee interstate incidents reported in TSIS since 2006

Incident Type	Count
Crash	16,137
Incident	9,000
Disabled vehicle	7,679
Special event - high traffic volumes	970
Vehicle or cargo fire	711
Overturned vehicle	651
Gusty winds	28

Vertical Alignment

From Mile	To Mile	Grade
0.0	3.0	3%
3.0	5.0	2%

Traffic

From Mile	To Mile	Traffic
0.0	2.0	87,000
2.0	4.0	91,000
4.0	5.0	100,000

Vertical Alignment and Traffic

From Mile	To Mile	Grade	Traffic
0.0	2.0	3%	87,000
2.0	3.0	3%	91,000
3.0	4.0	2%	91,000
4.0	5.0	2%	100,000

FIGURE 3 Dynamic Segmentation Example

TABLE 2: Half-Mile Correlation Analysis Results

	VPL	Multi-Truck Unit %	Serious Incident Count
VPL	1	0.348	0.368
Multi-Truck Unit %	Negative	1	0.218
Serious Incident Count	Positive	Negative	1

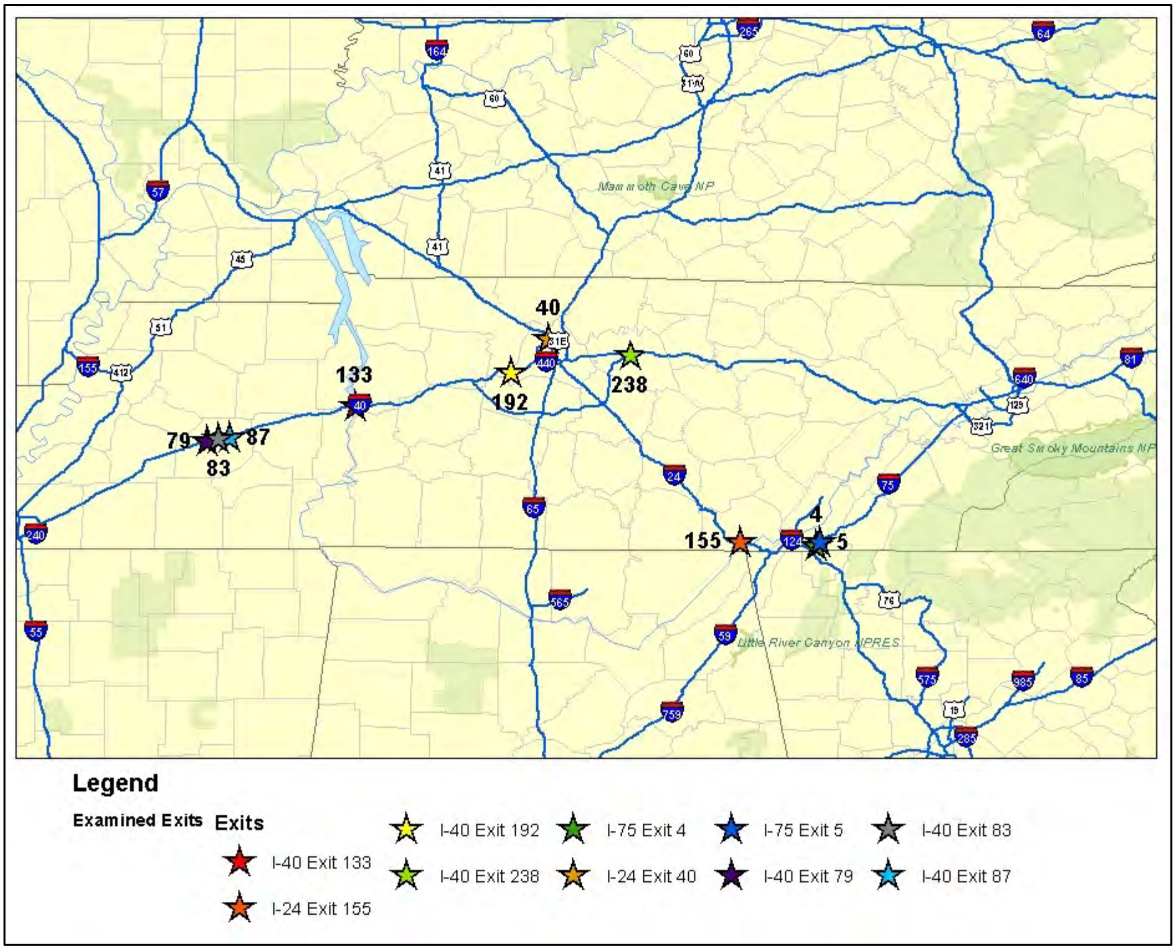

FIGURE 4 Ten Interstate Segment Locations at High Risk of Closure

TABLE 3: Segments and Factors Affecting Alternate Routes

	Segment 3	Segment 4	Segment 6	Segment 8	Segment 9	Segment 10
Over Capacity	X	X	X			
School Zones				X		X
Bridge Clearance					X	

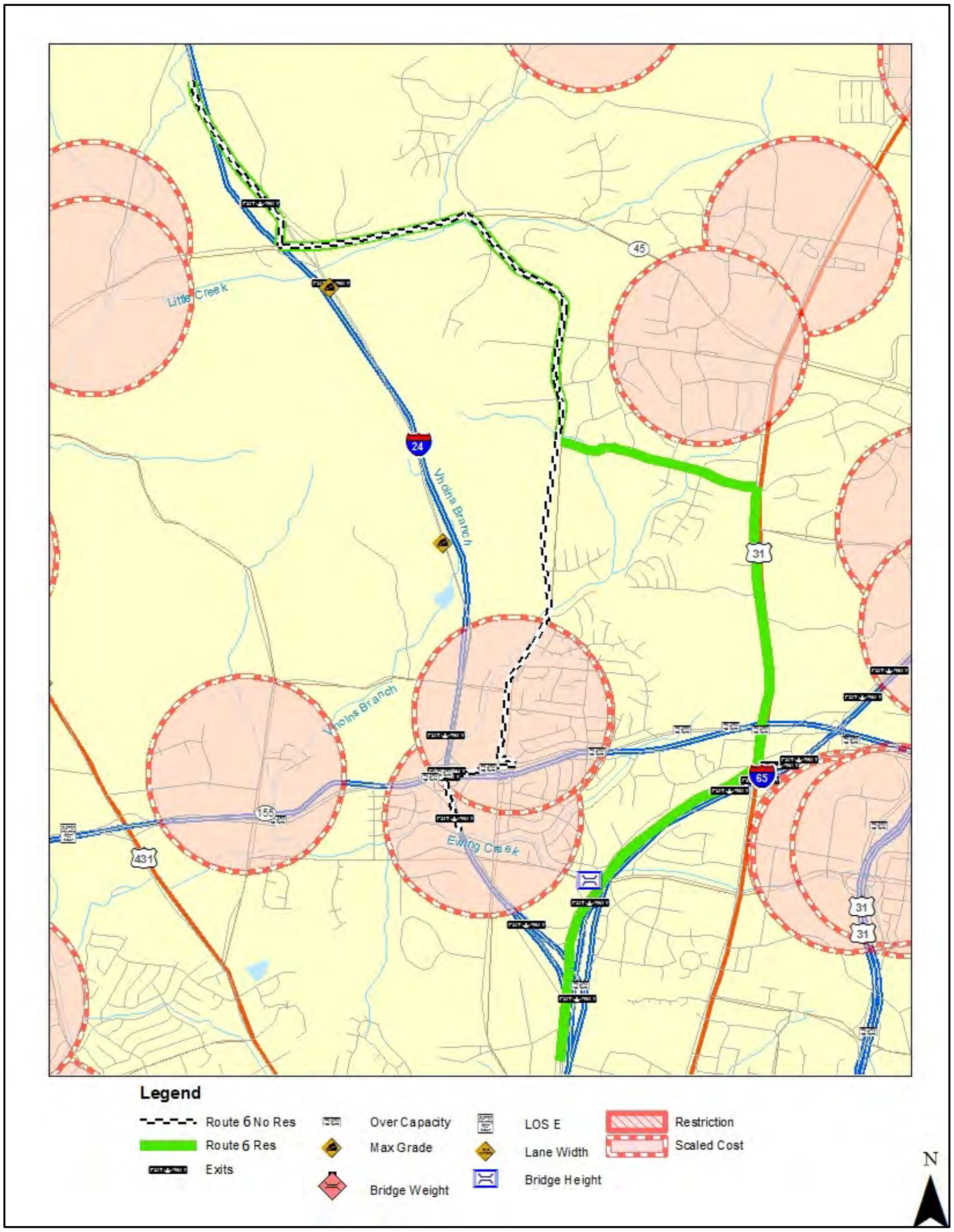

FIGURE 5 Segment 6 Truck and Passenger Car Alternate Routes

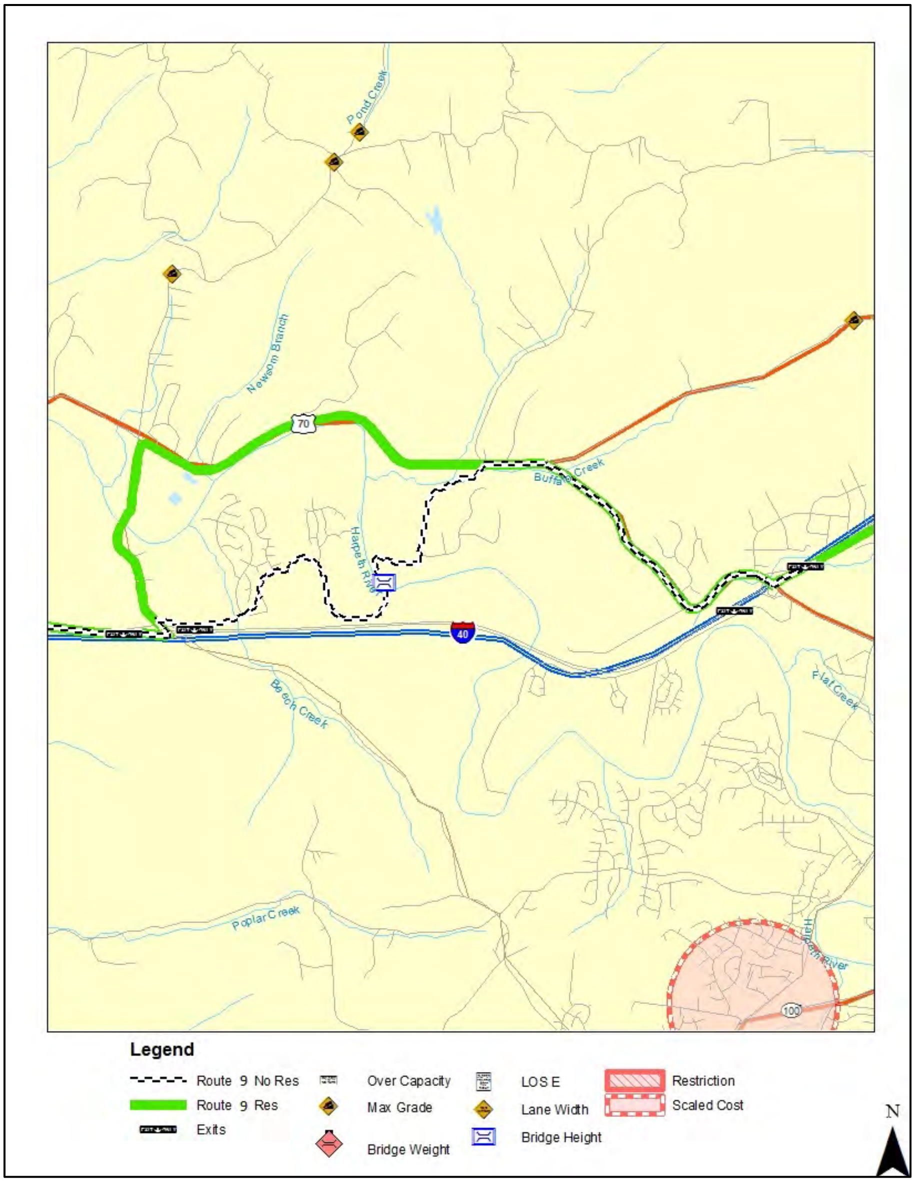

FIGURE 6 Segment 9 Truck and Passenger Car Alternate Routes