DEVELOPMENT OF TRUCK ROUTE DIVERSION STRATEGIES IN RESPONSE TO INTERSTATE INCIDENTS

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ABSTRACT

Roadway closures due to highway incidents are detrimental to the American economy and result in lost time for motorists. Route diversion can help lessen the effects of highway incidents, if the decision is based upon a set of criteria that helps evaluate the impacts of the rerouted traffic. These criteria must meet two conditions: 1) quantifiable and 2) can be evaluated in a time-efficient manner. Based on a review of existing routing methods, criteria were defined according to three key considerations: 1) geometric characteristics, 2) proximity, and 3) capacity. Performance measures for these criteria were determined and applied to the Tennessee interstate highway network by utilizing GIS software to determine incident "hot spots" worthy of rerouting consideration. The application of the criteria led to diversion route selections that minimized travel time, while satisfying truck operational constraints, and maintaining an acceptable level of service (LOS) when additional traffic was assigned to the route. The methodology described in this document can be applied to roadway networks in other locations in order to facilitate diversion decisions. The research presented can also be used as a basis for developing more enhanced tools for making more efficient rerouting decisions while maintaining operational safety.

TABLE OF CONTENTS

Introduction

America has benefitted greatly from a highway system which connects our vast country. This network has led to economic growth, increased mobility and shaped many of the land development patterns of the United States. When incidents occur that result in the partial or complete closure of a highway segment, people and businesses suffer time and monetary loss.

Economic analyses have been performed in an attempt to quantify this impact. For example, the State of Kentucky estimated that the closure of one lane of traffic for 20 minutes on an interstate has an equivalent monetary loss of $10,000, due to decreased productivity, the rise in price for a good or service that is passed on to the customer, and the loss due to decreased fuel efficiency (Kentucky Transportation Cabinet, undated). The closure of one lane of US-101 in Mendocino County, California was estimated in 2003 to cost travelers approximately $56,000 per day due to delay (Office of Transportation Economics, 2003). On a larger scale, the Texas Transportation Institute estimated in 1992 that delay due to incidents in Texas cost $1.25 billion per year (Wohlschlaeger, 1992). Such numbers are not surprising when one considers that roughly one-half of the congestion on American roads is due to traffic incidents (Booz Allen Hamilton, 1998).

Highway delays caused by crashes are having an even greater impact on businesses with the popularity of just-in-time delivery. Companies utilize this strategy to reduce inventory costs by eliminating the need to store merchandise or raw goods in a warehouse. As this strategy depends on reliable delivery of goods in a timely manner, any unexpected delays can be quite costly since they can hold up production or delay the delivery of final products. The negative effects of traffic delays due to crashes are only expected to amplify in coming years as the highway system continues to become more congested.

The aforementioned information underscores the need to implement effective strategies for diverting traffic onto other roads in response to crash events. Rerouting traffic during a highway incident can also provide safety benefits by reducing the frequency of secondary collisions, those caused by distraction or traffic congestion following an initial incident (U.S. Fire Administration, 2008). On the Capital Beltway that encircles Washington D.C., secondary crashes are estimated to account for approximately 36 percent of all crashes (Hegarty, 2011). While motorists are often these victims, a surprisingly large number of law enforcement personnel also perish in this manner. In Arizona, 66 percent of Highway Patrol officers have died in crashes in the past two decades due to secondary crashes (Arizona Highway Patrol Memorial, 2011). California lost three highway patrol officers in just one month (June 2010) due to similar circumstances (Remembering CHP's Finest, 2011). Secondary crashes also add congestion to the already backed up traffic following an initial crash (U.S. Fire Administration, 2008).

While there are many methods for attempting to reduce crashes on interstates, such as setting appropriate speed limits, utilizing rumble strips, and improving highway geometry, crashes are still inevitable. When the incident is severe enough to shut down one or more lanes along an interstate, questions of whether and how to divert traffic undoubtedly arise. While many states have implemented guidelines for determining when to reroute traffic (see Table 1), current recommendations fail to account for specific factors such as traffic types and volumes along the original route, and travel time and geometric/structural limitations of the diversion route. By taking these factors explicitly into consideration, the potential exists for highway authorities to make better route diversion decisions.

Table 1 demonstrates the commonality and variation in re-routing criteria used by different states. While most organizations deploy diversion routes based on the number of lanes affected and the anticipated incident duration, they differ in the temporal threshold for making that decision.

Of note, however, none of these organizations cite the characteristics of the alternate route as part of the criteria for determining whether diversion at the incident site is warranted. This is surprising given that the capacity and safety considerations associated with the diversion route could exacerbate the consequences of the initiating event.

The intent of this research is to develop a decision-support tool that assists agencies with decisions of whether and how to divert truck traffic onto alternative routes based on the crash conditions on the origin route and the characteristics of the candidate diversion route. In the discussion to follow, the design, development and implementation of this tool is described.

Table 1: Selected State Criteria for Alternate Routing

AGENCY	CRITERIA
North Carolina	• Complete closure of the highway in either direction is anticipated to last 15 minutes or longer.
New Jersey	• Complete closure of highway is anticipated to last more than 90 minutes.
Oregon	• Incident with two or more lanes blocked, or • Incident with one lane blocked and expected to last more than 20 minutes.
New York	• Implemented only when the highway is completely closed.
Florida	• Two or more lanes blocked for at least 2 hours.
ARTIMIS (Ohio/Kentucky)	• Deployed during peak hours when more than two lanes are closed for at least 30 minutes.
Idaho	• An incident taking over 2 hours from detection to anticipated fully restored traffic flow.
Wisconsin	• Incident causes delays that will exceed 30 minutes.

Source: FHWA Alternate Route Handbook, 2006

Literature Review

While the need to divert traffic during incident response and emergency evacuation are topics that have been fairly well chronicled, there has been a paucity of research directed at alternate route criteria and its effect on diversion decisions. Related research that has been published falls into two general categories: 1) analyzing diversion strategies, and 2) hazardous materials routing.

Analyzing Diversion Strategies

In terms of comparing diversion strategies, a study carried out in Virginia focused on the delay caused when traffic is rerouted and the corresponding level-of-service experienced on the route used for diversion. Models were developed and applied to gain insight into predicted traffic flows when rerouting a partially or fully closed interstate segment (Cragg, 1995). At the time, computing constraints made model processing sufficiently time intensive that the decision-support could not be provided commensurate with when the information was needed. The notion that these decisions had to be made in real-time (as opposed to having a "playbook" available) and given the significant computational improvements that have been made over the past sixteen years present a different opportunity today.

Another study focused on interstate diversion for interstate accidents in Lexington, Kentucky (Stamatiadis, 1999). The key criteria for determining alternate routes were travel time, ease of access, navigability (minimizing number of turns), geometric limitations, and available capacity. Traffic signal timing along potential alternate routes was also considered. Traffic engineering software was used in the determination of alternate routes, but was focused on optimizing signal timing plans to provide for the efficient flow of traffic along alternate routes. Final study recommendations included rerouting traffic onto different alternate routes depending on the time of day and implementing alternative signal timing plans to better accommodate the diverted traffic in conjunction with existing traffic.

An intelligent transportation system diversion planning study used the following six criteria categories to initially determine alternate routes: 1) roadway ownership, 2) roadway infrastructure including traffic signals, 3) geometric restrictions, 4) existing traffic conditions, 5) land use surrounding roadway, and 6) logicalness of the alternate route (Volkert and Associates, 2011). Specific criteria utilized in the study that are not often seen in similar work included the minimization of left turns and the avoidance of railroad crossings. In order to determine daily peak hour volumes, projected average daily traffic volumes were converted by utilizing a peak hour factor of 10 percent and a directional distribution factor of 60 percent. These volumes were thought to represent the worst case event. This study used Synchro software for simulation of traffic conditions in order to better determine alternative routes. This study also included an analysis of traffic signal timings along the proposed alternate routes.

A study that utilized GIS technology to aid in diversion decisions was performed on roadways in Connecticut (Wilbur Smith Associates and Fitzgerald & Halliday, 2011). The diversion plans assumed an all-lane closure of the interstate in one or both directions for a minimum of two hours. This study verified bridge and roadway data by performing field visits, a technique that is applicable only when there are a small number of locations that require field location.

Individual drivers and law enforcement agencies do not always agree on when diversion is warranted. A study performed by Virginia Polytechnic University indicated that the likelihood a driver will choose to divert due to a traffic incident is directly related to the number of lanes blocked (Wang, 2010). In contrast, while number of lanes blocked is an important criterion, law enforcement agencies have a responsibility to consider additional criteria, such as incident duration and alternate route suitability.

Hazardous Material Routing

As hazardous material (hazmat) routing decisions have been at the forefront of selection of preferred routes according to various criteria, there is the potential for transferability of approaches used in hazmat routing decisions to route diversion strategies. When evaluating the safest route for the transportation of hazardous material, efforts are made to balance efficiency and safety, albeit certain criteria may be weighted more heavily than others.

In a study conducted for the City of Boston, the primary criteria were population at risk, environmental impact, and proximity to emergency response capability (Battelle, 2011). Secondary criteria included the effect on commerce. The application leveraged the use of geographic information system (GIS) technology in both data collection and presentation of preferred routing alternatives.

The Boston study utilized a multi-step process to select alternative routes. First, all candidate routes were identified, with the assistance of local officials, law enforcement, emergency response, and transportation personnel. Candidate routes were then eliminated from further consideration if they met one or more of the following criteria:

- Roadway width of less than 10 feet
- Vertical clearance of less than 15 feet underneath a bridge
- Bridge with height and width restrictions
- Bridge that was in fair to serious condition (ranking of 5-3).

Secondary criteria, such as population density and alternate route length, were also considered. While these secondary criteria did not automatically exclude a candidate route, they could be used to select a preferred route from those that met the initial criteria. Estimated travel times along alternate routes were based on recorded observations. Assumptions were made about the overall traffic patterns in the Boston area, with night travel assumed to take less time than during the day.

In providing guidance to states and communities, the Federal Highway Administration (FHWA) has developed a list of criteria for determining alternate routes that is part of their Alternate Route Handbook. These are displayed in Appendix B.

In addition to hazmat routing studies directed at the trucking mode, there has been similar interest in rail routing of hazardous material. The Federal Railroad Administration (FRA) has recently adopted a rulemaking requiring railroads moving certain materials in specified quantities to consider twenty-seven different criteria in making routing decisions (see Appendix A).

The aforementioned research activity demonstrates the importance of traffic incident management and the use of route diversion as a mitigation strategy. However, consideration of alternate route criteria in selecting the preferred diversion route has been limited. A natural expansion in this area is to explore this consideration in greater depth. Current federal routing guidelines can serve as a good starting point for identifying potential route diversion criteria. In the discussion to follow, a new route diversion methodology is developed based on this premise.

Route Diversion Methodology

As an initial step in selecting alternate route criteria, all previous criteria set forth by the FHWA and FRA were reviewed. This list was first narrowed down by the ease of measurability. This eliminated criteria that were considered difficult to quantify or systematically derive at a network segment level (e.g., air quality). Other criteria were omitted if they were judged to measure the same effect, thereby eliminating redundancy. The remaining criteria and rationale for inclusion are listed in Table 2.

Table 2: Select List of Alternate Route Criteria

Criteria	Description
Proximity to primary route	Alternate route is near enough to the original route to provide a time savings and is appropriate given the amount of local and/or regional traffic
Height, weight, width, and turning restrictions	Alternate route is usable by all vehicles, including commercial vehicles
Number of travel lanes/ capacity	Alternate route provides sufficient capacity for the rerouted traffic plus the normal traffic on route and should have at least the same LOS as the primary route
Existence of schools	Increased traffic can cause negative effects on routes that serve schools

Source: FHWA Alternate Route Handbook, May 2006

Once the list of criteria was narrowed, a decision was made as to whether an inability to meet a certain criterion should remove the alternate route from consideration altogether. The three measures that warranted this consideration were:

1. Height, weight, width, and turning restrictions
2. Proximity to primary route
3. Number of travel lanes/capacity

For the existence of schools, a scaled "cost" was applied to the candidate route, creating an impedance but not eliminating the route from consideration altogether.

Height, Weight, Width and Turning Restrictions

Since tractor trailers are prevalent on Tennessee's interstates due to the state's location as a major distribution hub, these vehicles tend to comprise a sizeable amount of the interstate traffic. If an alternate route cannot accommodate commercial truck traffic, then the route is not an acceptable diversion option. The characteristics that make a candidate route impassable for tractor trailers were specified as follows:

- Clearance issues due to bridge overhead clearance
- Inadequate lane width
- Bridges along route that are not rated for tractor trailers

Standards for each of these three characteristics were researched and the following ranges of values were deemed to be acceptable:

Criterion	Acceptable Value
Bridge Clearance	≥ 14 ft.
Lane Width	≥ 9 ft.
Bridge Load Rating	≥ HS 20*

*The HS 20 bridge load rating corresponds to a semitrailer with three axles weighing a total of 72,000 pounds. The load is distributed with 8,000 pounds on the steering axle, 32,000 pounds on the drive axle, and 32,000 pounds on the semitrailer axle.

Proximity

The proximity of an alternate route to the original route, along with the speed limit, help dictate the travel time along the alternate route. The proximity measure utilized was the travel time ratio of the alternate route travel time to the original route travel time. The travel time for both routes was determined by dividing each segment length by the speed limit for that segment and then summing each of the individual segment values in order to obtain the total travel time for the entire route. For example, if a 3-mile alternate consists of three segments, 1 mile at 25 MPH, 0.5 mile at 30 MPH and 1.5 miles at 40 MPH, the travel time calculation would be:

$$\frac{1\ \text{mile}}{25\ \text{MPH}} + \frac{0.5\ \text{miles}}{30\ \text{MPH}} + \frac{1.5\ \text{miles}}{40\ \text{MPH}} = 0.094\ \text{hours or approximately}\ 5.6\ \text{minutes}$$

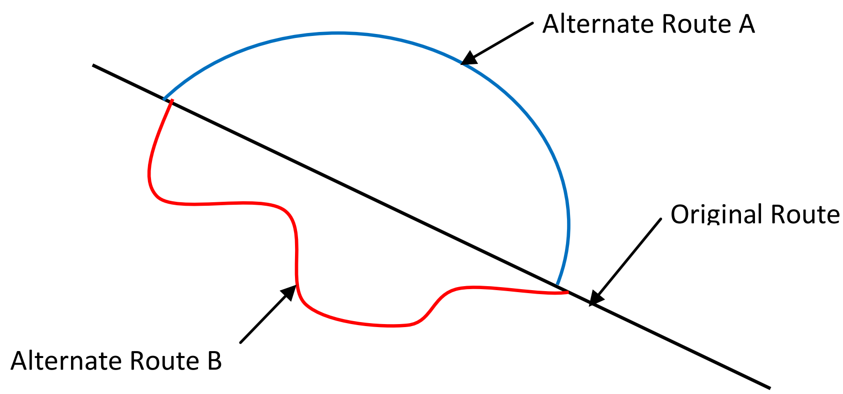
Capacity

The capacity of an alternate route can be used to formulate a bottleneck index, which measures the traffic constraints that will be experienced along an alternate route if traffic is diverted onto the route. Interstates tend to handle more traffic than state and local roads and thus these roads cannot always accommodate the rerouting of interstate traffic. In order to ensure that rerouting will not cause a total breakdown of traffic flow on the alternate route, the available capacity on the alternate route is determined and then compared to the AADT for the interstate segment. To determine the available capacity, the number of lanes, type of route, and land type are defined. These three characteristics can then be applied to the LOS chart (See Appendix C) to derive a total capacity value. The current traffic on the alternate route is then subtracted from the total capacity to determine the available capacity.

While there might be multiple segments that comprise an alternate route, the most constrained segment was used to derive the overall available capacity since the entire route can only operate at the capacity of the bottleneck. The available capacity of the bottleneck divided by the traffic currently on the interstate was developed as the bottleneck index. Any alternate route having a bottleneck index of greater than one was considered over capacity; in such cases, these candidate routes were eliminated from further consideration. In addition, alternate routes with a LOS E rating were assigned a scaled cost.

The following examples are presented to illustrate how the methodology is applied. Figure 1 depicts the roadway network for all scenarios.

Figure 1: Example Roadway Network



<u>Scenario A</u>

Alternate Route A has the following characteristics:

- Passable for all vehicles
- Ample capacity
- Length of 15 miles
- Speed limits are 25 MPH for 10 miles and 35 MPH for 5 miles

Alternate Route B has the following characteristics:

- Passable for all vehicles
- Ample capacity
- Length of 20 miles
- Speed limits are 30 MPH for 14 miles and 40 MPH for 6 miles

Travel time along the original route is estimated to be 30 minutes due to lane closures stemming from a highway incident.

Both alternates have no geometric or capacity constraints so both routes are viable candidates in terms of those criteria. With regard to the third criterion, travel times along Alternate Route A and Alternate Route B are estimated to be 32.5 minutes and 37.0 minutes, respectively. Since the travel times for both alternate routes are greater than the estimated travel time with delays on the original route, traffic should be kept on the original route and not diverted.

Scenario B

Alternate Route A has the following characteristics:

- Vertical clearance is 12.5 feet
- Lane widths are 12 feet
- Bridge load rating is HS 20
- Ample capacity
- Length of 10 miles
- Speed limits are 40 MPH for 5 miles and 35 MPH for 5 miles

Alternate B has the following characteristics:

- Vertical clearance is 14 feet
- Lane widths are 11 feet
- Bridge load rating of less than HS 20
- Ample capacity
- Length of 12 miles
- Speed limits are 50 MPH for 6 miles and 45 MPH for 6 miles

Travel time along the original route is estimated to be 45 minutes due to lane closures stemming from a highway incident.

Both alternates have no capacity constraints so the capacity criterion is met. Travel time along Alternate Route A will be approximately 16.1 minutes and travel time along Alternate Route B will be approximately 15.2 minutes. Since the travel time for both alternate routes is less than the estimated travel time along the original route, both alternates are viable candidates for rerouting traffic. Unfortunately, both alternates have geometric constraints that would eliminate them from consideration. Alternate Route A only has a vertical clearance of 12.5 feet, while the vertical clearance for most commercial trucks is a minimum of 14 feet. Alternate Route B has a bridge load rating that cannot accommodate large commercial vehicles. Since neither route can handle all vehicles that would be diverted, traffic should remain on the original route.

Scenario C

Alternate Route A has the following characteristics:

- Passable for all vehicles
- Capacity of 3,000 vehicles/hour
- DHV= 1,200 vehicles/hour
- Length of 10 miles
- Speed limits are 40 MPH for 5 miles and 35 MPH for 5 miles

Alternate B has the following characteristics:

- Passable for all vehicles
- Capacity of 6,000 vehicles/hour
- DHV=1,500 vehicles/hour
- Length of 12 miles
- Speed limits are 30 MPH for 14 miles and 40 MPH for 6 miles

Travel time along the original route is estimated to be 30 minutes due to lane closures stemming from a highway incident and the AADT is 20,000 vehicles.

Both alternates have no geometric constraints therefore they are both viable candidates in terms of those two criteria. Travel time along Alternate Route A will be approximately 16.1 minutes. Travel time along Alternate Route B will be approximately 15.2 minutes. Since the travel times for both alternate routes are less than the estimated travel time along the original route, rerouting traffic off of the original road and onto one of the alternates would be beneficial.

Once the decision to reroute traffic has been made, the best alternative route must be determined. For this scenario, the level of service (LOS) that will be experienced along each alternate will be the determining factor. The first step is to convert the AADT into a design hourly volume (DHV). Since we want to predict the heaviest traffic conditions that could be rerouted, we need to multiply the AADT by a K-factor. We will assume a K value of 0.095, the K-factor normally used for rural developed land areas. In order to convert a two-way traffic count to a single directional volume, the count must be multiplied by a directional split. In this case a 65-35 split was assumed, so the AADT is multiplied by 0.65. Therefore the DHV for the original route is:

$$DHV = 20,000 + 0.095 * 0.65 = 1,235 \text{ veh/h}$$

If traffic is to be rerouted onto Alternative A, the v/c ratio would be 0.81, which corresponds to LOS D. The v/c ratio if traffic is diverted onto Alternative A would be 0.46, which corresponds to LOS B. Since traffic would experience better flow conditions on Alternative Route B, the diversion route represents the preferred alternative.

Case Study Application

In order to better facilitate the evaluation of alternate routes, a GIS model of the roadway system in Tennessee was developed. Besides depicting routes throughout the state, the model also contained school locations. Geometric data for each road segment was compiled along with traffic conditions. Based on criteria thresholds for lane width, capacity and vertical clearance, routes that featured characteristics that made them impassable as an alternate route were eliminated from consideration. In addition, a slight penalty (scaled cost) was assigned to roadways that were within a specified distance of a school.

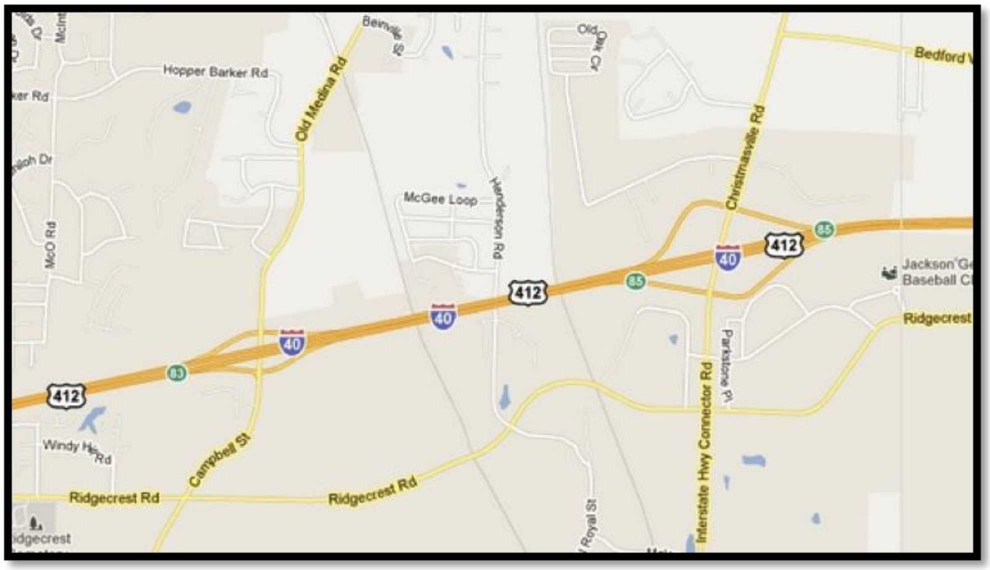
As a proof of concept, a group of roadway segments that had significantly higher than average incident rates was identified to test the methodology. Results produced from applying the methodology were also manually verified to ensure that the process was working as intended. This proved successful.

The analysis of each segment took just a few minutes to complete and modifications to the roadway characteristics were able to be made in real-time. The case study application was limited to identifying the preferred diversion route assuming that a decision had been made that traffic would be rerouted.

The following results are presented for three of the "hot spots" evaluated as part of the case study. The descriptions include a map of the "hot spot", directions associated with the preferred diversion route, and a diagram showing the location of the alternate route.

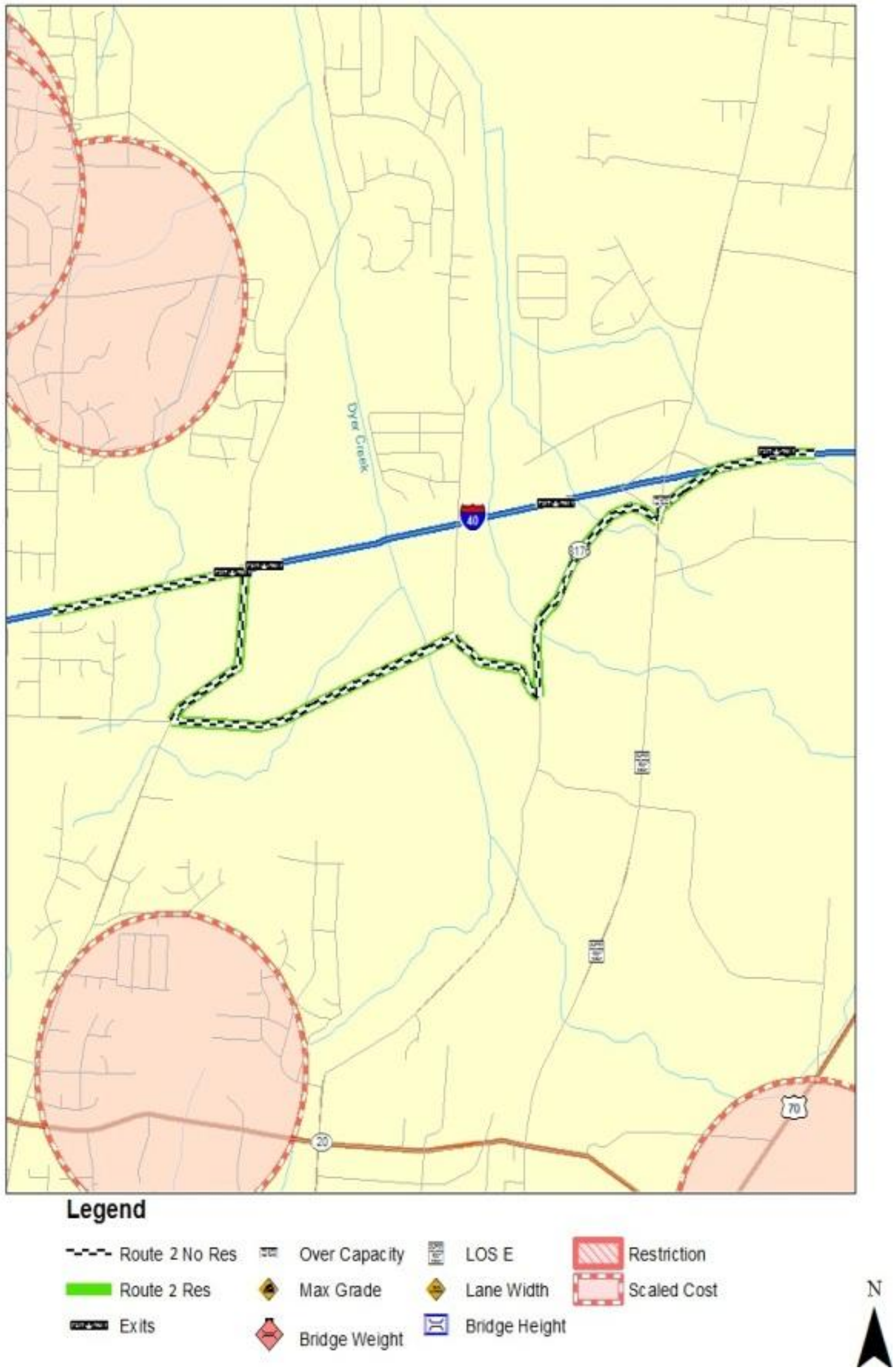
Hot Spot 1: I-40 Route Segment Between Exits 83-85 (Jackson, TN)

Figure 2: Map of I-40 Route Segment Between Exits 83 and 85



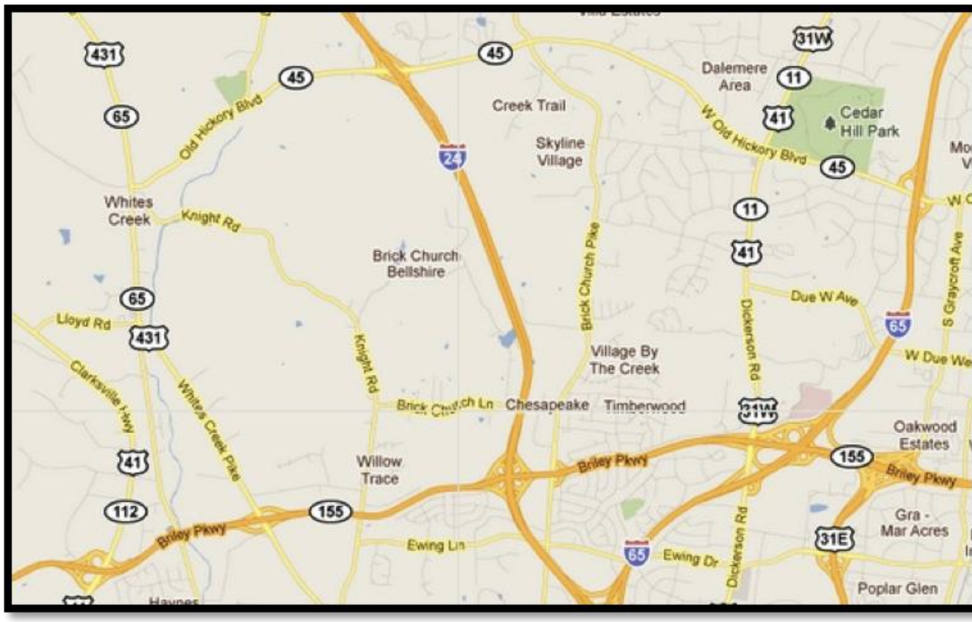
Step	Directions	Distance
1	Start	
2	Go east on I 40 toward CAMPBELL ST/OLD MEDINA RD	0.2 mi
3	Turn right on CAMPBELL ST	0.6 mi
4	Make sharp left on RIDGECREST RD	1.1 mi
5	Turn right on HENDERSON RD	0.4 mi
6	Make sharp left on CHRISTMASVILLE RD (STATE RD 8176)	0.9 mi
7	Turn left at DR F E WRIGHT DR to stay on CHRISTMASVILLE RD	< 0.1 mi
8	Turn right	0.2 mi
9	Bear right on I 40	0.2 mi
10	Finish	
	Driving Distance:	**3.6 mi**

Figure 3: Diversion Route to Bypass I-40 Route Segment Between Exits 83 and 85



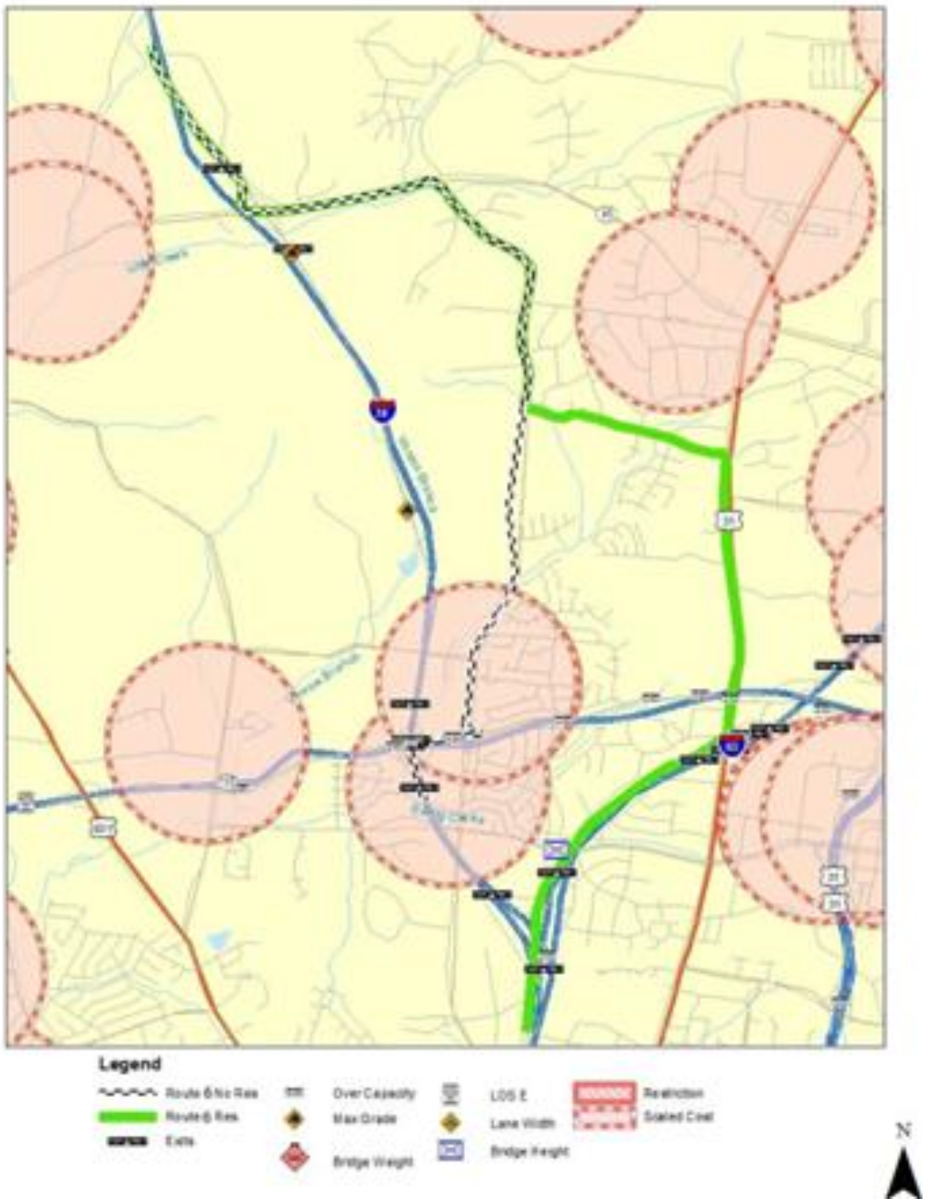
Hot Spot 2: I-24 Route Segment Between Exits 40-43 (Whites Creek and Nashville, TN)

Figure 4: Map of I-24 Route Segment Between Exits 40 and 43



Step	Directions	Distance
1	Start	
2	Go southeast on I 24	< 0.1 mi
3	Turn right	0.1 mi
4	Turn left on OLD HICKORY BLVD (STATE HWY 45)	0.3 mi
5	Continue on W OLD HICKORY BLVD (STATE HWY 45)	0.7 mi
6	Turn right on BRICK CHURCH PIKE	1.4 mi
7	***Turn left on BELLSHIRE DR***	1.1 mi
8	***Turn right on DICKERSON PIKE (STATE HWY 11)***	1.4 mi
9	***Turn right***	0.2 mi
10	***Continue on I 65***	1.5 mi
11	***Continue on I 24***	< 0.1 mi
12	Finish	
	Driving Distance:	**6.9 mi**

Figure 5: Diversion Route to Bypass I-24 Route Segment Between Exits 40 and 43

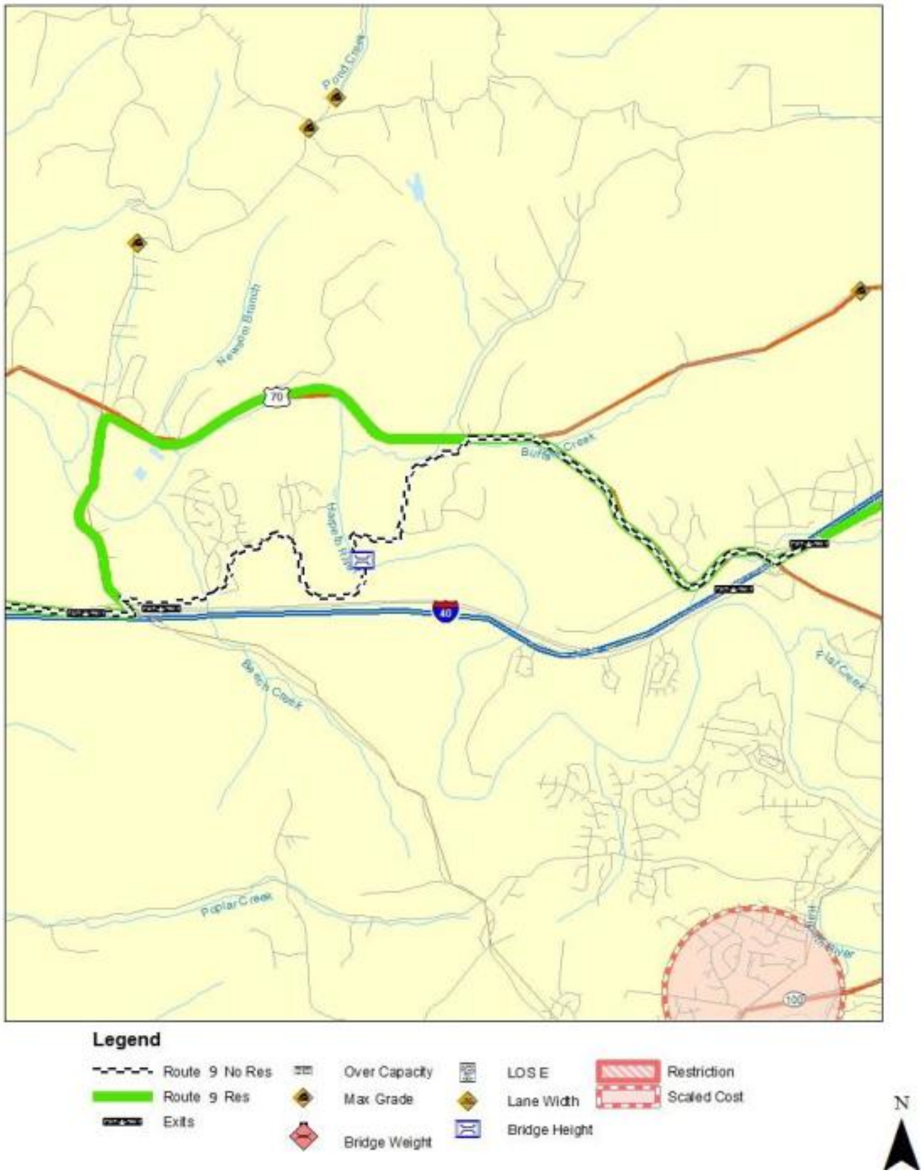


Hot Spot 3: I-40 Route Segment Between Exits 192-196 (Nashville, TN)

Figure 6: Map of I-40 Route Segment Between Exits 192 and 196

Step	Directions	Distance
1	Start	
2	Go east on I 40	0.2 mi
3	Continue	0.2 mi
4	Turn left	< 0.1 mi
5	***Turn left on MC CRORY LN***	1.3 mi
6	***Continue on OLD CHARLOTTE PIKE***	< 0.1 mi
7	***Turn right on US HIGHWAY 70 (CHARLOTTE PIKE)***	2.6 mi
8	Bear right on MEMPHIS BRISTOL HIGHWAY (US HWY 1)	1.8 mi
9	Turn left on I 40	0.3 mi
10	Finish	
	Driving Distance:	**6.4 mi**

Figure 7: Diversion Route to Bypass I-40 Route Segment Between Exits 192 and 196



Conclusions

The research presented in this document demonstrates the importance of considering a variety of factors when making truck route diversion decisions. These factors should be quantifiable and able to be evaluated in a time-efficient manner. During the course of this project, geometric characteristics of the diversion route, proximity of the diversion route to the original route, and capacity of the diversion route were determined to be critical in evaluating whether to divert traffic and selection of the preferred routing option.

The geometric characteristic criterion helps eliminate alternate routes that would not be able to accommodate large truck traffic. These characteristics include vertical clearance, land width, and bridge load ratings. Proximity measures the travel time on the alternate route relative to the original route, taking incident delay into consideration. The third criterion, diversion route capacity, allows for the evaluation of whether an alternate route can handle additional traffic demand. Rerouting traffic onto an alternate route that does not have sufficient capacity can lead to a breakdown in the flow of traffic (LOS F).

The case study application demonstrated that the methodology can be useful in supporting decisions regarding re-routing of traffic on roads in Tennessee or elsewhere. One challenge to expanding its use would in developing and populating the GIS network at a larger scale. This could be a time-intensive endeavor since a variety of information must be calculated and added as network attributes. Another challenge to using this approach would be the characteristics of road closure itself. The methodology currently assumes that all lanes must be closed and thus a partial road closure could make the methodology ineffective in determining the most desirable route choice. An additional methodological hurdle is data quality. A GIS model is also only as good as the data upon which it is constructed; in multiple instances, it was observed that data had been incorrectly recorded as evidenced by attribute values that were not within a realistic range. A better penalty system could also be established for diminishing the attractiveness of an alternative route without eliminating it from consideration, and formulating. A final area of potential improvement is in the calculation of travel time along the alternate route. While using segment length and the associated speed limit is a reasonable first-order approximation, this method ignores such factors as the number of traffic lights and access/egress points. Overcoming the aforementioned challenges represent research opportunities to enhance the developed methodology.

Appendices

Appendix A: Rail Route Risk Analysis Factors

This sets forth the minimum criteria that must be considered by rail carriers when performing hazardous materials safety and security risk analyses. Factors to be considered include:

1. Volume of hazardous material transported
2. Rail traffic density
3. Trip length for route
4. Presence and characteristics of railroad facilities
5. Track type, class, and maintenance schedule
6. Track grade and curvature
7. Presence or absence of signals and train control systems along the route (“dark” versus signaled territory)
8. Presence or absence of wayside hazard detectors
9. Number and types of grade crossings
10. Single versus double track territory
11. Frequency and location of track turnouts
12. Proximity to iconic targets
13. Environmentally-sensitive or significant areas
14. Population density along the route
15. Venues along the route (stations, events, places of congregation)
16. Emergency response capability along the route
17. Areas of high consequence along the route, including high consequence targets as defined in § 172.820(c)
18. Presence of passenger traffic along route (shared track)
19. Speed of train operations
20. Proximity to en-route storage or repair facilities
21. Known threats, including any non-public threat scenarios provided by the Department of Homeland Security or the Department of Transportation for carrier use in the development of the route assessment
22. Measures in place to address apparent safety and security risks
23. Availability of practicable alternative routes
24. Past incidents
25. Overall times in transit
26. Training and skill level of crews
27. Impact on rail network traffic and congestion

Appendix B: Highway Criteria for Alternate Route Selection

CRITERION	ENTITY IMPACTED	ACTION

Proximity of alternate route to closed roadway	Motorist	• Determine whether the alternate route is intended for local traffic or for regional traffic.
		  ○ For local traffic, it should ideally be in close proximity to the primary route.
		  ○ In a metropolitan area, the closest alternate route may be an adjacent parallel street or a freeway frontage road.
		  ○ In rural areas, alternate routes may be farther away from the primary route.
		• Provide a time savings to motorists.
		  ○ If an alternate route is too far away from the primary route, then travel time may be longer than that on the primary route in some instances.
		  ○ For a regional alternate route, connecting successive cities or major interchanges served by the primary route, it is less important that the alternate route be in close proximity to the main route; however, the alternate route should not be significantly longer than the primary route.

Ease of access to/from alternate route	Motorist	• Select access points between the primary and alternate route that do not create bottleneck points in the corridor. • Consider alternate routes that provide high-capacity connections, or sufficient space and geometry to establish special traffic control during implementation, to/from the primary route.

Safety of motorists on alternate route	Motorist	• Select routes that are easy for motorists to navigate and provide a sense of comfort.
		  ○ Long routes may be difficult for motorists to navigate
		  ○ Motorists may be uncomfortable using alternate routes that take them through unfamiliar areas and/or offer few service stations.
		  ○ Motorists may feel more comfortable driving on an alternate route where the primary roadway is visible, rather than driving through an unfamiliar area.
		• Do not use a street that has known safety problems, unless it is patrolled by law enforcement to ensure the safety of motorists.

Height, weight, width, and turning restrictions on alternate route	Motorist	• Consider roadways without physical constraints limiting the height, weight, and width of vehicles along the alternate route.
		• Be aware that constraints may render an alternate route impassable for commercial vehicles.
		• Choose an alternate route that is usable by all vehicles.
		    o If commercial vehicles cannot be accommodated on what is otherwise the best alternate route, then an additional route should be selected for commercial vehicles.
		• Review operations of intersections that do not allow vehicles to make certain turns, especially left turns that may be required during alternate route operation.
		    o A turn that is normally banned may be allowed on the alternate route, using special law enforcement control and signage.

Number of travel lanes/capacity of alternate route	Motorist	• Require sufficient capacity to accommodate the vehicles diverted while carrying day-to-day background traffic. o For example, if traffic from a busy six-lane urban freeway is diverted to a two-lane local street, there may not be enough extra capacity on the street to accommodate the diverted traffic. • Assure that diverted traffic does not encounter an even worse level of service than it would encounter on the primary route.
Congestion induced on alternate route	Motorist	• Avoid routes where motorists do not realize a travel time savings because of demand-induced congestion on the alternate route.
Traffic conditions on alternate route	Motorist	• Assure that an alternate route is not already operating near capacity, and does not have sufficient extra capacity to accommodate the diverted traffic. The diverted traffic should not encounter an even worse level of service than on the primary route.
Number of signalized intersections, stop signs, and unprotected left turns on alternate route	Motorist	• Assure that signalized intersections, stop signs, and unprotected left turns do not cause substantial delay to motorists along an alternate route. o An unprotected left turn or a left turn from a stop sign may also cause safety problems under heavy traffic conditions.
Travel time on alternate route	Motorist	• Assure that the alternate route is free-flowing and is not excessively long relative to travel distance on the primary route, so that motorists can save time.

		◦ Likewise, motorists may not save any time if travel time is long due to congested traffic, even if the alternate route has a shorter travel distance than that on the primary route.
Pavement conditions on alternate route	Motorist	• Assure that good pavement conditions exist. ◦ Pavement conditions may be uncomfortable to motorists, cause safety problems, and even cause damage to vehicles. ◦ If pavement condition is already poor, then diverted truck traffic not normally serviced on an alternate route may further damage the pavement.
Type and intensity of residential development on alternate route	Community	• Do not divert traffic to residential or mixed-residential streets, if possible. ◦ Residential streets are generally low capacity and are often not designed as through-streets. ◦ It is usually best to avoid the use of residential streets as alternate routes.
Existence of schools and hospitals on alternate route	Community	• Consider impact on local driveway access. ◦ One side effect of alternate routes is that the increased traffic may increase the difficulty of local driveway access. For this reason, it is usually best to avoid the use of streets that serve schools and hospitals as alternate routes because it is important that easy access be maintained for these facilities. • Consider impact of heavy traffic that may negatively affect ambulance access to hospitals. • Consider the impacts of heavy traffic that may increase pedestrian/vehicular conflicts.
Percentage of heavy vehicles (e.g., trucks, buses, RVs) on route from which traffic is to be diverted	Motorist	• Examine high volume of heavy vehicles that will significantly reduce available remaining capacity on the alternate route. ◦ The acceleration and operating characteristics of trucks may constrain traffic flow on the alternate route.
Grades on alternate route	Motorist	• Examine impact of steep upgrades or downgrades that may cause safety problems, especially in bad weather. ◦ A steep upgrade can significantly reduce capacity on a roadway carrying a high volume of commercial vehicles because upgrades limit their speed.

Type and intensity of commercial development on alternate route	Community	• Examine capacity constraints at heavy commercial developments, such as a shopping mall.
		  o If a large traffic generator is located adjacent to a candidate alternate route, then it may generate traffic demand that approaches or even exceeds available roadway capacity, thus making the roadway undesirable for use as an alternate route.
		  o Streets in commercial areas usually have a large number of unsignalized driveways, which cause both traffic and safety problems when volume is heavy.

Availability of fuel, rest stops, and food facilities along alternate route	Motorist	• Consider that motorists may feel more comfortable using a route on which these facilities are available. o On an extended or regional alternate route, motorists may wish to stop and eat, rest, and/or to refuel their vehicles.
Noise pollution	Community	• Consider the impact of increased traffic that may significantly increase the amount of noise pollution along a route. o A significant increase in noise level during alternate route implementation may cause unacceptable disturbance to affected areas of the community.
Transit bus accommodation	Motorist	• Examine potential impacts on transit vehicle station stops due to increased volumes of diverted traffic.
Air quality	Community	• Examine impact of increased traffic that may significantly increase pollution and decrease air quality. • Remember, the goal of alternate route deployment is improving mobility and system operations.
Ability to control timing of traffic signals on alternate route	Motorist	• Identify possible modification to day-to-day traffic signal timing plans in order to accommodate the additional diverted traffic. • Choose an alternate route that allows an operator to modify remotely the timing of traffic signals upon alternate route deployment.
Ownership of road	Motorist/ Agency	• Coordinate efforts among agencies responsible for operations on the primary route and the alternate route. o If traffic is being diverted from a State road, it is desirable to divert traffic to another State road. The State can modify the traffic signal timing on a State road, whereas it may not be allowed to modify

		traffic signal timing on a county or local road. - o Diverting from one State road to another State road avoids jurisdictional difficulties.
Availability of ITS surveillance equipment on alternate route	Motorist	• Consider the benefits of an alternate route having an ITS instrumented system. - o ITS surveillance equipment, such as CCTV cameras, allows an operator to monitor traffic conditions on an alternate route during plan implementation.
Availability of ITS information dissemination equipment on alternate route	Motorist	• Utilize ITS information dissemination equipment, such as CMSs or HAR, to give motorists information on how to access the alternate route as well as traffic information required to navigate the alternate route and reach a downstream connection with the primary route.

Source: FHWA Alternate Route Handbook, May 2006

Appendix C: Level of Service (LOS) Chart

Road Type	LOS A	LOS B	LOS C	LOS D	LOS E
4 Lane Freeway	31,700	45,300	56,200	68,000	90,700
6 Lane Freeway	47,600	68,000	84,300	102,000	136,000
8 Lane Freeway	63,500	90,600	112,400	136,000	181,300
10 Lane Freeway	79,300	113,400	140,600	170,000	226,700
12 Lane Freeway	95,200	136,000	168,600	204,000	272,000
4 Lane Expressway	23,300	33,400	41,400	50,000	66,700
6 Lane Expressway	35,000	50,000	62,000	75,000	100,000
8 Lane Expressway	47,000	66,000	82,000	100,000	133,000
2 Lane Arterial Urban	6,500	9,400	11,600	14,000	18,700
3 Lane Arterial Urban	8,200	11,600	14,400	17,500	23,300
4 Lane Arterial Urban	10,700	15,400	19,000	23,000	30,700
5 Lane Arterial Urban	12,400	17,600	21,900	26,500	35,300
6 Lane Arterial Urban	20,500	29,400	36,400	44,000	58,700
7 Lane Arterial Urban	22,400	32,000	39,700	48,000	64,000
8 Lane Arterial Urban	25,700	36,600	45,400	55,000	73,300
2 Lane Arterial Rural	8,400	12,000	14,900	18,000	24,000
3 Lane Arterial Rural	10,500	15,000	18,600	22,500	30,000
4 Lane Arterial Rural	13,100	18,600	23,100	28,000	37,300
5 Lane Arterial Rural	15,200	21,600	26,800	32,500	43,300
2 Lane Collector Urban	5,100	7,400	9,100	11,000	14,700
3 Lane Collector Urban	6,400	9,200	11,300	13,700	18,300
4 Lane Collector Urban	8,400	12,000	14,900	18,000	24,000
5 Lane Collector Urban	10,700	15,400	19,000	23,000	30,700
2 Lane Collector Rural	6,500	9,400	11,600	14,000	18,700
3 Lane Collector Rural	8,200	11,600	14,500	17,500	23,300
2 Lane One-Way Roadway	6,500	9,400	11,600	14,000	18,700
3 Lane One-Way Roadway	8,400	12,000	14,900	18,000	24,000
4 Lane One-Way Roadway	11,200	16,000	19,800	24,000	32,000
1 Lane Ramp One-Way	4,200	6,000	7,400	9,000	12,000
2 Lane Ramp One-Way	8,400	12,000	14,900	18,000	24,000
3 Lane Ramp One-Way	12,600	18,000	22,300	27,000	36,000

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