Emergency Routing Signs Pilot on the I-81 Corridor in the Staunton Area

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Final Report VTRC 26-R48

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Standard Title Page - Report on Federally Funded Project

1. Report No.: FHWA/VTRC 26-R48	2. Government Accession No.:	3. Recipient's Catalog No.:
4. Title and Subtitle: Emergency Routing Signs Pilot on the I-81 Corridor in the Staunton Area		5. Report Date: June 2026 6. Performing Organization Code:
7. Author(s): Mo Zhao and Chien-Lun Lan		8. Performing Organization Report No.: VTRC 26-R48
9. Performing Organization and Address: Virginia Transportation Research Council, 530 Edgemont Road, Charlottesville, VA 22903		10. Work Unit No. (TRAIS): 11. Contract or Grant No.: 126328
12. Sponsoring Agencies' Name and Address: Virginia Department of Transportation, 1221 E. Broad Street, Richmond, VA 23219; Federal Highway Administration, 400 North 8th Street, Room 750, Richmond, VA 23219-4825		13. Type of Report and Period Covered: Final 14. Sponsoring Agency Code:
15. Supplementary Notes: This is an SPR-B report.		

16. Abstract:

Traffic incidents on the Interstate 81 corridor account for approximately 77% of all delays, significantly affecting regional mobility and roadway capacity. To enhance incident management and reduce the logistical burdens associated with manual detour deployment, the Virginia Department of Transportation's (VDOT) Staunton District initiated a pilot project to evaluate the efficacy of permanently-installed emergency routing signs. This study assessed the effect of these signs on detour operations and traffic diversion behavior using a mixed-methods approach that integrates qualitative data from semi-structured interviews with quantitative metrics from traffic incidents, traffic speeds, origin-destination, and traffic volume data from multiple VDOT and third-party sources.

The study employed a comparative before-and-after analysis across four case studies, including three incident-related and one work zone-related detours, to quantify improvements in operational efficiency and shifts in motorist route choice. Information gathered through interviews with Staunton District personnel provided critical context for interpreting quantitative analysis, offering insights into personnel requirements and decision-making workflows.

Findings indicate that permanently-installed emergency routing signs facilitated more rapid detour activation by eliminating the need for manual signage setup, thereby reducing activation latency and allowing VDOT incident responders to focus on scene clearance. Compared with the before period, the time required to activate the detour decreased by approximately 1 hour. These operational efficiencies translate into reduced queuing delay benefits; at the 28% baseline compliance rate, rapid activation generates roughly $16,000 in benefits, based on case study results. The results of this pilot provide a technical foundation for future VDOT policy decisions. The study recommends refining operational procedures and processes to maximize the effectiveness of permanently-installed routing signs, particularly to better guide motorists onto the designated detour route when queue spillback extends beyond the primary decision points of the designated detour route.

17. Key Words: Emergency Routing Sign, Detours, Incident Management, Traffic Diversion		18. Distribution Statement: No restrictions. This document is available to the public through NTIS, Springfield, VA 22161.	
19. Security Classif. (of this report): Unclassified	20. Security Classif. (of this page): Unclassified	21. No. of Pages: 54	22. Price:

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

FINAL REPORT

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(A partnership of the Virginia Department of Transportation
and the University of Virginia since 1948)

Charlottesville, Virginia

June 2026
VTRC 26-R48

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ABSTRACT

Traffic incidents on the Interstate 81 corridor account for approximately 77% of all delays, significantly affecting regional mobility and roadway capacity. To enhance incident management and reduce the logistical burdens associated with manual detour deployment, the Virginia Department of Transportation's (VDOT) Staunton District initiated a pilot project to evaluate the efficacy of permanently-installed emergency routing signs. This study assessed the effect of these signs on detour operations and traffic diversion behavior using a mixed-methods approach that integrates qualitative data from semi-structured interviews with quantitative metrics from traffic incidents, traffic speeds, origin-destination, and traffic volume data from multiple VDOT and third-party sources.

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INTRODUCTION

Traffic incidents can significantly disrupt normal operations, leading to substantial delays on highway facilities. A study by the Virginia Transportation Research Council (VTRC) found that most nonrecurring delays in Virginia are attributable to incidents and work zones (Lan et al., 2019). This trend is particularly evident in rural areas, where nonrecurring delays cause dominate delays. For instance, on the Interstate 81 (I-81) corridor, a critical route that carries significant truck traffic, approximately 77% of all delays are attributed to nonrecurring sources (Lan et al., 2019). Major incidents often necessitate lane closures and reduce roadway capacity, leading to significant delays. Effective planning and implementation of detour strategies can improve agencies' traffic management capabilities by effectively and efficiently diverting traffic through alternative routes. The designated incident detour routes can be activated for both planned events, such as major roadway work zone closures, and unplanned events, such as crashes. Unlike evacuation routes designed for unidirectional, mass movement (often using strategies such as contraflow), incident detour routes must accommodate both diverted traffic and background traffic (Federal Highway Administration [FHWA], 2006). Effectively executing a well-designed detour plan can significantly mitigate the delays for roadway users on both the freeway and the detour routes during the period of incident impact.

The success of a detour operation depends on meticulous planning, accurate activation timing, and clear communication with motorists. Implementing a traffic incident detour plan requires seamless collaboration across multiple agencies and jurisdictions. The Virginia Department of Transportation (VDOT) developed Freeway Traffic Management Incident Detour Plans that establish standard procedures and guidelines for detour operations (VDOT, unpublished data). These plans assist incident responders in implementing a unified traffic detour plan during major traffic incidents involving partial or full freeway closures. During major incidents, the fire and rescue agency often serves as the incident commander, responsible for establishing a unified command. As part of the unified command structure, a primary VDOT responsibility is providing temporary traffic control. Traffic control setups for detours often span multiple jurisdictions. Without permanently-installed emergency routing signs, additional time and resources are required to deploy temporary signage before a detour can be activated. Although VDOT has made efforts to estimate the quantities of traffic control devices required for each developed Incident Detour Plan (VDOT, unpublished data), the necessary resources occasionally exceed the capacity of the residency office nearest the incident scene. In addition, the current interstate maintenance contractor resources do not cover operations on arterial roads, which further limits the resources VDOT responders can use for temporary traffic control on alternative arterial routes. The logistics of securing these required resources can further delay detour activation. Furthermore, resources are required to retrieve the temporary signs after the detour is lifted.

VDOT's Staunton District has experienced difficulties in setting up temporary detour signs in a timely manner while simultaneously managing an active incident. Consequently, it was often difficult to activate detour operations immediately after a detour decision was made. On State Route 262 (Rt. 262) in the City of Staunton area, VDOT previously installed "flip-down" signs on guide signs at key locations to facilitate detour operations. Nonetheless, staff must still traverse the entire detour route to set up the signs, which can often be delayed by the very congestion the detour aims to alleviate.

To help address these challenges, VTRC conducted a technical assistance study, *Best Practices for Rural Freeway Detour Trailblazing Signs*, to identify the best national practices and recommend potential solutions for VDOT (Lan and Zhao, unpublished data). The study noted that some agencies, such as the New York State Thruway Authority, Michigan Department of Transportation, and Pennsylvania Department of Transportation, have implemented permanently signed detour routes. This approach eliminates the need to manually set up temporary signs during incidents, thereby saving critical incident response time and resources. Figure 1 illustrates the *Manual on Uniform Traffic Control Devices* (MUTCD) approved emergency routing signs and plaques (FHWA, 2025). These permanently-installed signs and plaques provide directional guidance on designated detour routes, beginning at an exit upstream of incident-susceptible areas and returning traffic to the original route at a downstream point. These signs are intended to provide drivers with the assurance that the detour route will successfully return them to their original path.

Following the recommendation of the VTRC study, the Staunton District initiated a pilot project to test the use of permanently-installed emergency routing signs. The MUTCD M4-11 and M4-12 signs in Figure 1 were installed on I-81, westbound I-64 and on Rt. 262 (Woodrow Wilson Parkway) in the Staunton area in 2025. Rt. 262 serves as the primary detour route for incidents occurring on I-81 between Exits 220 and 225. Prior to this pilot, no permanently signed emergency detour routes had been designated in Virginia, except for hurricane evacuation routes.

On June 9, 2025, VDOT released public communications regarding the installation of these permanent signs. Figure 2 shows the signs on I-64 westbound near Exit 87, where I-64 merges with I-81, and Figure 3 illustrates the two signed detour routes. Route A (green arrow line in Figure 3) is designated for I-81 southbound closure, and Route C (blue arrow line in Figure 3) is designated for I-81 northbound closure. The public was advised to follow these signs and the changeable message signs (CMSs) on I-81 when a directional closure is in place and during temporary interstate closures for critical work zone operations.

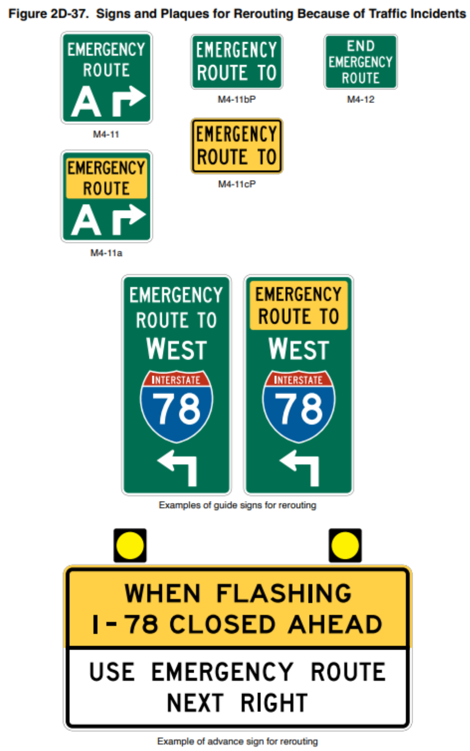


Figure 1. ***Manual on Uniform Traffic Control Devices*** **Approved Emergency Routing Signs and Plaques (FHWA, 2025)**

Figure 2. Emergency Routing Signs on I-64 Westbound

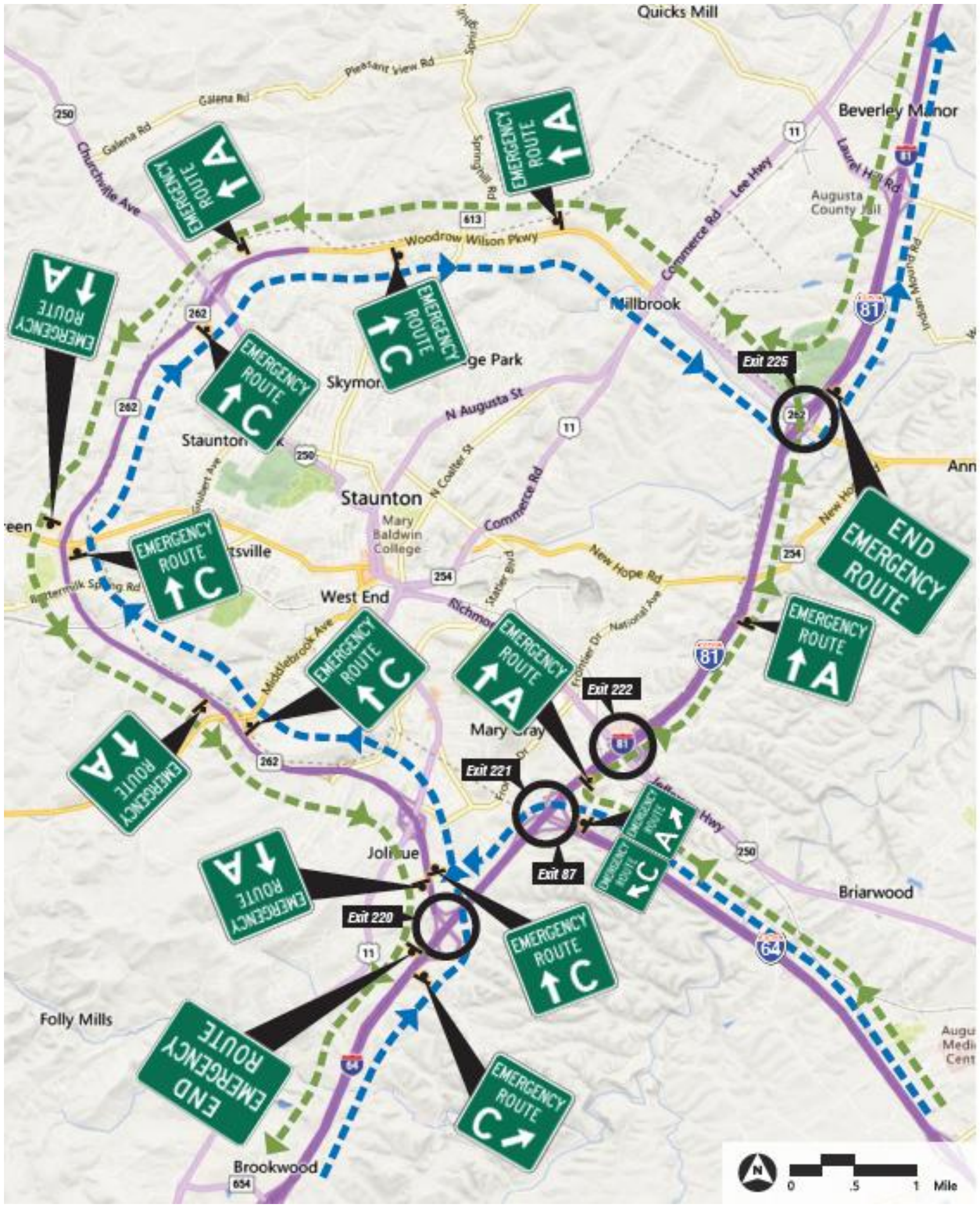


Figure 3. Detour Routes in Staunton Area. Green arrow line indicates Route A, and blue arrow line indicates Route C.

PURPOSE AND SCOPE

The purpose of this study was to assess the potential effect of emergency routing signs installed in the Staunton District. Specifically, the study assessed the effects on incident detour operations and traffic diversion to inform VDOT's future deployment strategies for permanently-installed emergency routing signs. Given that incidents causing full roadway closures are rare, the scope was limited to case studies of detour operations observed during the study period. In addition, the number of traffic sensors is limited within the pilot area to provide traffic speed and volume information. Traffic diversion was analyzed leveraging the datasets available at the time of the study.

METHODOLOGY

The following tasks were conducted to achieve the study objectives:

1. Literature review.
2. Data collection and preparation.
3. Case study.
4. User experience interview.

Literature Review

The VTRC technical assistance study in 2022 conducted a comprehensive review of the best practices of deploying emergency routing signs, including sign selection and placement, detour route design, detour activation criteria, and so on. Building on that foundation, the current study conducted a targeted literature review to explore methodologies for assessing the cost-effectiveness of permanently-installed emergency routing signs. The literature review focused specifically on recent research conducted by various departments of transportation. The goal was to gather insights into benefit-cost analysis methods and performance measures suitable for evaluating the operational benefits of emergency routing signs, including reductions in emergency detour response times and effects on traffic mobility and safety.

Data Collection and Preparation

The primary data sources for this study included traffic incident and volume data from multiple VDOT sources, INRIX probe speed data, and origin-destination (O-D) data from StreetLight. To supplement these sources, trailer-mounted radar sensors were deployed at five key locations within the study area to collect traffic volume data. Although 1 year "before" and 1 year "after" data were desired, the data collection period was constrained by available research resources. Consequently, temporary sensor data were collected from mid-November 2024 to January 2026. Given that the Staunton District initiated the pilot project in June 2025, the period from July 2025 to January 2026 was considered the "after" period.

Figure 4 shows the study area. It includes I-81 between Exits 213 and 227; U.S. Route 11 (US 11), which runs parallel to I-81; I-64 between Exits 87 and 91; Rt. 262; and major collectors connecting to I-81 within the City of Staunton area. The boundaries of this study area were defined based on the maximum queue lengths observed on I-81 and I-64 during the case studies, as well as the major alternative routes available in the region.

The following sections describe the data sources and preparation procedures.

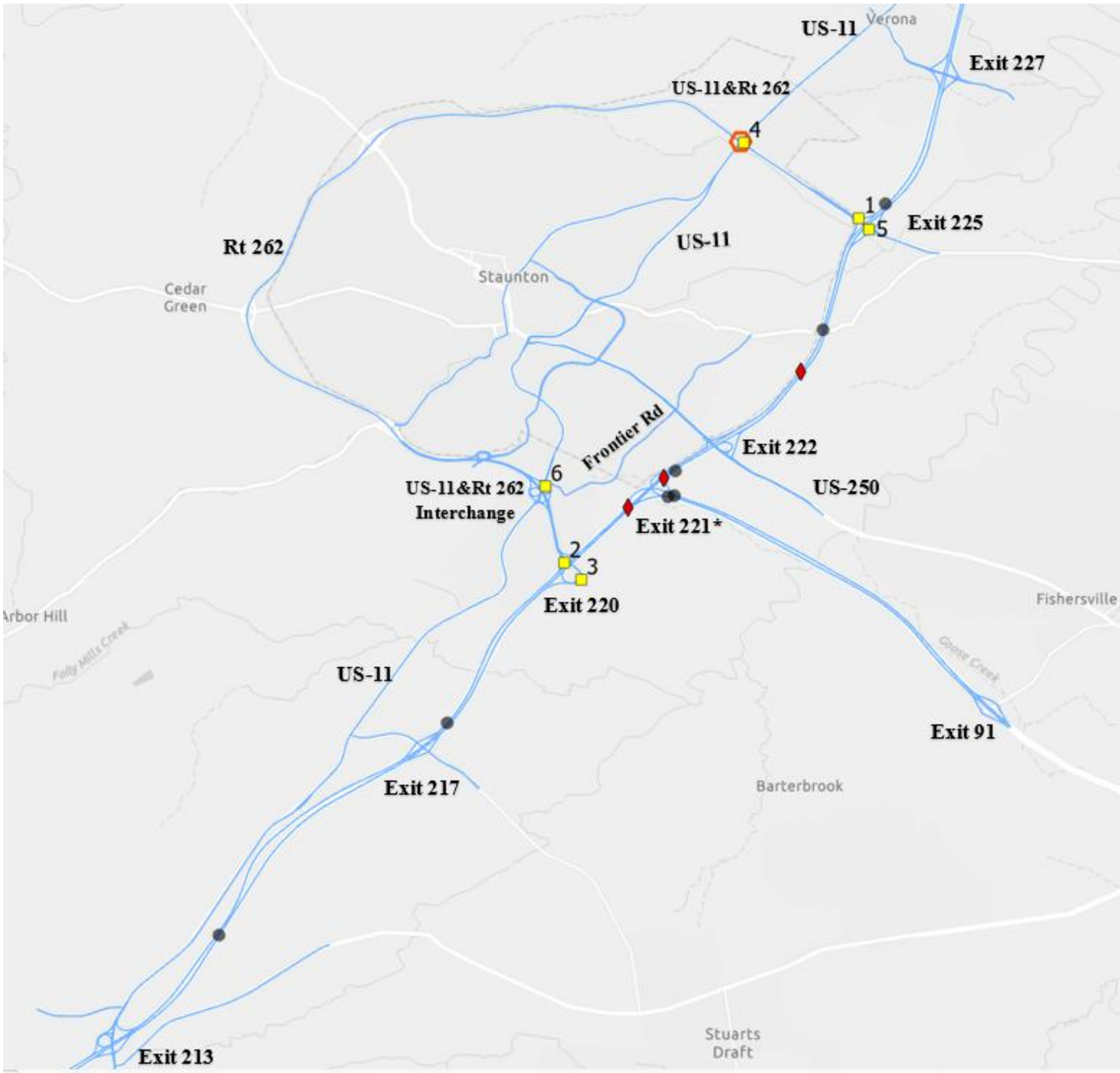


Figure 4. Study Area. Blue lines indicate INRIX XD segment, gray circles indicate locations of continuous count stations, yellow squares represent trailer-mounted sensors, the orange hexagon indicates the location of a signal system detector, and red diamonds represent locations of three full closure incidents in the case studies. An asterisk indicates the location of the I-81 (Exit 221) and I-64 (Exit 87) interchange. Trailer-mounted sensors: 1 = I-81 southbound Exit 225 exit ramp; 2 = Route 262 to I-81 southbound entrance ramp; 3 = I-81 northbound Exit 220 off-ramp; 4 = State Route 262 and U.S. Route 11 intersection; 5 = I-81 northbound Exit 225 on-ramp; 6 = State Route 262 off-ramp to U.S. Route 11.

Data Sources

Traffic Incident Information

Traffic incident information collected included basic incident information for incidents that occurred in the Staunton District between January 1, 2023, and January 31, 2026, and detailed incident logs for selected incidents. The basic incident information was obtained from multiple datasets maintained by VDOT's Traffic Operations Division, including time, location, duration, type, and incident severity, the maximum number of lanes closed, and the executive notification status.

For specific events of interest, the Staunton District provided Traffic Operations Center (TOC) incident logs. These logs provide a high-resolution, chronological record of actions incident responders took throughout an incident, as well as updates on scene conditions. These logs are essential for establishing the timeline of detour operations and for extracting information for key performance measures.

Continuous Count Stations

Traffic volume data aggregated at 15-minute intervals were obtained from seven continuous count stations shown in Figure 3. Data from January 1, 2023, to March 16, 2026, were utilized to evaluate traffic conditions on I-81 and the ramp from I-64 westbound to I-81 southbound during both normal and incident scenarios. This dataset also includes observations from the I-81 northbound overnight work zone closure that occurred on March 14 and 15, 2026.

Trailer-Mounted Sensors

To capture traffic diverting from I-81 onto the detour route, the research team used trailer-mounted traffic sensors to collect volume data on I-81 ramps and at key route choice decision points along Rt. 262. The trailers were generally positioned off shoulders or behind guardrails to ensure safety. Specific details for each sensor location are as follows:

1. Sensor on exit ramp at I-81 southbound Exit 225 (Figure 5): This unit was located on the left-hand shoulder to monitor Lane 1 of the I-81 southbound Exit 225 off-ramp as it monitors the traffic turning right onto Rt. 262 southbound.
2. Sensor on the Rt. 262 ramp to I-81 southbound on the south side of Staunton: This unit was located on the left-hand shoulder to capture traffic moving from Rt. 262 southbound onto I-81 southbound.
3. Sensor on I-81 northbound Exit 220 off-ramp: This unit was located on the right-hand shoulder of the off-ramp at Exit 220, capturing traffic from I-81 northbound Exit 220 onto Rt. 262 northbound.
4. Sensor at the intersection of Rt. 262 and US 11 on the north side of Staunton (Figure 6): This unit was located at the intersection of Rt. 262 and US 11 (Commerce Road) between a railroad signal and the route signs. This setup was configured to capture through traffic on Rt. 262 southbound, right-turn traffic from Rt. 262 southbound to US 11 southbound, and traffic to Rt. 262 northbound from both US 11 northbound and Rt. 262 northbound.
5. Sensor near the on-ramp to I-81 northbound at Exit 225 (Figure 7): This unit was located on Rt. 262 near the ramp onto I-81 northbound at Exit 225, which captured Rt. 262 northbound traffic entering I-81 northbound at this exit.
6. Sensor on Rt. 262 northbound off-ramp (Figure 8): This unit was located on the right-hand shoulder of Rt. 262 northbound off-ramp to US 11 on the south side of Staunton. It was used to monitor the traffic turning right from Rt. 262 northbound onto US 11 northbound.

Figure 5. Sensor on I-81 Exit 225 Off-Ramp

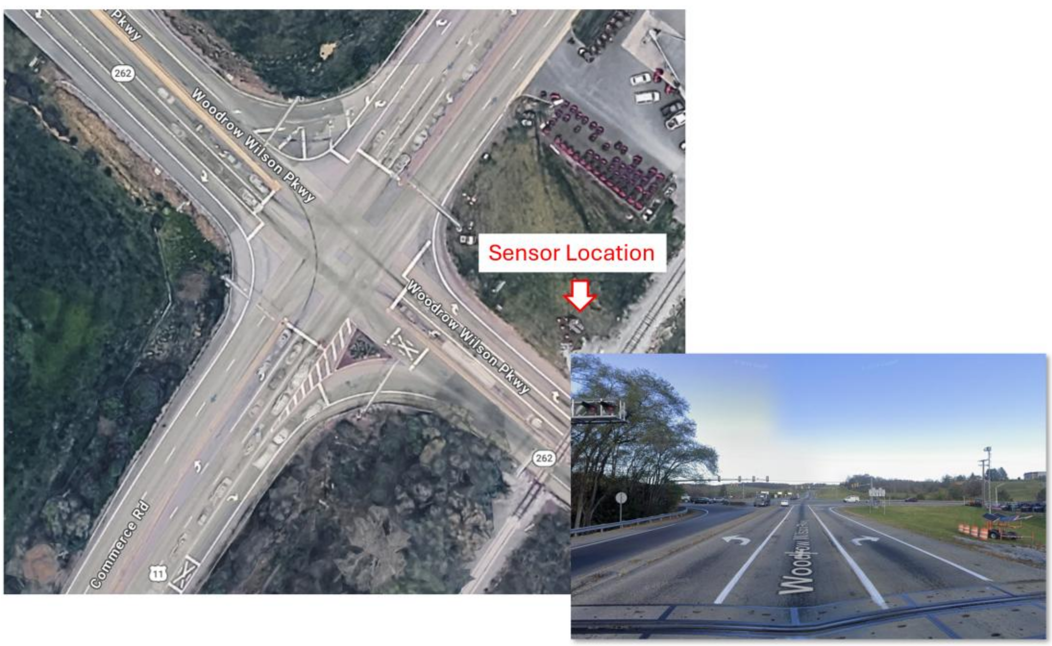


Figure 6. Sensor at the Intersection of State Route 262 and U.S. Route 11

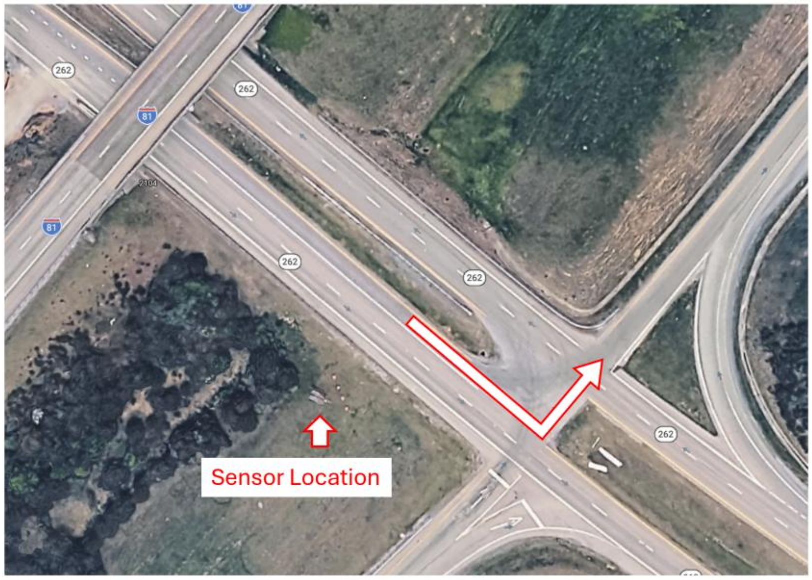


Figure 7. Sensor near I-81 On-Ramp at Exit 225

Figure 8. Sensor on Rt. 262 Northbound Off-Ramp on the South Side of Staunton

It should be noted that many of these sensors are near intersections that frequently experience stop-and-go traffic and vehicle queueing. Sensors at these locations may produce inaccurate volume readings because of the inherent technical limitations of microwave traffic sensors when monitoring slow-moving or congested traffic.

Traffic Signal System Detector

Traffic system signal detector data were available for the signalized intersection of US 11 and Rt. 262 on the north side of Staunton. This site is a major decision point on the detour route when I-81 southbound is closed. Drivers may follow the emergency routing signs and stay on Rt. 262 or turn south and use US 11 southbound to cross the city and rejoin Rt. 262 on the south side of the city. This dataset included traffic volume, occupancy, and speed information, and it provided the traffic volume that the trailer-mounted sensor at this site cannot collect, including the right-turn traffic from US 11 northbound onto Rt. 262 northbound and Rt. 262 northbound traffic traveling through the intersection. System detector data for July 1, 2025, to March 16, 2026, were obtained from VDOT's central traffic signal system.

INRIX Speed Data

INRIX XD speed data were utilized to evaluate traffic performance across the study area. This probe-based dataset is derived from the fusion of anonymized Global Positioning System (GPS) telemetry from commercial fleets, connected vehicles, and mobile applications. The XD network is characterized by its high spatial resolution and extensive coverage, encompassing not only limited-access highways but also major arterials and secondary roadways. XD segments are defined by short, granular lengths, typically ranging from 250 feet to 0.5 miles. This distance allows for the precise identification of localized congestion and queue locations.

For this study, INRIX XD speed data were obtained from the Regional Integrated Transportation Information System (RITIS, 2025) for 542 segments, highlighted in blue in Figure 3. Data were collected at a 15-minute granularity from January 1, 2023, to March 15, 2026. In addition, the RITIS Trend Map and Incident Timeline tools were employed to analyze queue development during incidents.

StreetLight Data

StreetLight's enhanced Connected Vehicle Data (CVD+) were utilized to investigate driver route choice during incidents (StreetLight Data, 2026). This dataset is derived from real-time broadcasts of vehicle telematics, and it provides traffic metric estimates such as volumes and O-D flow. The data were accessed through StreetLight's Insight platform. In this study, StreetLight volume and truck trip data were analyzed to identify the most used routes between selected origins and destinations. At the time of this study, data were only available for 2022 (all months), January to May of 2023, and all months in 2024 and 2025.

Data Preparation

Data quality screening, data cleaning, and conflation were performed for each dataset. All traffic volume and speed datasets were assembled to create a unified dataset aggregated at the INRIX XD segment level and in 15-minute intervals. The locations of continuous count stations, temporary sensors, and signal system detectors were matched to corresponding XD segments based on their GPS coordinates. Traffic incidents that occurred on the XD segments were also identified using incident coordinates and road names. For the purpose of this study, only incidents that blocked one or more travel lanes were considered.

During data screening, the research team identified several issues with the system detector data, including large gaps in the data and numerous invalid readings. Data quality was generally better for detectors used with signal phase association, but these detectors are not designed for continuous traffic counting and cannot provide the volume and speed data needed. For detectors not used with signal phase association, substantial volume differences were observed when compared with volumes from trailer-mounted sensors at the same location. Therefore, the system detector data were not used for traffic diversion analysis.

Development of Volume and Speed Profiles

Traffic volume and speed profiles were developed for locations with continuous count stations or temporary sensors, segmented by time of day, day of week, and month of year. These profiles were used to estimate traffic conditions in the absence of incidents. To ensure these profiles represented the "normal" conditions, any 15-minute intervals during which an incident occurred on any of the 542 XD segments were excluded from the analysis.

Review of Incident Logs

The TOC incident logs provided to the research team were more than 25 pages for each incident. These logs contain rich information to develop performance metrics for detour operations. This information is the primary source to assess the effect of emergency routing signs on the incident management process. Information retrieved from the logs included but was not limited to the following:

- Timestamps of key response milestones: The timestamps when the incident was verified, detour decision was made, detour was activated or deactivated, and lanes cleared were identified.
- Scene status updates: The logs recorded periodic updates from the field, such as lane status (e.g., "all southbound lanes remain blocked"), and estimated traffic queue length.
- CMS messages: As CMS messages were used together with static signs to guide road users, the time, location, and message contents used were retrieved to better understand the detour operation process.
- Labor and resource deployment: The logs document the resources deployed and activities performed by VDOT responders and contractors. For example, "18:24—Per Robert with DCS, they have set up a temporary detour at the 225."
- Coordination among agencies: Records show coordination between the TOC, Virginia State Police (VSP), and local jurisdictions. For instance, one of the incident records showed "19:39—Per VSP, requesting assistance from the City of Staunton for detour signage, TOC made contact with Staunton Emergency Communications Center, and they are responding to assist at US 250 and Statler Blvd."

Case Study Selection

The detour routes equipped with permanently-installed emergency routing signs are designed to activate when any part of I-81 between Exits 220 and 225 is completely closed in at least one travel direction. The lanes affecting incidents that occurred on I-81 northbound between mile marker (MM) 220.7 and MM 226.4 and those that occurred on I-81 southbound between MM 221.2 and 226.6 during the study period were considered potential candidates for case studies. For each target incident that occurred in the "after" period, the researchers tried to identify comparable incidents from the "before" period based on factors including incident time and location, duration, severity, type, number of lanes closed, queue length, detour activation, and input from the study's technical review panel. Because each incident is unique, substantial variability is expected among incidents and in the traffic conditions present when they occur. As a result, perfect matching is unattainable because of inherent differences in incident characteristics and traffic dynamics. Given the exploratory nature of this study, the technical review panel deemed this comparative approach acceptable. Because only a small number of full-closure events occurred during the study period, matching each target incident with a comparable incident cannot be guaranteed.

Case Studies

Four case studies were conducted to evaluate the effectiveness of emergency routing signs on incident response and traffic diversion. These evaluations included three incident-related detours and one work zone-related detour. In addition, a comparative analysis was performed to explore potential changes in road users' route choices between the before and after periods.

For cases in which StreetLight data were available, the route choices were analyzed using the "Top Routes Between Origin and Destination" tool within the StreetLight Insights portal (StreetLight Data, 2026). Furthermore, traffic volumes and speeds during the incident were compared with normal conditions using trailer-mounted sensor data and INRIX speeds, supplemented by visualizations to assess the effect of the routing signs on traffic diversion. The changes in detour operation in the before and after periods were quantified and compared using information extracted from the incident logs.

User Experience Interview

The research team conducted semi-structured in-person interviews with key personnel from the Staunton District to gather insights not typically captured in the standard incident logs. These conversations focused on the manual effort involved in setting up detour signage, improvements in incident management processes, and staff perceptions of the new signs' effectiveness.

Questions on equipment and labor needs, the time previously required to activate a detour, and changes in responder decision-making processes were also included in the discussions. The qualitative insights obtained through these interviews were used to validate information from incident logs and to support the development of benefit estimates. By integrating operator experience with quantitative traffic data, the study aimed to develop a more comprehensive understanding of the effects of emergency routing signs.

RESULTS AND DISCUSSION

Literature Search

This study aimed to evaluate the effect of permanently-installed emergency routing signs on VDOT's incident management process and their effectiveness in diverting traffic. Most recent research on detour signage focuses on how CMSs can support driver navigation, mitigate congestion, and improve safety during incident and work zone detours. Although agencies typically use static detour signs in conjunction with CMS, existing literature rarely quantifies the isolated effect of static signage. In many cases, the use of static signs is not mentioned at all, making it difficult to determine the specific static signage used. One relevant study investigated static detour signs used for nightly work zone closures on two freeways in the Netherlands (van Leeuwen, 2024). This study reported low detour compliance rates and mentioned concerns were raised about the effectiveness of static detour signs following several incidents involving workers installing temporary traffic control devices.

Because field data are difficult to obtain, many studies rely on qualitative surveys or simulations to evaluate the effectiveness of detour signs. Empirical measures of how detour signage influences traffic diversion during incidents are still limited. Existing research suggests that the effect of detour signage depends on several factors, including clear and conspicuous sign design and placement, integration with dynamic incident information and advanced detection technologies to provide timely guidance, and driver responsiveness to signage when supported by supplemental communication methods (Chang et al., 2022; Popescu et al., 2017; Qi et al., 2018).

Studies evaluating the effectiveness of CMS show that their effect on traffic diversion depends on several key factors:

- The clarity and specificity of message content strongly influence driver compliance with detour guidance. Diversion rates increase when CMS indicate heavy congestion on the primary route, and drivers often adjust their detour decisions based on real-time information (Khoo and Asitha, 2016; Sailesh and Mekker, 2022).
- CMS located closer to an incident generate higher diversion rates, and sequential CMS installations are more effective than a single upstream sign. The limitations of CMS include restricted message capacity and reduced effectiveness when traffic at the sign location is not yet congested—conditions common during major closures that require advance detours (Sullivan et al., 2023).
- Driver willingness to divert is also affected by their familiarity with alternate routes and by socioeconomic or vehicle-specific factors, such as those associated with truck drivers (Peeta et al., 2000).

In addition, advancements in driver-assistance and vehicle-to-everything communication technologies offer the potential to enhance the delivery of CMS information and influence driver routing decisions, further improving the effectiveness of traffic diversion (Raslan et al., 2024).

Case Studies

To assess the effectiveness and efficiency of using emergency routing signs, this study conducted case studies of four events during which the signs were deployed.

1. Tractor trailer accident on I-81 northbound at MM 222 on October 22, 2025.
2. Vehicle fire on I-81 southbound at MM 223.8 on January 28, 2026.
3. Vehicle fire on I-81 southbound at MM 223 on January 30, 2026.
4. I-81 northbound work zone closure between MM 221.45 and MM 225.65, from 7 pm on Saturday, March 14, to 9 am on Sunday, March 15, 2026.

Figure 3 shows the locations of the first three incidents.

Detour Routes

Figure 3 also illustrates the detour routes studied. In VDOT's Incident Detour Plans, these routes are designated as the primary alternative for incidents on I-81 between Exits 220 and 225 (VDOT, unpublished data). A total of 33 permanent emergency routing signs were installed along I-64, I-81, and Rt. 262.

Route A is designated for southbound I-81 closures:

- Southbound I-81 drivers passing Staunton area are instructed to exit at Exit 225, follow Rt. 262 southbound (counterclockwise) around Staunton, and re-enter I-81 southbound at Exit 220.
- Drivers on I-81 southbound who need to access I-64 eastbound are also advised to detour at Exit 225, follow the Rt. 262 southbound around Staunton, then enter I-81 northbound at Exit 220 and use Exit 221 to reach I-64 eastbound.
- Westbound I-64 drivers intending to travel on I-81 southbound are advised to take I-81 northbound at Exit 87, use Exit 225 to reach Rt. 262, follow Rt. 262 southbound around Staunton, and enter I-81 southbound at Exit 220.

Route C is designated for I-81 northbound closures:

- Northbound I-81 drivers are advised to exit at Exit 220, follow Rt. 262 northbound (clockwise) around Staunton, and re-enter I-81 northbound at Exit 225.
- Drivers on I-81 northbound who need to reach I-64 eastbound should detour at Exit 220, follow Rt. 262 northbound around Staunton, enter I-81 southbound at Exit 225, and then use Exit 221 to join I-64 eastbound.
- Westbound I-64 drivers traveling to I-81 northbound are advised to take I-81 southbound at Exit 87, exit at 220 to reach Rt. 262 northbound, follow the detour to join I-81 northbound at Exit 225.

Most of Rt. 262 is a two-lane, undivided highway with a posted speed limit of 55 mph, and congestion is unlikely even during peak hours. The travel time on the entire 13.7-mile route, bounded by I-81 Exits 220 and 225, is about 15 minutes at the posted speed limit.

US 11 (Commerce Road) through Staunton is an alternative that drivers often use instead of Rt. 262. The section from the Rt. 262 off-ramp south of the city to the Rt. 262-US 11 intersection on the north side is about 5.18 miles long, shorter than Rt. 262, but it is subject to lower posted speed limits (25–35 mph) and has 12 traffic signals. Accounting for the distance to and from I-81, the travel time between Exits 220 and 225 via US 11 is approximately 11 to 15 minutes. Furthermore, the City of Staunton maintains this portion of US 11, which is not VDOT's preferred detour option.

Incident History

Between January 1, 2023, and January 31, 2026, a total of 162 lane-blocking incidents were recorded for I-81 between Exits 220 and 225. Among them, 38 incidents (34%) resulted in a full closure of all travel lanes in one direction for a portion of the incident duration. Based on TOC logs and incident records, detour operations were activated for six incidents: one in 2023, one in 2024, two in 2025, and two in January 2026. One-half of these detours occurred after the emergency routing signs were installed. Although full-closure incidents are inherently random and each incident has unique characteristics, these data suggest that the use of permanent signs may have facilitated more efficient decision-making and sign deployment, reducing the time required to set up a detour.

Case Study 1

The new emergency routing signs were first used on Wednesday, October 22, 2025, when a tractor trailer accident at MM 222 blocked both northbound travel lanes. The incident involved cargo spills and resulted in damage to pavement and guiderails. Table 1 lists the timeline of this incident.

Table 1. Timeline of Incident on October 22, 2025

Time	Status	CMS on I-81 NB at MM 217	CMS at I-64 WB MM 102
16:01	Virginia State Police reported the incident, VDOT IMC was notified and responding	CRASH 4 MILES AHEAD ALL LANES BLKD USE ALTERNATE ROUTE	CRASH I-81 NB MM 222 ALL LANES BLKD USE ALTERNATE ROUTE
16:16	**IMC requested detour**		
16:26	**Detour activated**	I-81 CLOSED AHEAD USE EXIT 220 EMERGENCY ROUTE C	I-81 NORTH CLOSED AHEAD USE EXIT 220 EMERGENCY ROUTE C
16:45	I-64 WB to I-81 NB ramp closed		
17:48	Right lane opened, **detour lifted**	CRASH 4 MILES AHEAD ALL LANES BLKD USE ALTERNATE ROUTE	CRASH I-81 NB MM 222 ALL LANES BLKD USE ALTERNATE ROUTE
17:54	I-64 WB to I-81 NB ramp reopened		
20:05	Right lane and auxiliary lane reopened, left lane remains blocked	CRASH 4 MILES AHEAD LEFT LANE BLKD	CRASH I-81N MM 222 LEFT LANE BLKD
21:37	Scene cleared, delay remains		
22:30	Delay cleared		

BLKD = blocked; CMS = changeable message sign; IMC = Incident Management Coordinator; MM = mile marker; NB = northbound; WB = westbound.

Detour Operation

VSP first reported the incident at 4:01 pm. Fifteen minutes elapsed between the time TOC was notified and when the detour decision was made, followed by an additional 10 minutes between the detour request and activation. On reopening one travel lane at 5:48 pm, the detour was immediately deactivated.

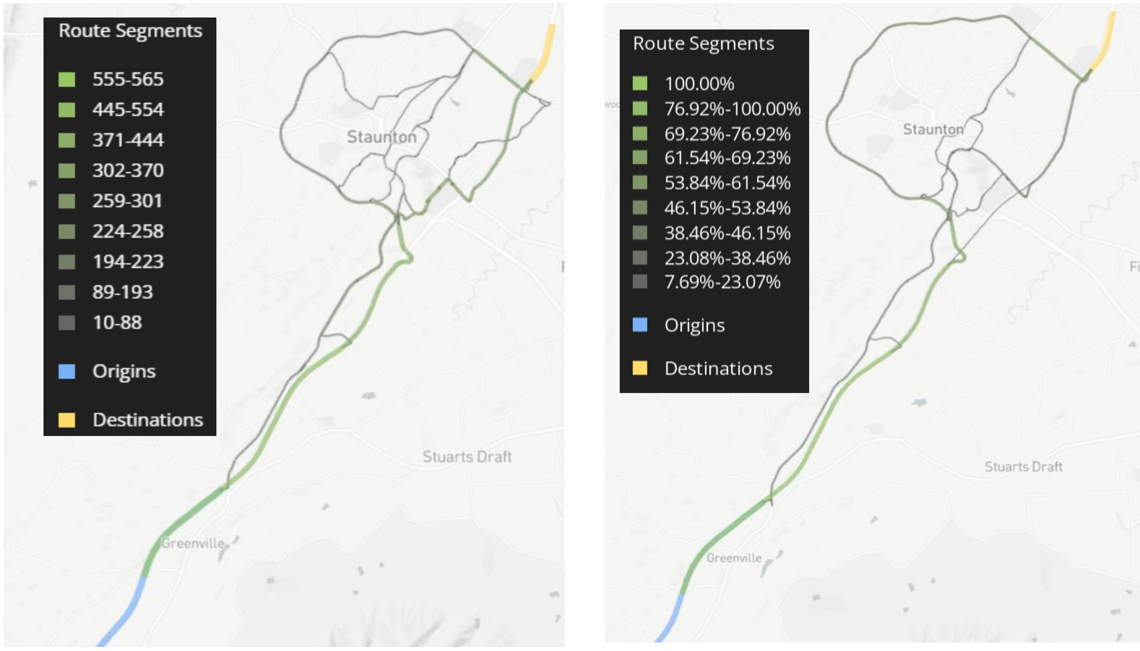
The message displayed on CMS transitioned according to the status of the detour operation. Prior to detour activation and following its deactivation, drivers were advised to use alternative routes. However, during the active detour, the guidance was changed to a two-phase message reading "I-81 CLOSED AHEAD USE EXIT 220 EMERGENCY ROUTE C." This message was posted on CMS units on I-81 northbound at MMs 212, 217, and 220 and on a portable CMS between them. On I-64 westbound, a direction-specific message, "I-81 NORTH CLOSED AHEAD USE EXIT 220 EMERGENCY ROUTE C," was displayed approximately 15 miles upstream at MM 102 and on the portable CMS between that location and I-64 Exit 87. Both messages specified the detour route name and exit location.

The alert was published on the Virginia 511 website and application; however, it did not provide guidance on which alternate route to use. For example, the message posted at 5:25 pm stated: "On I-81 at mile marker 222 in Augusta County, motorists can expect delays due to a tractor-trailer crash. All northbound lanes are closed. Traffic backups are approximately 10.0 miles. The I-64W to I-81N ramp is blocked."

Traffic Diversion

StreetLight O-D data were used to study drivers' route choice during the incident. Figure 9 shows the route choices for all vehicles and trucks during 4 and 5 pm. Due to the limitations of the StreetLight "Top Route Between Origin and Destination" tool, the analysis was conducted at the hourly level, and more granular time intervals were not available. As a result, the trip data for the 4–5 pm period include some observations prior to activating the detour. The blue line at the bottom of the figures indicates the origin on I-81 northbound upstream Exit 213, and the yellow line represents the destination downstream of Exit 225. The green and gray colored lines represent the routes used. It should be noted that the values shown in the legends do not represent absolute traffic volumes on the road segments but rather a scaled proportion that represents vehicle trips. For all vehicle trips shown in Figure 9a, the values represent trip counts; in Figure 9b, the values are truck trip indexes that indicate the percentage of trips.

When the detour was activated at 4:26 pm, the end of the queue was observed upstream of Exit 217. Although a CMS was available on I-81 upstream of this location, the first emergency routing sign along this travel direction was approximately 7 miles away near Exit 220. VDOT field staff observed that some drivers had diverted onto US 11 northbound from Exits 217 and 213, before reaching the designated start point of Route C at Exit 220. According to the TOC logs, no CMS messages were displayed along US 11 to guide traffic to Route C (Rt. 262).



(a) (b)

Figure 9. Top Used Routes Between I-81 Exits 213 and 225 for (a) All Vehicles and (b) Trucks During 4 and 5 pm on October 22, 2025

The following lists the primary routes drivers used between 4 and 5 pm.

- Route C: 28% of total vehicle trips used the designated detour route along Rt. 262 to rejoin I-81 northbound. These trips included traffic that exited onto Rt. 262 from Exit 220 (start of Route C on I-81 northbound) and those who exited at Exits 213 or 217 and used US 11 northbound to join Route C at the US 11-Rt. 262 interchange.
- US 11 through the City of Staunton: Nearly 8% of trips traveled through the city via US 11 (Greenville Avenue and Commerce Road), then joined Rt. 262 on the north end and re-entered I-81 northbound at Exit 225.
- Frontier Drive and US 250: About 47% of all trips took Frontier Drive at the Rt. 262-US 11 interchange and then continued on US 250 to rejoin I-81 northbound at Exit 222, likely because navigation applications identified it as the fastest route at that time. Because the incident was upstream of this exit, no congestion was observed beyond that point.

Compared with all vehicle trips, truck trips were less diverse.

- Route C: More than 38% of all truck trips used Rt. 262 around Staunton to re-enter I-81 at Exit 225.
- US 11 through the city: 15% of truck trips traveled through the city via US 11 and rejoined I-81 northbound at Exit 225.
- Frontier Drive/Statler Boulevard and US 250: Nearly 38% of truck trips re-entered I-81 at Exit 222 via Frontier Drive or the parallel Statler Boulevard and then US 250.

The US 11-Rt. 262 interchange seems to be a major decision point for drivers. At this location, they decided between following the signed detour route and entering the city through either US 11 or Frontier Drive. Among the all-vehicle trips that left I-81 at Exit 220, 40% entered the city at this interchange. Of the 60% that continued on Rt. 262, roughly 70% used Route C, and the rest exited at other points to travel through the city.

Travel time is a key factor influencing route choice. Figure 10 compares trip travel times on the three primary routes during the incident with those on a typical Wednesday in October. The trip started at the I-81 northbound Exit 220 off-ramp and ended at the I-81 northbound Exit 225 on-ramp. US 11 through the city consistently showed the highest travel time during the detour and exhibited the most significant fluctuation, indicating that the incident had a strong negative effect on the route travel time and reliability. Although travel times on Rt. 262 were generally higher than those on US 11 on normal days, during the incident, they were lower. This contrast suggests that the effect on Rt. 262 was less severe and shorter in duration than on US 11, likely because the higher capacity of Rt. 262 allowed it to better absorb diverted traffic and maintain reliability. Re-entering the interstate via Frontier Drive and US 250 at Exit 222 was the shortest and most used path, but travel times on this route also increased substantially (about 60% during peak). Frontier Drive, a two-lane, undivided roadway with limited shoulders, is not designed to accommodate high traffic volumes, which can lead to more traffic conflicts and increased safety risks. As average speed and time spent are key determinants of service quality on two-lane roads, the level of service on Frontier Drive during the incident dropped significantly. In addition, more than 15% of truck trips during 4 and 5 pm used this route. These observations highlight the importance of directing travelers toward more reliable alternative routes during incidents.

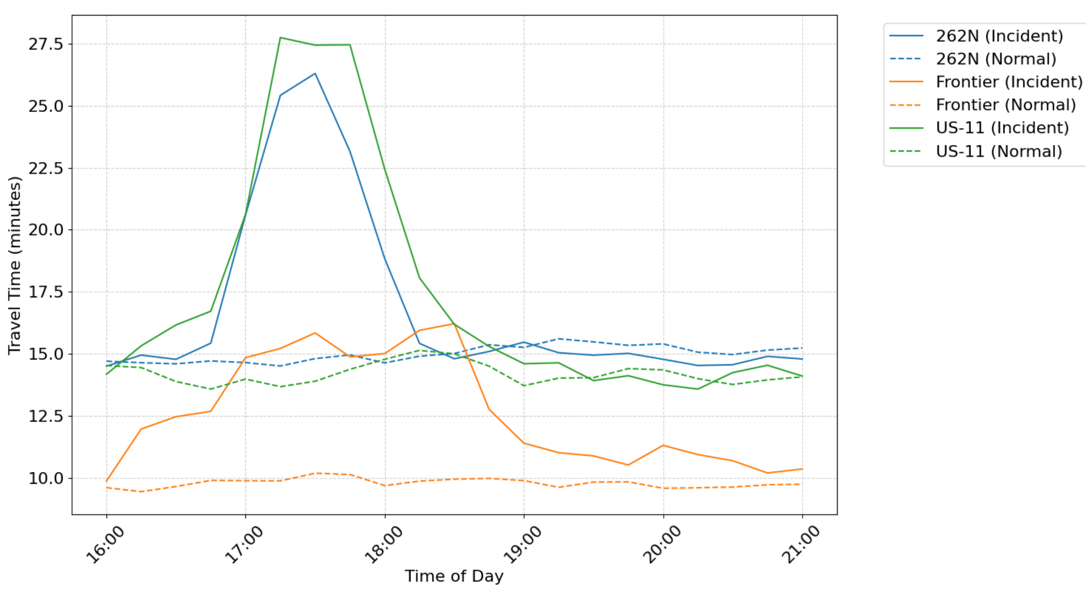


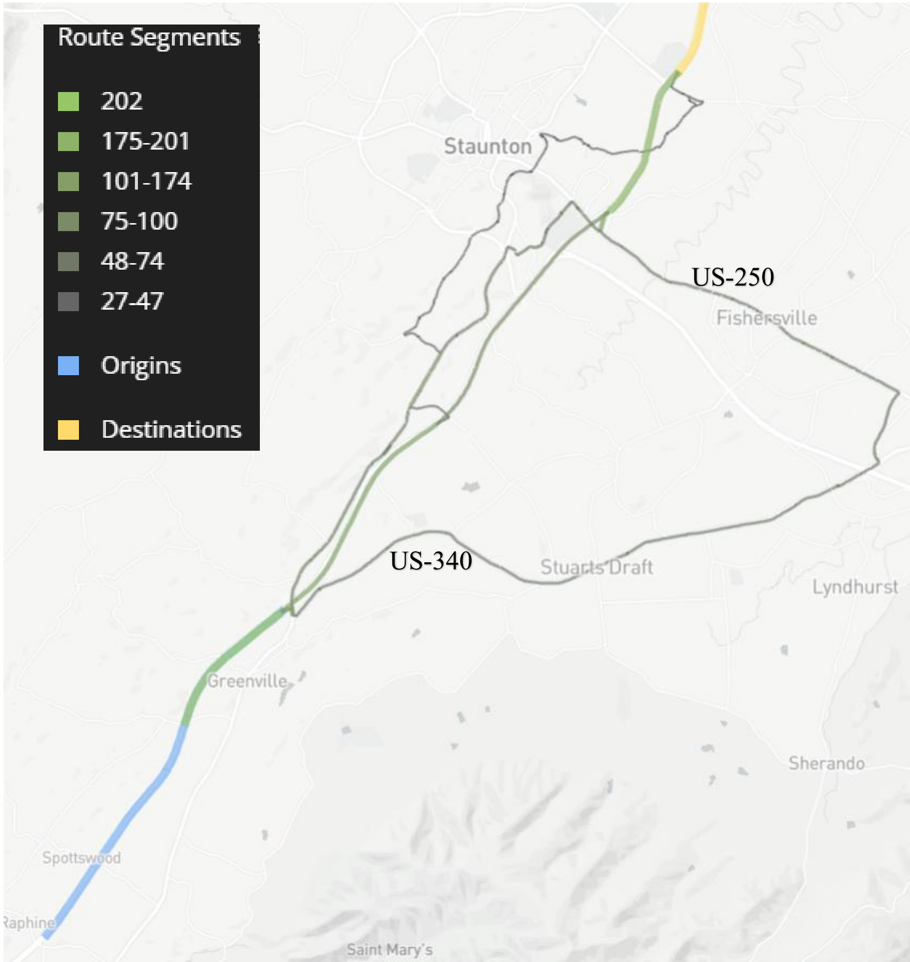
Figure 10. Travel Times on Alternative Routes During the Incident on October 22, 2025

As congestion continued to build, the end of the queue extended to roughly the midpoint between Exits 213 and 217 during 5 and 6 pm, about 7 miles downstream from the incident scene. The detour was deactivated at 5:48 pm after the right lane was reopened. Figure 11a shows the route choices during this hour. The most frequently used routes from 5 to 6 pm were:

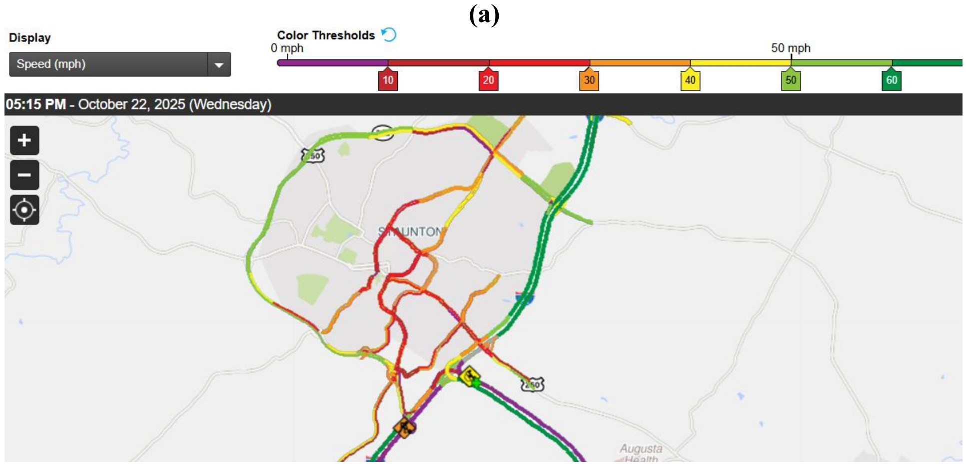
- I-81: A little more than 37% of drivers remained on I-81 because one of the travel lanes was open.
- US 11, Frontier Drive, and US 250: As the queue was beyond Exit 217, 26% of drivers exited at Exit 213 or 217, traveled along US 11 and Frontier Drive, and then turned onto US 250 to re-enter the interstate at Exit 222.
- US 11, Old Greenville Road, and New Hope Road: 13% of all trips exited at Exit 213 or 217 and traveled through the city via Old Greenville Road and New Hope Road to rejoin I-81 northbound at Exit 225.
- US 340 (Stuarts Draft Highway) and US 250: Surprisingly, nearly 24% of trips took a long route through US 340 and US 250 to re-enter I-81 northbound at Exit 222.

During this hour, neither Route C nor US 11 through the city was among the primary route choices. As Figure 10 shows, travel times on both routes were among the highest, with US 11 experiencing nearly double its usual travel time. These travel times did not include the additional delay caused by the long queue leading to the entrance of Route C. Moreover, as Figure 11b shows, heavy congestion at the I-81 Exit 220 off-ramp, the Rt. 262-US 11 interchange, and the Rt. 262-Rt. 252 interchange further restricted access to Route C, contributing to the limited use of this route.

These observations are consistent with findings in the literature that drivers are more likely to follow a designated detour route during the early stage of an incident, typically within the first hour when limited real-time information is available. During this period, drivers rely predominantly on physical signage. However, as more real-time information becomes available through navigation applications and other traveler information systems, drivers increasingly adjust their routes based on current conditions such as congestion or travel time. This shift reflects a transition from adhering to a predetermined detour route to making real time, adaptive routing decisions aimed at minimizing travel time. This highlights the importance of activating detours in a timely manner and providing clear and effective communications to the public in the early stages of incidents.



(a)



(b)

Figure 11. (a) Top Used Routes Between I-81 Northbound Exits 213 and 225 and (b) Speed During 5 and 6 pm on October 22, 2025

During 6 and 7 pm, with one lane open, the queue was reduced to about 5.5 miles long. Figure 12 shows the primary routes in this hour.

- I-81: About 49% stayed on I-81, marking 12% higher than the previous hour as the queue was gradually dissipating.
- Route C: Although the detour was lifted, 36% of the all-vehicle trips used Route C to re-enter I-81 northbound at Exit 225. As Figure 10 shows, travel times on Rt. 262 gradually returned to a normal level and were comparable with those on Frontier Drive and US 250, encouraging more use of this route compared with the previous hour.
- Frontier Drive and US 250 East: 15% of all trips re-entered at Exit 222 via Frontier Drive and US 250. Travel time on this route initially increased during the first part of this hour but then sharply decreased, likely because more trips stayed on the interstate or used Route C.

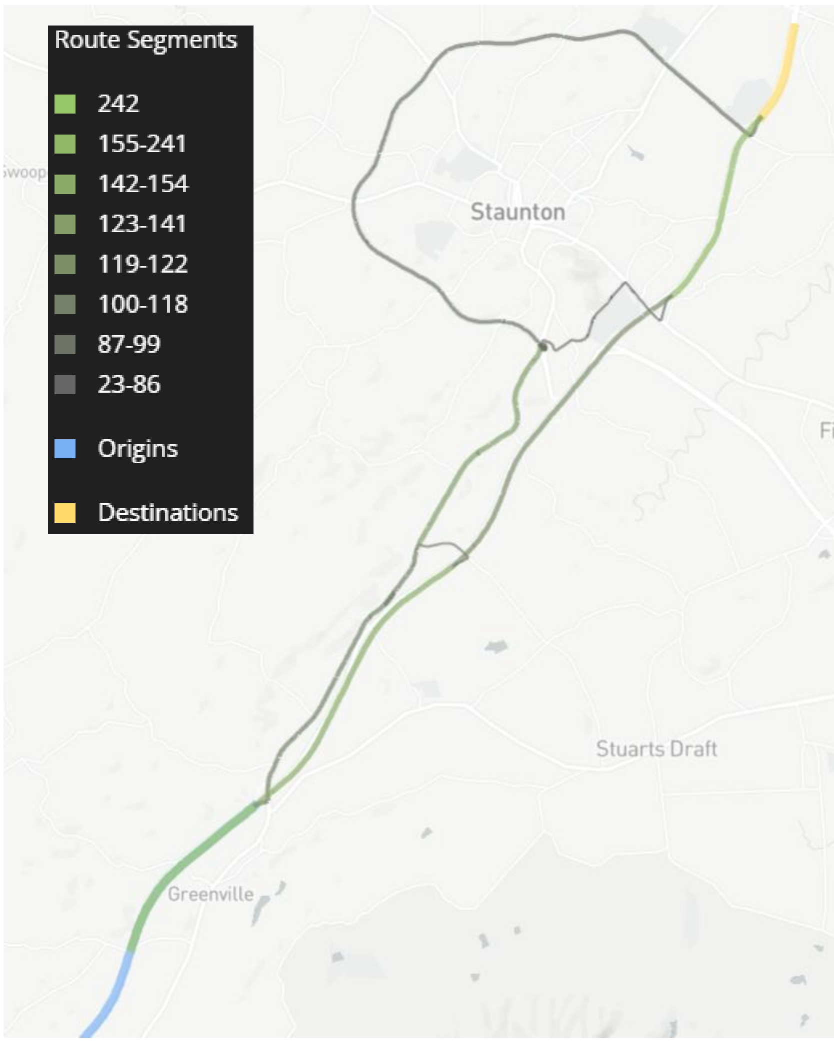


Figure 12. Top Used Routes Between I-81 Northbound Exits 213 and 225 from 6 to 7 pm on October 22, 2025

From 7 to 8 pm, the queue reached upstream to Exit 213. More than 70% of trips made between 7 and 10 pm exited the interstate at Exit 213 or 217 and used US 11 and then Frontier

Drive to get back to I-81 at Exit 222. Only about 12% remained on the interstate. As Figure 10 shows, the travel times on Route C and US 11 through the city were about 5 minutes higher than the Frontier Drive option, making them less preferable. The queue was finally cleared around 10:30 pm, nearly 3 hours after the detour was deactivated.

The incident also disrupted traffic on I-64 westbound. During the detour, drivers were instructed to take I-81 southbound and then use Rt. 262 to enter I-81 northbound at Exit 225. CMS on I-64 westbound at MM 102, about 14 miles upstream of the first two emergency routing signs (Figure 2, one Route A sign and one Route C sign on the same pole at MM 88.4), displayed the messages in Table 1. At the time the detour was activated, the end of the queue had almost reached I-64 westbound Exit 91.

During 4 pm, the most frequently used routes were:

- I-81 Exit 222 via US 250: As Figure 13 shows, most drivers (49%) exited I-64 at Exit 91 and took US 250 to enter I-81 northbound at Exit 222.
- I-81 southbound and US 11 through the city: As the ramp to I-81 northbound at I-64 Exit 87 was closed at 4:45 pm, the traffic stuck between Exits 87 and 91 was forced to take I-81 southbound. 23% of all trips used US 11 through the city to enter I-81 at Exit 225,
- Route C: More than 19% of all trips from the origin followed Route C.
- I-81 Exit 225 via US 250 and Balsley Road: 9% of all trips used US 250 and Balsley Road to enter I-81northbound at Exit 225.

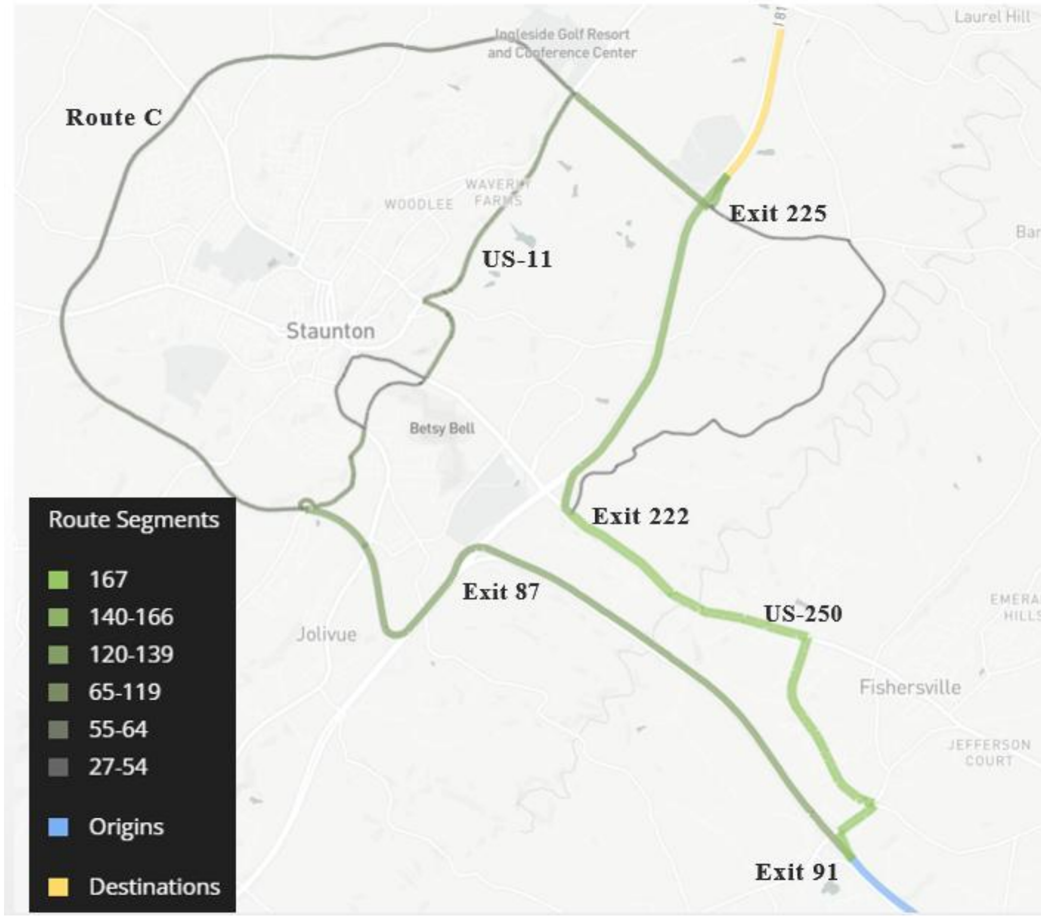
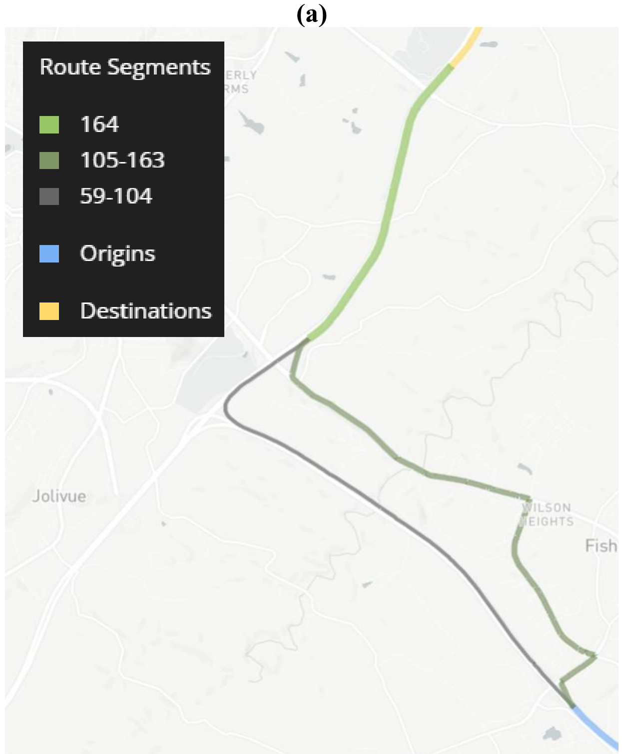


Figure 13. Top Used Routes from I-64 Westbound to I-81 Northbound During 4 and 5 pm on October 22, 2025

At 5 pm, the end of the queue was at I-64 westbound Exit 91, and 91% of trips exited at this location. The detour had been deactivated near 6 pm. Figure 14a shows the route choices from 5 to 6 pm.

- Route C: Only 9% of the trips followed the detour because of the heavy congestion between the origin and the Route C entrance (I-64 Exit 87).
- US 250 through Fisherville: 42% of all trips took Tinkling Spring Road and then traveled along US 250 to enter I-81 northbound at Exit 222. More drivers took this longer route through Fishersville, likely because of growing congestion on the local road network.
- US 250: 38% of all trips accessed US 250 via Lifecore Drive and joined I-81 northbound at Exit 222.

(a)



(b)

Figure 14. Top Used Routes from I-64 Westbound to I-81 Northbound During (a) 5 and 6 pm and (b) 6 and 7 pm on October 22, 2025

Although the ramp to I-81 northbound at Exit 87 was re-opened at 5:54 pm, traffic both downstream and upstream of the ramp was heavily congested. Nearly 36% of trips from I-64 westbound entered I-81 northbound at Exit 87 during 6 pm, whereas 64% still traveled along US 250 to join I-81 northbound at Exit 222. Traffic was back to normal during 7 and 8 pm.

Comparable Incident

A two-vehicle crash occurred at the same location on Sunday, April 14, 2024, at 9:27 pm and caused two northbound travel lanes to be closed for about 48 minutes from 9:27 to 10:14 pm. No detour was activated. The maximum queue was about 5 miles. Figure 15 illustrates the route choices from 9 to 11 pm.

Primary routes used during 9 pm included:

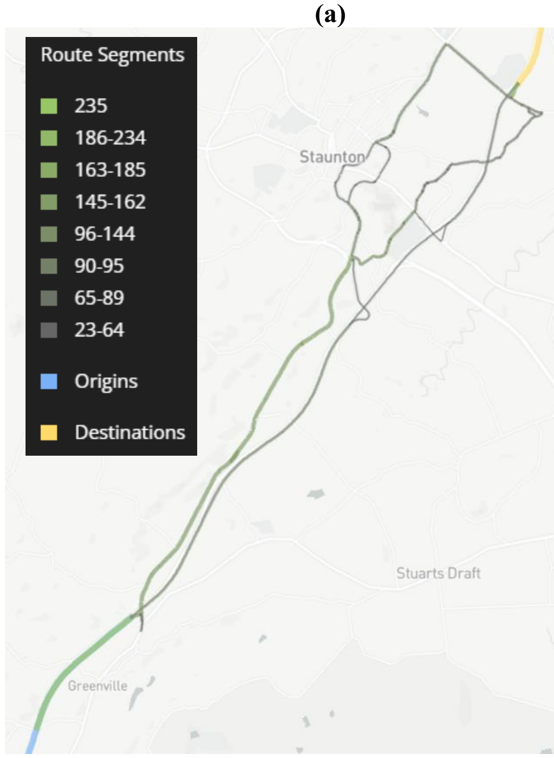
- Frontier Drive and New Hope Road: Nearly 45% of trips exited I-81 at Exit 220 and re-entered I-81 northbound at Exit 225 via Frontier Drive and New Hope Road.
- I-81: Approximately 40% of trips remained on I-81 because the lanes were open before 9:27 pm.
- US 11 through the city: Nearly 15% of trips rejoined I-81 northbound at Exit 225 via US 11 through the city.

The entrance ramp at Exit 222 was shut down around 9:48 pm, so all diverted traffic used Exit 225 to re-enter I-81 northbound. The most used routes during 10 pm included (Figure 15b):

- US 11 through the city: During 10 and 11 pm, the traffic queue extended beyond Exit 217. More than 38% of all trips exited at Exit 213 and used US 11 to rejoin I-81 at Exit 225.
- Frontier Drive and New Hope Road: Approximately 31% of trips exited at Exit 213, entered the city via US 11, and then continued along Frontier Drive and New Hope Road to rejoin I-81 at Exit 225.
- I-81: Nearly 30% of trips remained on the interstate because one travel lane was re-opened at 10:14 pm.

During this incident, the designated detour route (current Route C) was not the preferred alternative.

(a)



(b)

Figure 15. Top Used Routes on I-81 Northbound Between Exits 213 and 225 During (a) 9 pm and (b) 10 pm on April 14, 2024

Findings

Drivers mostly follow designated detour routes in the early stage of the incident. During the incident on October 22, 2025, 28% of trips on I-81utilized the designated detour route in the first hour of the incident. Later, as real-time application information accumulates, drivers shift to self-selected routes based on travel time. When the queue length extended beyond the entrance of the designated detour route, drivers were more likely to exit the interstate early and take the shortest route. The US 11-Rt. 262 interchange was a key decision point on Route C. In the period before the incident on April 14, 2024, even though all travel lanes were closed, the designated detour route (current Route C) was not the preferred route during the incident.

Case Study 2

On January 28, 2026, a vehicle fire at MM 223.8 on I-81 southbound, between Exits 222 and 225, caused the closure of both directions on I-81. Detour Route C and Route A were activated at the same time. Table 2 shows the timeline of this event. Besides removing the vehicle on fire from the road, a recent snowstorm and frigid temperatures required additional time to address icy road conditions. These extra efforts resulted in a longer overall clearance duration.

Table 2. Timeline of Incident on January 28, 2026

Time	Status
12:31	Virginia State Police reported incident, all northbound lanes blocked
12:37	All northbound and southbound lanes blocked; Incident Management Coordinator responding
12:49	Incident Management Coordinator on scene
12:54	Southbound detour (Route A) activated
12:55	Northbound detour (Route C) activated
12:56	Incident Management Coordinator advised that southbound closure would be prolonged
13:12	I-81 northbound Exit 222 northbound ramp blocked
13:30	All northbound lanes reopened
13:31	Northbound detour (Route C) deactivated
15:05	All southbound lanes reopened
15:05	Southbound detour (Route A) deactivated

Detour Operation

VSP reported the incident at 12:31 pm, and the VDOT Incident Management Coordinator (IMC) arrived on scene 18 minutes later. The logs obtained did not include the exact time that the detour decision was made. However, it was only 5 minutes between IMC’s arrival and detour activation and 23 minutes between when the TOC was notified and the detour was activated.

The CMS messages used were the same style as those in Table 1. Figure 16a shows the CMS message displayed on I-81 southbound at MM 229, and Figure 16b shows an example of the Virginia 511 messages posted during the southbound detour.

Traffic Diversion

Because StreetLight O-D data for 2026 were not yet available at the time of this analysis, traffic volumes and speeds observed during the incident were compared with normal-day profiles to assess the changes. The queue and congestion locations were identified based on TOC logs, and analyses were conducted using temporary sensor data and the RITIS Trend Map tool (RITIS, 2025). Figure 17 shows the travel times on Rt. 262. The green line represents the speed on a normal Wednesday in January based on data from January 2023 to January 2026, and the orange line represents the speed on the day of the incident. Travel times on both the northbound and southbound directions of Rt. 262 began to increase once the detours were activated, indicating higher volumes than normal. When the detour via Route C was initiated, the northbound travel time on the incident day was about 0.5 minutes longer than on a normal day. By the time the Route C detour was deactivated, this difference had grown to 1 minute. The maximum delay of about 4 minutes occurred at 2:00 pm, roughly 30 minutes after the Route C detour was lifted.

(a) (b)

Figure 16. Changeable Message Sign on (a) I-81 and (b) Virgina 511 Message Used During the Incident on January 28, 2026

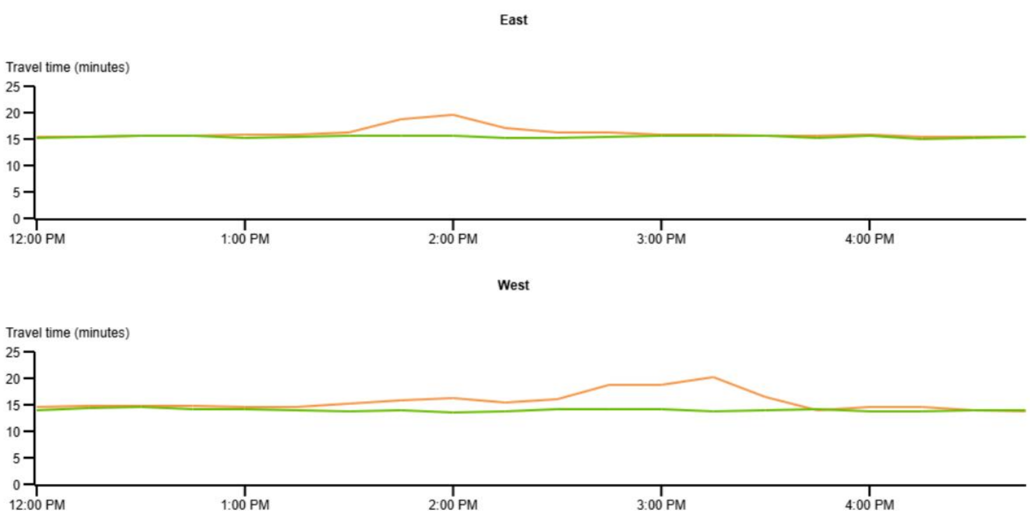


Figure 17. Travel Times on Route 262 on January 28, 2026. Green line = normal day; orange line = incident day.

A similar pattern was observed on Rt. 262 southbound on Route A. At the onset of detour, the southbound travel time was about 0.4 minutes higher than typical conditions. When the detour ended, the difference had increased to 4.6 minutes, with the largest delay of 6.5 minutes occurring 10 minutes after the detour was deactivated. For both travel directions, the congestion near the intersection of Rt. 262 and US 11 (Commerce Road) mainly caused the increased travel times.

Traffic volumes at key route choice decision points were also compared. To follow Route C, I-81 northbound traffic is expected to exit at Exit 220 and re-enter at Ext 225 through Rt. 262 northbound. Figure 18 shows the traffic volumes at the I-81 northbound off-ramp at Exit 220 and the on-ramp from Rt. 262 to I-81 northbound at Exit 225. The detour on Route C started at 12:55 pm and ended at 1:31 pm. The traffic volume observed from 1:00 to 1:30 pm at Exit 220 off-ramp was 1.7 times that of a normal day. If all the additional traffic had followed Route C, a corresponding increase would be expected at the Exit 225 on-ramp about 15 minutes later, based on the travel times in Figure 14. However, the volumes at the Exit 25 on-ramp during the incident were higher than on a normal day, but only a small increase occurred during 1:45 and 2 pm, indicating drivers entered I-81 through other entrances.

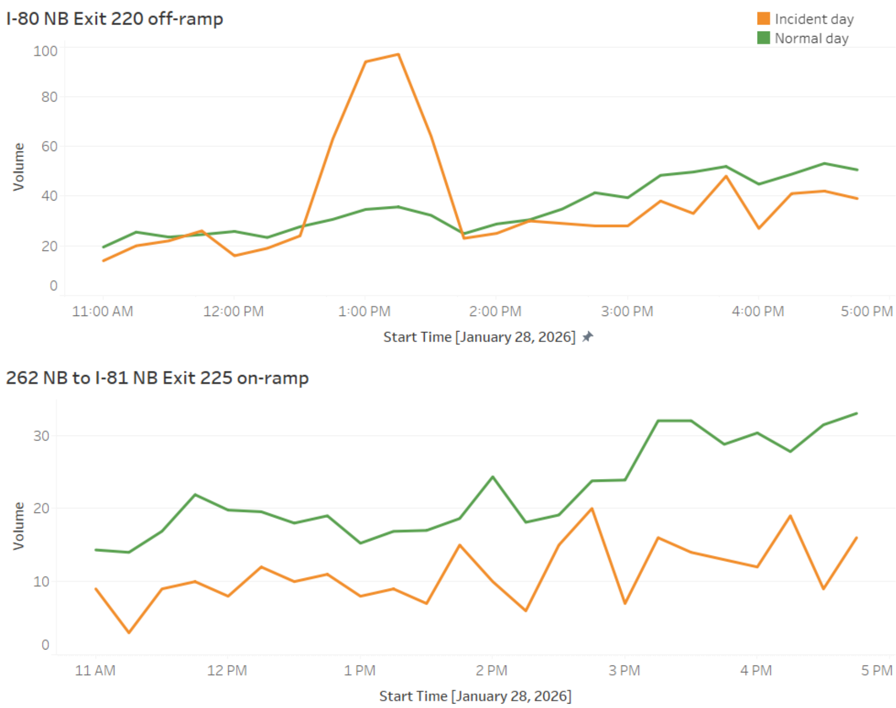


Figure 18. Traffic Volume Changes on Detour Route C on January 28, 2026. NB = northbound.

When detour Route A was activated at 12:54 pm, traffic volumes exiting I-81 southbound at Exit 225 showed a slight decrease (Figure 19). The queue developing between Exits 225 and 227 likely influenced this reduction. As congestion grew on this section, many drivers diverted earlier by exiting at Exit 227 and using US 11 southbound as an alternative route. During the detour hours from 1 to 3 pm, traffic volume on the ramp from Rt. 262 southbound to I-81 southbound was more than double (214%) that of a normal Wednesday in January. The intersection of US 11 (Commerce Road) and Rt. 262 is the key decision point on Route A where drivers decide whether to continue on Rt. 262 or turn right onto US 11. The temporary sensor data indicated that between 12:30 and 1:00 pm, the ratio of left-turn traffic to through traffic was more than twice its usual value, suggesting drivers were using US 11 as an alternative route. However, this ratio dramatically decreased to around 0.1 between 1:30 and 2:30 pm, before returning to its normal range by 3:30 pm, suggesting that drivers may opt to use US 11 when it is not congested. As travel time along US 11 increases, more drivers tend to remain on the detour route.

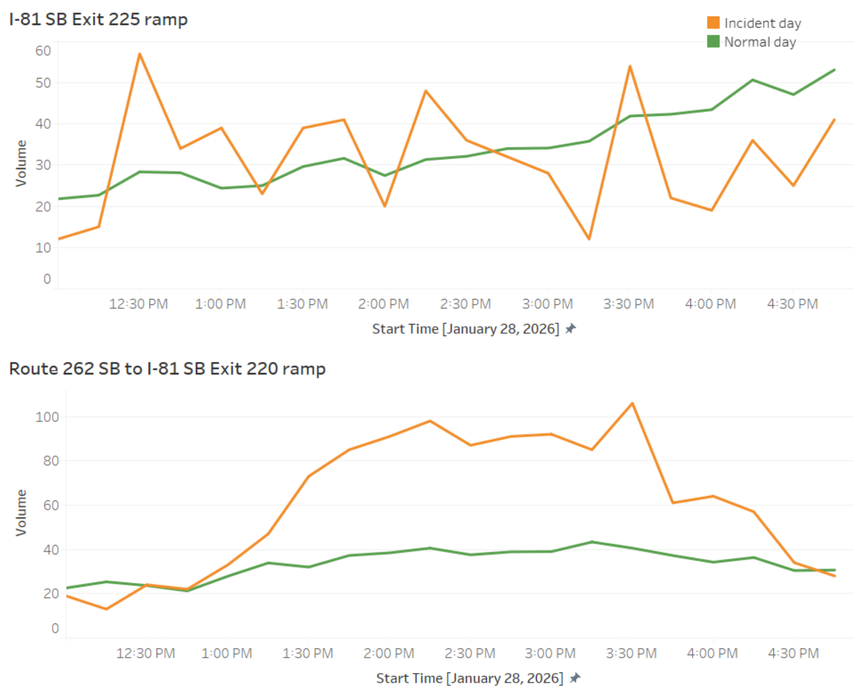


Figure 19. Traffic Volume Changes on Detour Route A on January 28, 2026. SB = southbound.

Findings

Because StreetLight data were not available, the effects were measured by comparing speeds and volumes on incidents with those on normal days. The analysis found that travel times and volumes on both Routes A and C increased during the detour operation, but the fluctuation in travel times was less significant than those observed on other alternatives like US 11 through the city. Drivers changed routing behavior dynamically depending on where congestion formed.

No comparable incident was identified for this incident on January 28, 2026.

Case Study 3

A vehicle fire occurred on I-81 southbound at MM 223 at the ramp to US 250 on January 30, 2026. All southbound lanes were closed, and the detour using Route A was activated. As the location was upstream of the I-81-I-64 interchange, traffic from I-64 westbound to I-81 southbound was not affected. Table 3 shows the incident timeline.

Table 3. Timeline of Incident on January 30, 2026, to January 31, 2026

<table>
<tr><th>Time</th><th>Status</th><th>CMS Message Displayed at Mile Marker 228.7</th></tr>
<tr><td>21:34</td><td>Traffic Operations Center verified the incident, both southbound lanes blocked</td><td rowspan="2">VEHICLE FIRE 5 MILES AHEAD
ALL LANES BLOCKED</td></tr>
<tr><td>21:42</td><td>Virginia State Police requested detour</td></tr>
<tr><td>21:49</td><td>Detour was activated</td><td rowspan="4">I-81 CLOSED AHEAD
USE EXIT 225 EMERGENCY ROUTE A</td></tr>
<tr><td>21:56</td><td>Local police department diverted traffic off at Exit 225</td></tr>
<tr><td>22:24</td><td>Contractor shut down Exit 225 on-ramp</td></tr>
<tr><td>22:35</td><td>Incident Management Coordinator arrived on scene</td></tr>
<tr><td>0:26</td><td>All lanes have been salted and preparing to open</td><td rowspan="3">VEHICLE FIRE 5 MILES AHEAD
ALL LANES BLOCKED</td></tr>
<tr><td>0:39</td><td>Exit 225 on-ramp was reopened</td></tr>
<tr><td>0:37</td><td>Incident Management Coordinator confirmed scene was clear</td></tr>
<tr><td>0:49</td><td>Detour was deactivated</td><td>Message blank</td></tr>
</table>

CMS = changeable message sign.

Detour Operation

Augusta County reported the incident, and the TOC verified it through closed-circuit television cameras at 9:34 pm. The detour decision was made at 9:42 pm, and it took only 7 minutes for VDOT to activate it, even before the IMC arrived on scene. As in the two previous cases, the TOC updated the CMS messages in a timely manner based on field updates.

Traffic Diversion

As StreetLight O-D data were not yet available for this event, speed and volume data were used to explore the traffic diversion trends. When the detour was implemented, the traffic queue was close to 1.5 miles. As Figure 20 shows, travel times on Rt. 262 southbound were generally consistent during the entire detour operation. The peak difference of 1.4 minutes between normal and incident day travel times was observed at 10:45 pm. At this point, the end of the queue was between Exits 225 and 227. As more drivers egressed Exit 227 to use southbound US 11 as an alternative, congestion developed at the intersection of US 11 and Rt. 262. Despite some fluctuations, generally more traffic was exiting I-81 southbound at Exit 225 and re-entering via the ramp on Rt. 262 southbound at I-81 southbound Exit 220 during the detour (Figure 21). However, it is unclear which routes were mostly used to reach the Rt. 262 and I-81 interchange.

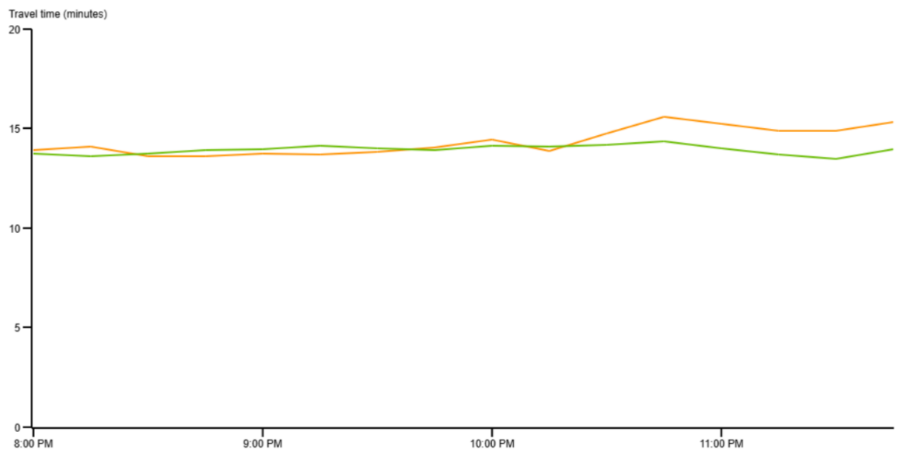


Figure 20. Travel Times on Route 262 Southbound on January 30, 2026. Green line = normal day; orange line = incident day.

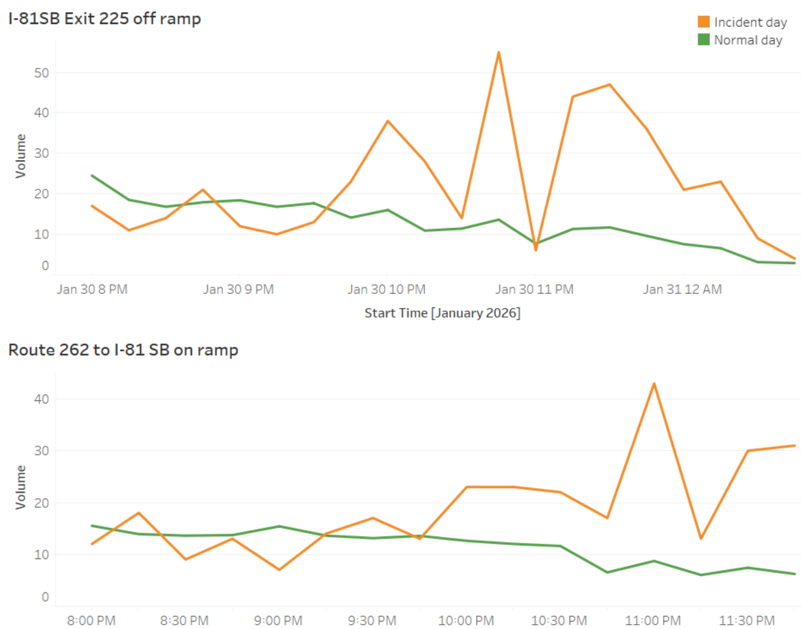


Figure 21. Travel Volume Changes on Route A on January 30, 2026. SB = southbound.

From 9:30 pm to the end of the day, both the through and left-turning traffic from Rt. 262 southbound were higher than normal at the intersection of Rt. 262 and US 11 (Figure 22). The ratio of left-turning traffic to through traffic was higher than normal between 9:30 and 10:15 pm, which may suggest that US 11 was preferred over Rt. 262 because of shorter travel times.

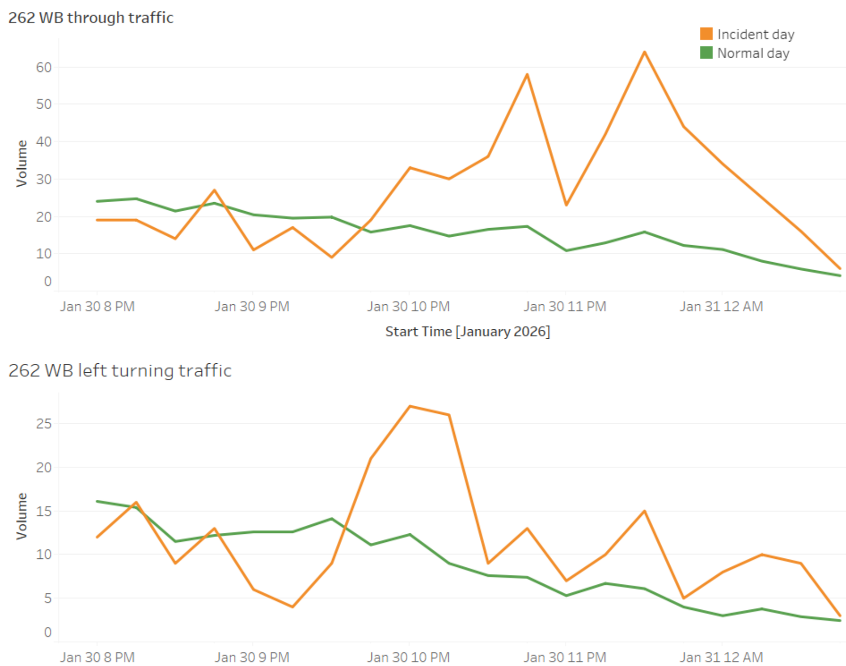


Figure 22. Through and Left-Turning Traffic on U.S. Route 11 and State Route 262 on January 30, 2026. WB = westbound.

Comparable Incident

A tractor trailer accident on January 9, 2023, was identified as a comparable case. The accident also occurred on the ramp to US 250 at MM 223 and caused a full closure of the I-81 southbound lanes for 137 minutes. A detour was activated in this case. Table 4 lists the incident timeline.

Table 4. Timeline of Incident on January 09, 2023

Time	Status
18:03	Incident verified by CCTV, Incident Management Coordinator notified
18:16	Virginia State Police requested detour, traffic queue was about 3 miles
18:24	Contractor set up a temporary detour at Exit 225
18:29	Crew were mobilized to assist with shutting down the left-turn lane at State Route 254 and U.S. Route 11 to keep traffic from turning onto I-81
18:56	Local police department diverted traffic off at Exit 225
19:26	Contractor shut down the Exit 225 on-ramp
19:39	Incident Management Coordinator arrived on scene
20:21	All lanes have been salted and preparing to open
20:47	Exit 225 on-ramp was reopened
20:49	Incident Management Coordinator confirmed scene was clear
21:11	Detour was deactivated

CCTV = closed-circuit television.

In the 2023 incident, a detour was requested at 6:16 pm, and 8 minutes later, a temporary detour was set up at Exit 225. The exact time of full detour was unclear, but TOC field updates at 7:26 pm, 70 minutes after the detour was requested, show that crew were still setting up the detour at that point, and assistance with signage was requested from the locality at 7:39 pm. The detour was lifted 70 minutes after that. The time required for crews to mobilize, request resources, and establish the detour highlights the need and benefit of implementing permanently-installed signs.

Figure 23 shows drivers' route choice during the comparable incident, although no O-D data were available for the incident on Jan 30, 2026 discussed previously. The trip origin was set at upstream I-81 southbound Exit 235, and the destination was set at upstream Exit 213. During the 6 pm hour, drivers took the following main routes:

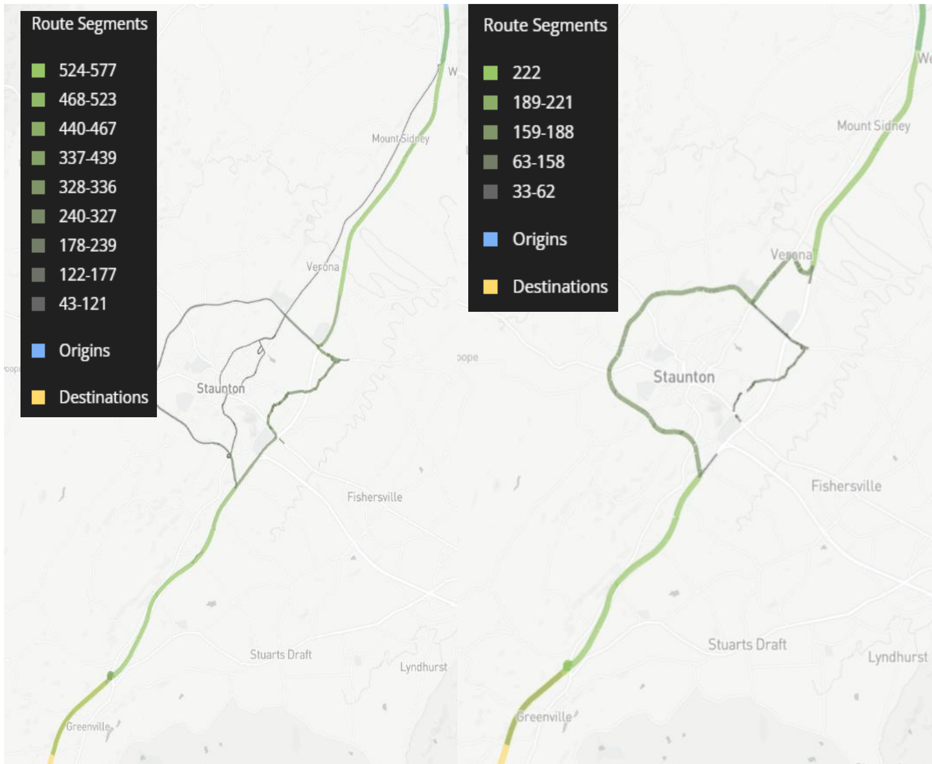
- New Hope Road and Frontier Drive: 57% of trips exited the interstate at Exit 225 and re-entered I-81 southbound at Exit 222 via New Hope Road and Frontier Drive.
- Route C: 26% of trips followed Route C, joining it at either Exit 225 or the intersection of US 11 and Rt. 262.
- US 11 through the city: 17% used US 11 through the city to enter I-81 southbound at Exit 220.

Between 7 and 8 pm, Route C was the most frequently used route, accounting for more than 51% of all trips. According to TOC logs, VDOT staff and contractors were directing traffic near Exit 225, which may have encouraged additional drivers to use Route C. After the detour was deactivated, a larger proportion of drivers (67%) chose to use the interstate between 8 and 9 pm. During this time, as the queue extended beyond Exit 227, 33% of all trips exited I-81 at Exit 235 and took US 11 to rejoin I-81 at Exit 222. Route C was no longer the preferred option.

Because the StreetLight data coverage in the study area is unknown, a potential sampling bias exists. The few disconnected segments in Figure 23b indicate data quality issues.

Findings

When the incident occurred during the nighttime, when traffic volumes were relatively lower, travel times on Route A (Rt. 262) only slightly increased. After detour activation, more traffic exited at Exit 225 and used Route A to re-enter I-81 at Exit 220. Drivers' choice between US 11 and Route A depended on the congestion level. As US 11 became congested, more drivers stayed on Route A. Even at night with lower baseline volumes, detour activation produced detectable shifts in travel paths, especially toward Rt. 262 when US 11 congested. In the before period, the time and resources required to set up a full detour limited the incident response time, and the queue grew to about 1.5 miles long between when the detour was requested and when the detour began.



(a) **(b)**

Figure 23. Alternative Routes Between I-81 Southbound Exits 213 and 225 Used in the Incident on January 9, 2023: (a) 6–7pm; (b) 7–8pm.

Case Study 4

A widening project on I-81 northbound and southbound between Exits 221 and 225 (MMs 221.45 and 225.6) has been under construction since late 2023 and is expected to be completed in summer 2027. The active construction includes significant lane restrictions, traffic shifts, and bridge work in both directions. Northbound I-81 was completely closed from 7 pm Saturday, March 14, through 9 am Sunday, March 14, 2026, to set up for a traffic-pattern shift. A detour was in place utilizing the emergency routing signs during this time. VDOT released the news on March 4, and the local Augusta County news also reported the planned work zone closure (Graham, 2026). Motorists were advised to follow the "Emergency Route C" signs to navigate the detour.

The use of permanently installed emergency routing signs can reduce the time and resources required to set up and clean up temporary traffic for the work zone detour. The work zone detour was implemented as scheduled. Traffic was diverted at I-81 Exit 220 (Figure 24a) and I-64 Exit 87 (Figure 24b).

(a) (b)

Figure 24. Traffic Diverted on I-81 and I-64 During Work Zone Closure on March 14, 2026: (a) I-81 Southbound Exit 220; (b) I-64 Westbound Exit 87

Before the closure, alert messages were displayed on permanent and portable CMS units along I-81 and I-64, as well as US 250 (Figure 25b) and US 340 to alert drivers. Figure 25a shows a message posted on I-64 westbound about 15 miles upstream of the detour location. Figure 26 shows a sequence of CMS messages posted on I-64 westbound during the detour. The message content was adjusted based on the distance to the diverging point and the size of the CMS screen. On US 250 and US 340, instead of the generic "USE EXIT 220 ROUTE C," messages were tailored to more effectively guide drivers on local roads. For example, on US 250 eastbound at MM 60 near I-81 Exit 222, the message "I-81 NB closed, follow detour via I-81 SB" was displayed to direct drivers who would otherwise use the northbound entrance at Exit 222 if no detour was in place.

(a) (b)

Figure 25. Messages Displayed on Changeable Message Signs on I-64 and US 250 on March 14, 2026: (a) I-64; (b) U.S. Route 250

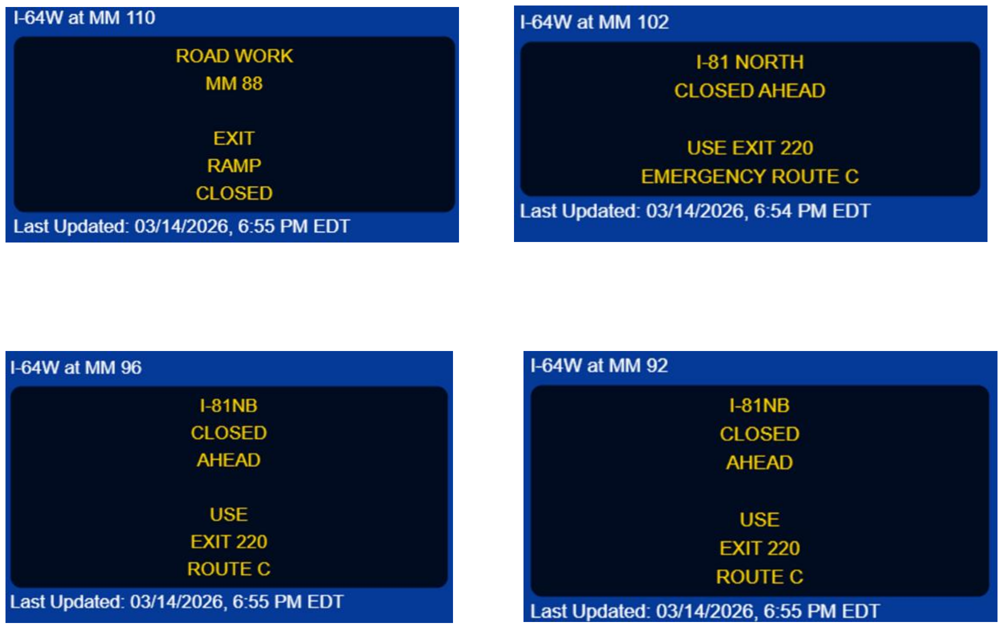


Figure 26. Messages Displayed on Changeable Message Signs Along I-64 on March 14, 2026

Because StreetLight data and temporary sensor data were not available, traffic patterns during the work zone detour were explored using INRIX XD, system detector data, and continuous count station data. Figure 27 shows the travel times on Rt. 262 northbound during the overnight closure. The travel times were generally longer than a weekend night in March, especially between 8:15 and 9:15 pm. The largest difference of 5 minutes was observed at 8:45 pm. Congestion was observed near the interchange of Rt. 262 and US 11 south of the city, as well as at the intersection of Rt. 262 and US 11 on the north side.

Northbound I-81 traffic passing through the Staunton area during the overnight closure was slightly below typical levels, according to continuous count data recorded near MM 219. The total volume during the closure decreased by 13%. The most significant drops were observed from 7 to 9 pm. This reduction is likely attributed to motorists from the Augusta County area adjusting their travel plans after learning about the planned closure, leading some drivers to avoid the corridor altogether. The traffic volume on the ramp from westbound I-64 to southbound I-81 increased by nearly 30%, as traffic to northbound I-81 was diverted to southbound I-81.

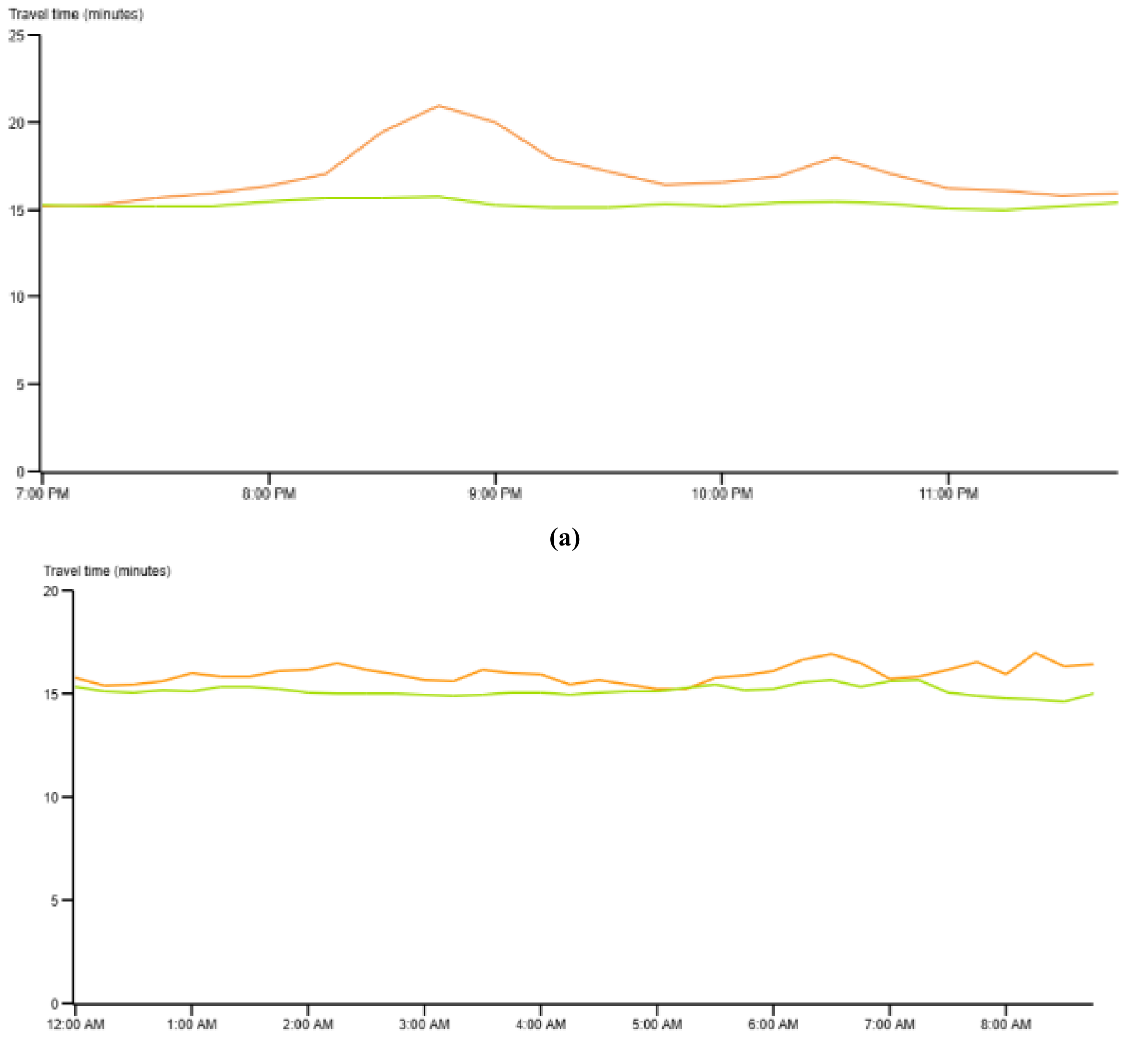


Figure 27. State Route 262 Northbound Travel Time on (a) March 14, 2026, Between 7:00 pm and 11:59 pm and (b) March 15, 2026, Between 12:00 am and 9:00 am. Green line = typical condition; orange line = work zone detour condition.

As previously noted, system detectors at the intersection of US 11 and Rt. 262 are not intended for continuous collection of traffic volume and speed data, resulting in a significant discrepancy between the volumes recorded by these detectors and the trailer-mounted sensors. Nonetheless, the trends indicated by volumes from both types of sensors were generally consistent. Although the system detector data were used to illustrate trends, they did not accurately represent the actual volumes at the location. Figure 28 shows the changes in 15-minute volumes at the intersection during the detour operation. During the overnight closure, total traffic passing through the intersection from Rt. 262 northbound surged by 135% compared with a typical weekend night in March, suggesting that motorists followed detour Route C. In addition, traffic turning right onto Rt. 262 northbound from US 11 northbound rose by 103%, indicating motorists also used US 11 as an alternative. Given that truck volumes on I-81 during nighttime hours can exceed more than 50%, these figures may imply that trucks are more likely to use Route A.

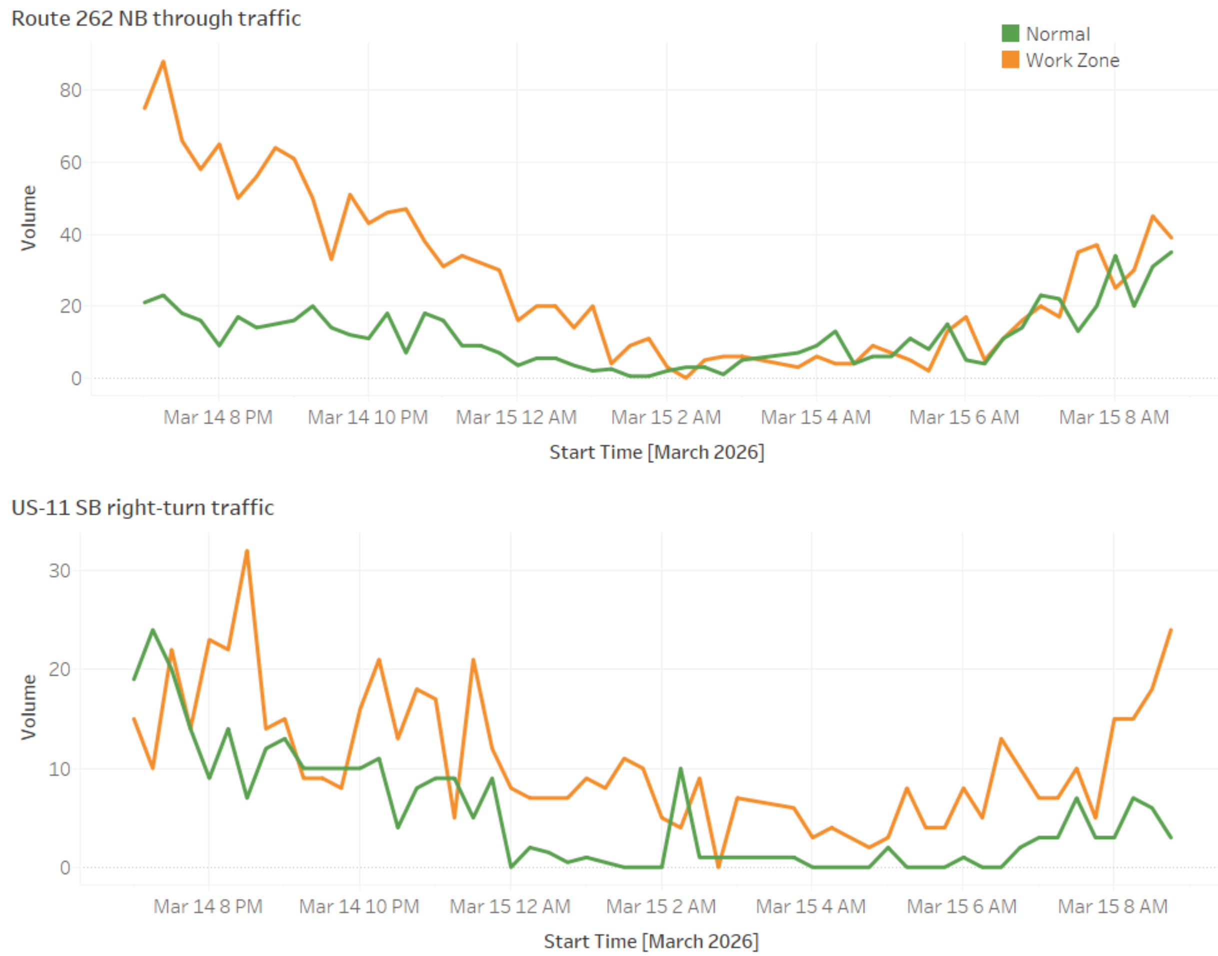


Figure 28. Traffic Trends at the Intersection of U.S. Route 11 and State Route 262 on March 14–15, 2026. NB = northbound; SB = southbound.

Findings

The Emergency Route C was first deployed for work zone closure. Traffic posts were set up to divert traffic at I-81 northbound Exit 220 and I-64 westbound at Exit 87, and CMS messages displayed were tailored by location and more detailed than in unplanned incidents. Northbound Rt. 262 traffic passing through the US 11-Rt. 262 intersection increased by 135%, confirming high compliance with the planned detour. Although travel times on Route C were up to 5 minutes longer than typical March weekend nights, no significant congestion was observed.

Summary of Case Studies

Across incidents, detour activation was consistently faster after emergency routing signs were installed. The time it took to activate detour operations was identified from TOC logs and associated incident records. For the three incidents that occurred during the before period, the time between the detour decision and the actual activation was consistently more than 1 hour. The shortest activation time observed in this period was 1 hour and 7 minutes. In contrast, during the after period, detour activation times were dramatically shorter. In all three cases, the detour was fully activated within approximately 10 minutes or less following the decision, representing a substantial improvement in operational responsiveness and highlighting the effectiveness of the permanent signs.

Route choice shifted significantly after detours were activated, and behavior evolved during the course of each incident. In the first hour of the incident, drivers relied more on physical signs, resulting in higher compliance with Route C or A. In Case Study 1, 28% of all vehicles and 38% of trucks on I-81 northbound used Route C immediately after activation. As navigation applications updated real-time congestion, drivers increasingly avoided the designated detour routes when access points (e.g., the I-81 Exit 220 off-ramp and the Rt. 262-US 11 interchange) became congested. In Case Study 1 (5–6 pm), Route C dropped from a primary option to only 9% usage because of heavy congestion at the access points.

Across multiple cases, US 11 functioned as a major alternative when:

- Queue spillback blocked access to Routes C and A.
- Travel times on Rt. 262 were generally higher than those on US 11.

For example, in Case Study 2, during the I-81 southbound detour, left-turn volumes from Rt. 262 southbound toward US 11 southbound at the US 11-Rt. 262 intersection more than doubled during the early detour period. In Case Study 3, during the I-81 southbound detour, the ratios of left-turn to through traffic at the US 11-Rt. 262 intersection were higher than normal early on, indicating a preference for US 11 over the designated detour route.

The designated detour route was more reliable than the alternatives through the city. In Case Study 1, even under heavy congestion, travel times on Route C remained less than those on the US 11 route, despite being longer on normal days. An approximate 60% increase in travel time during peak diversion was observed on Frontier Drive, indicating capacity limitations.

The overnight work zone closure (Case Study 4) demonstrated higher compliance compared with unplanned incidents. Even with a 13% reduction in demand along I-81 northbound, the volume on Route C increase by 135%, indicating higher use of the designated detour route.

In general, analysis across four case studies shows that emergency routing signs significantly enhance VDOT's ability to activate detours quickly and provide consistent guidance. However, congestion at key access and decision points, especially the US 11-Rt. 262 interchange south of the city and the US 11-Rt. 262 intersection on the north end, strongly influences driver compliance and overall system performance. Understanding the changes in VDOT's detour operation and drivers' route choices is important for optimizing the detour process and procedure, improving real-time delivery, and supporting future operational improvements.

User Experience Interviews

The qualitative data gathered from semi-structured, in-person interviews with VDOT's Staunton District staff, including the District Traffic Operations Director, the District Traffic Operations Manager, the TOC Program Manager, and a Traffic Engineer, provided critical context for evaluating the operational impact of emergency routing signs. These interviews focused on how the transition from manual to permanent signage changed their incident management practices and the staff-perceived benefits and opportunities.

Challenges of Flip Signs

Prior to the pilot, implementing a detour on Rt. 262 required a labor-intensive "flip-down" process. Although flip-down signs were pre-installed, activation required staff to physically traverse the route to manually flip down the signs. This traditional deployment process generally required 30 minutes to assemble the necessary personnel, truck-mounted attenuators, arrow board trucks, and miscellaneous equipment. Driving along the entire route to set up signs was often slowed by the same congestion the detour is intended to relieve. Once on site, flipping down the signs and installing the temporary signs added another 30 minutes. As a result, a detour may not be fully operational until at least 1 hour after the activation decision was made. After the detour is deactivated, completing the route to reset all the signs could take up to an hour.

In general, setting up the flip signs and the temporary signs required six to seven staff members. Contractors usually performed setting up traffic control devices. However, during major incidents, more roles needed to be filled when detour operations were necessary, and VDOT often needed to dispatch one or two staff to support the contractor. Because of the challenges in deploying enough personnel in time, the flip-down signs were never fully activated at the time detour was activated in some past events.

Implementing permanent signage reduces contractor labor requirements, although the existing fixed-cost maintenance contract currently limits direct cost savings. However, the new signs also reduce internal staffing demands. Most importantly, eliminating the logistical requirement for manual sign deployment allows both contractors and VDOT staff to prioritize incident management and response operations.

Effects on Detour Activation Decision-Making

Interviews revealed that the permanent signs have shifted the decision-making for the VDOT field commander. When making a detour decision, the incident commander and VDOT field commander must account for the time and resources required to deploy a detour. The delays associated with setting up temporary traffic control signs can directly influence whether a full detour is considered. Interviewees noted that, in practice, they typically activate a full detour only when an incident is expected to last longer than 2 hours. By removing the mobilization and setup time (estimated at 1 hour) for setting up flip signs on Rt. 262, the new permanent signs allow VDOT to activate detours almost immediately on request, facilitating more effective resource management and providing critical operational flexibility during the initial stages of an incident.

Integration with Navigation Technology

The interviewees provided valuable insights into how static emergency routing signs complement the navigation tools drivers use. Although many drivers rely on GPS navigation applications, physical emergency routing signs offer immediate visual confirmation for those who have been rerouted by their devices. As stated in the MUTCD, routing signs are intended to provide drivers with assurance throughout the detour. Staff noted that the distinct green-and-white scheme effectively differentiates the official detour route from temporary construction (orange) or emergency scene (pink) signage, conveying a more professional and trustworthy appearance.

Furthermore, staff highlighted that an effective, layered communication strategy is essential. CMS provide real-time travel advisories on the interstate and at exit points, whereas the permanent routing signs ensure continuous guidance along the detour route.

Next Steps

Although the initial observations indicate that the new emergency routing signs offer considerable operational benefits, the interviewees expressed a need to further evaluate a broader set of results before making any definitive decisions. Participants viewed this expanded evaluation as an essential step to ensure that any subsequent expansion of the pilot to additional locations is well informed, effective, and aligned with stakeholder expectations. The pilot project will be considered for expansion only after these conditions are satisfactorily met. As the data for route-choice analyses for the January 28 and January 30, 2026, incidents were unavailable at the time of this study, interviewees expressed strong interest in reviewing the results once the StreetLight data become available.

Summary of Findings

The implementation of permanently-installed emergency routing signs reduces the personnel needed for establishing temporary traffic control, allowing incident responders to focus more effectively on managing the incident scene. During major incidents, the IMC typically serves as the VDOT field commander, representing VDOT on scene and participating in the unified command. The IMC often serves as the Interstate Maintenance Office designee at the same time and is responsible for requesting necessary resources. As observed in Case Study 1, the ability to initiate a detour within 10 minutes enabled the IMC to focus on managing a complex cargo spill and pavement damage, rather than coordinating the manual placement of signs. By facilitating rapid detour activation, VDOT reduces the communication overhead and logistical challenges that have traditionally encumbered these roles. This efficiency was further illustrated in Case Study 2, in which simultaneous closures in both travel directions were handled through the near-instantaneous activation of multiple detour routes (Routes A and C). These permanent signs also allow VDOT to disseminate traveler information more swiftly, thereby enhancing the overall credibility of VDOT's traveler information.

In past detour operations, instances have occurred in which detour signs could not be deployed in a timely manner to support detour activation. Failure to maintain detours can lead to liability. Tort liability related to traffic detours can arise when an agency or contractor is deemed negligent in the design, installation, or maintenance of temporary traffic control devices, resulting in accidents. A 2022 VDOT study found that the risk of tort liability inhibits VDOT incident responders from executing detour operations (VDOT, unpublished data). Common causes of tort liability include inadequate signage, confusing detour routes, lack of proper barricades, and poor lighting. By utilizing these MUTCD-compliant permanent emergency routing signs, VDOT significantly mitigates the risks of tort liability while ensuring that detour operations remain reliable and legally defensible.

Limitations

A primary limitation of this study is the limited samples observed in the "after" period. The after period following the installation of the permanent emergency routing signs was only 7 months, and only a few detour operations were observed. This constraint prevented the application of high-level statistical rigor. Consequently, this study relied on case studies to evaluate the signage's operational and route-choice effects. Although these case studies provide valuable, detailed evidence of improvements in detour activation latency, the findings represent specific instances rather than broader statistical trends. Furthermore, each incident possesses unique characteristics, such as specific closure locations, time of day, and varying traffic conditions, making it practically impossible to identify a perfectly matched "before" incident for direct comparison. Also, the current method could not account for the effect of navigation applications. In addition, the short study period does not allow for assessing how drivers' familiarity with these emergency routing signs may affect the compliance rate.

CONCLUSIONS

- *The permanently-installed emergency routing signs significantly reduce the time and manpower required to activate a detour*. The deployment of permanent emergency routing signs effectively eliminates the extensive labor and travel time required for traditional manual detour setups. Although manual deployment typically involves a mobilization and setup window of more than 1 hour, the permanent infrastructure allows the detour operation to be activated nearly instantaneously via CMS upon the field commander's request. This reduction in activation lag directly enhances VDOT's capability to manage incident-related traffic before extensive queues form.

- *The permanently-installed emergency routing signs mitigate operational vulnerabilities and legal risks*. Permanent signage overcomes the vulnerabilities of manual deployment while reducing the risk of tort liability. Previously, setting up and flipping down signs required responders to physically drive the entire detour route, which can take more than 30 minutes for Rt. 262, and was often hindered by the very congestion the detour was intended to alleviate. These logistical delays often resulted in operational inconsistencies in which some signs remained unfunctional at the time of activation, creating a fragmented guidance system that increased driver confusion. Permanent MUTCD-compliant signs ensure that reliable guidance is available along the entire detour route, mitigating the risk of negligence claims related to improper temporary traffic control.

- *Although benefits were observed during the case studies, the available data are insufficient to statistically quantify the effectiveness of permanently-installed emergency routing signs on operational efficiency and traffic diversion*. The small number of post-installation observations prevented rigorous statistical analysis of changes in detour activation latency or diversion patterns. In addition, the current approach cannot isolate the influence of navigation applications, making it impossible to determine how much of any observed diversion was directly attributable to the permanent signage.

RECOMMENDATION

1. *VDOT's Staunton District should further evaluate detour operations procedures and processes to more effectively deploy the permanently-installed emergency routing signs*. The district should collaborate with relevant stakeholders to evaluate critical operational variables, including but not limited to the messaging and placement of CMSs, the strategic placement of permanent signage, and strategies to encourage driver compliance. This evaluation should specifically address queue spillback beyond the primary decision points along the designated routes, causing drivers to divert onto alternative routes such as US 11. The review should help identify locations where additional signage or temporal traffic control posts are needed to ensure that drivers successfully navigate back to the designated detour route.

IMPLEMENTATION AND BENEFITS

The researcher and the technical review panel (listed in the Acknowledgments) for the project collaborate to craft a plan to implement the study recommendations and determine the benefits of doing so. This process is to ensure that the implementation plan is developed and approved with the participation and support of those involved with VDOT operations. The implementation plan and the accompanying benefits are provided here.

Implementation

Regarding the Recommendation, VTRC will provide two additional detour performance analyses within 6 months of the publication of this report. The analysis will focus on route choice and traffic diversion during the incidents at I-81 southbound at MM 223.8 on January 28, 2026, and I-81 southbound at MM 223 on January 30, 2026, as well as the work zone closure from March 14 to 15, 2026. The O-D data are expected to become available in May 2026 for the two incidents and in July for the work zone detour.

Regarding the Recommendation, within 1 year of the publication of this report, the Staunton District Traffic Operations Director will organize a technical meeting with relevant *stakeholders to review detour operations procedures and processes*. The meeting will focus on optimizing detour operations using the emergency routing signs. Topics to be discussed may include detour activation processes, the messaging and placement of CMSs, and the strategic locations of permanent detour signs, strategies to encourage driver compliance.

Benefits

The pilot deployment of permanent emergency routing signs has yielded substantial benefits in terms of both technical efficiency and economic value. These benefits are categorized into quantifiable user delay savings and improvements that enhance VDOT's incident management practices.

Quantifiable Economic Benefits

The implementation of the permanent detour signs significantly reduced the latency between incident verification and detour activation. By reducing the activation latency from 70 to 10 minutes, the system significantly mitigated the compounding effects of traffic congestion. This section quantifies the economic and operational benefits resulting from this 60-minute reduction, using deterministic queuing theory and value-of-time metrics.

It is important to note that this analysis is based on specific parameters and observed behaviors from Case Study 1. Consequently, these findings represent planning-level estimates and do not represent actual values for every incident. To ensure consistency, the following assumptions and data sources derived from Case Study 1 were used:

- Traffic demand (D), supply (S), and truck percentages were derived directly from traffic detectors.
- The analysis utilized the diversion rate observed during the first hour of the case study incident.

Travel times on Rt. 262 were modeled based on the case study, which recorded a baseline of 15 minutes from detour initiation until 45 minutes into the detour, subsequently increasing to 20 minutes by the end of the first hour.

The primary operational benefit was the reduction in the physical and numerical scale of the mainline queue. Using traffic volumes from Case Study 1, where the demand (D) was 1,918 vehicles per hour (vph) and a restricted incident-site supply (S) of 866 vph, the queue accumulated at an initial rate of 1,052 vph.

Mainline Queue Reduction

Assume the activation allows 28% of the approaching volume to take the detour starting at the 10-minute mark. By the end of the first hour, the comparative impact on the mainline queue is as follows in Table 5:

Table 5. Comparison of Estimated Before and After Queue Length[a]

Metric (at t = 60 min)	Before (70-Minute Latency)	After (10-Minute Latency)	Reduction
Queued Vehicles	1,052 vehicles	604 vehicles	**448 vehicles (43%)**
Queue Length (Miles)	2.63 miles	1.51 miles	**1.12 miles**

[a] Assumes the jam density is 200 vehicles per lane-mile.

Economic Benefit for Informed Travelers

The economic benefit is calculated for the 28% of motorists who successfully diverted at the 10-minute mark. To reflect the significant freight presence on the corridor, a weighted value-of-time is applied based on a traffic composition of 76% passenger cars and 24% heavy vehicles using value-of-time values calculated with the methodology in a previous VTRC study (Lan et al, 2021):

$$VOT_{weighted} = 76\% \times \$40.89\ (Car) + 24\% \times \$73.5(Truck)0 = \$48.72\ /\ hour$$

The calculation of the avoided delay uses deterministic queuing theory to compare the time spent in the mainline queue with that on the detour route. The avoided delay of 0.81 hours is derived as follows:

1. The wait time $W(t)$ for a vehicle arriving at time t is the current queue length divided by the service rate: $W(t) = \frac{(D-S)\times t}{S}$
2. Calculate boundary delays:

    - The delay of a vehicle arriving at the start of the new activation (10 minutes):
    $$W(0.167) = \frac{1052 \times 0.167}{866} \approx 0.2\ hours$$
    - The delay of a vehicle arriving at the end of the 1-hour window:
    $$W(1.167) = \frac{1052 \times 1.167}{866} \approx 1.42\ hours$$

3. Assume arrivals are uniform, the average delay avoided by the detour group is the mean of the boundary delays, which equals 0.81 hours

The direct economic benefit is determined by subtracting the additional detour travel times from the 0.81-hour avoided queue delay. Based on Case Study 1, the additional detour time was 10 minutes for the first 45 minutes and 15 minutes for the remaining 15 minutes, resulting in a net time saving of 0.62 hours per vehicle. With a total diverted volume of 537 vehicles during the 60-minute window (calculated as 28% of the 1,918 vph demand) and applying a weighted value-of-time of $48.72 per hour, the total direct economic benefit for this incident is estimated at $16,286.

Although $16,286 represents the direct savings for the 28% who detoured via Route C, the total system benefit is substantially higher because of the relief on mainline congestion. By removing 448 vehicles from the queue, the remaining 72% of motorists who stayed on the mainline experienced faster queue dissipation, reduced stop-and-go time, and lower fuel and emissions.

Sensitivity Analysis: Effect on Compliance Rates

Because broad conclusions about the effects on driver diversion could not be developed, a sensitivity analysis was performed to evaluate how varying levels of traveler compliance influence the congestion on I-81 and the direct economic savings generated during the 60-minute improvement window. As compliance increases, the "Mainline Queue" metrics reflect the reduction in vehicles remaining on the highway, and the "Economic Benefit" reflects the total savings for those who diverted (Table 6).

Table 6. Sensitivity of Operational and Economic Metrics to Traveler Detour Rates

Detour Rate	Mainline Queue (Vehicles)	Mainline Queue (Miles)	Economic Benefit ($)
15%	812	2.03	$8,704
20%	732	1.83	$11,616
25%	652	1.63	$14,527
28% (Baseline)	604	1.51	$16,286
30%	572	1.43	$17,439
35%	492	1.23	$20,350

The analysis demonstrates a perfectly linear relationship between traveler compliance and direct economic benefits. This linearity is a direct mathematical consequence of the deterministic queuing model employed. Specifically, because the arrival rate (D) is assumed to be uniform throughout the analysis period, every unit increase in the detour compliance rate results in a proportional and constant reduction in the volume of vehicles entering the mainline queue. Because the net economic benefit is calculated as a fixed unit value ($48.72/hour multiplied by a constant of 0.62-hour time savings) per diverted vehicle, the total monetary benefit scales at a constant rate relative to the number of vehicles responding to the detour signage. In this specific case study, every 5% increase in compliance removes approximately 96 vehicles from the hourly demand, yielding an additional $2,911 in user cost savings. It is important to note that these values are demand dependent. If traffic demand is higher, the economic benefits per diverted vehicle would grow significantly as the avoided mainline delay increases exponentially. Conversely, in lower-demand scenarios, the marginal utility of the detour decreases as the baseline mainline delay becomes less severe.

Effect on Noncompliant Detour Traffic on Local Operations

Although the detour provided substantial relief to the I-81 mainline, detour traffic that did not follow the suggested detour and traversed the city of Staunton introduced significant delays to the local network. Although the official detour was active from 4 to 7 pm, the influx of self-detoured vehicles caused travel times on the alternative route via US 11 to nearly double compared with typical conditions. These residual traffic effects persisted for approximately 1 hour after the detour was lifted, finally returning to a baseline level by 7 pm (Figure 29).

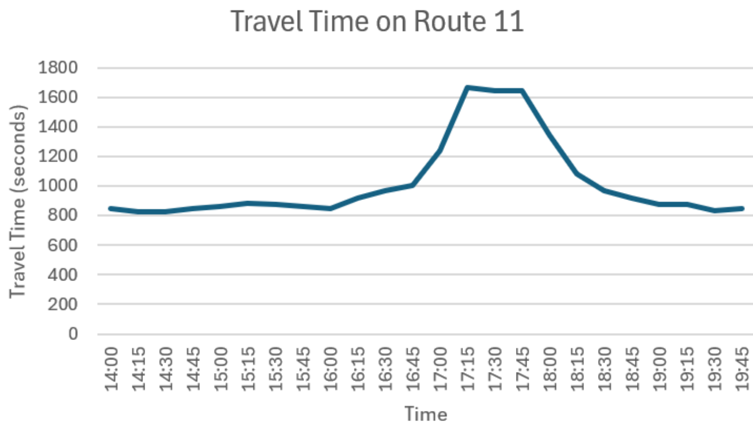


Figure 29. Observed Travel Time on Alternative Detour Route via U.S. Route 11

The estimation of local delays followed the following procedures:

1. Establish baseline: A normative travel time of 850 seconds was established for the primary alternative detour route following US 11 between I-81 Exits 225 and 220. This baseline captured the same O-D pair as the official detour (following Rt. 262) to ensure a consistent comparative framework.
2. Distribute excessive travel time: Observed increases in travel time were distributed proportionally across the segments on the alternative route via US 11, based on their individual lengths relative to the total corridor length.
3. Estimate local traffic demand: The city of Staunton local traffic demand on a normal day was represented using segment-specific annual average daily traffic and an hourly volume profile from VDOT's Pathways for Planning data around the Staunton area.
4. Temporal scope: The analysis accounted for both the active detour phase (4:00–6:00 pm) and the subsequent residual impact phase (6:00–7:00 pm). Although the official detour was lifted approximately at 6:00 pm, residual congestion persisted until the queued noncompliant vehicles cleared the local network. This recovery phase accounted for 15.7% of the total delay on local roads.
5. Monetary valuation: Local delay costs were estimated using a localized value-of-time of $41.54/hour, reflecting the 98% cars and 2% truck mix characteristics as reported in the annual average daily traffic report.

Analysis of this full period indicated a cumulative local delay of 224 vehicle-hours, representing an estimated cost of $9,309. This effect could have been substantially mitigated or reduced if noncompliant traffic had adhered to the official detour routes.

Summary of Quantifiable Benefits

The shorter detour activation time yields a 43% reduction in the total number of queued vehicles within the first hour. For a single incident on I-81 in the study area, this shorter activation time provides approximately $16,286 in direct user cost savings by diverting vehicles and preventing more than 1 mile of mainline backup, assuming the 28% compliance rate observed in Case Study 1.

The signs and installation cost nearly $74,000. Because these signs are long-term assets designed for multi-year utility, their fiscal justification is measured by the break-even frequency, the specific number of detour activations required to recoup the deployment costs through generated economic benefits.

Based on the operational metrics, the estimated economic benefit of a detour event scales directly with the traveler detour compliance rate. These benefits include reduced mainline queuing and reduced operational strain on local roads. To justify the investment, the authors calculated the number of detour activations required to achieve a zero net cost.

- At baseline (28% detour rate), the project requires 4.5 activations to fully recover the installation cost. In practical terms, the investment is fully amortized by the fifth activation.
- If the compliance rate improved to 35%, the project would be justified in 3.6 activations (the fourth use).
- If the compliance rate is less than expected at 15%, the project is still justified in 8.2 activations (the ninth use).

Furthermore, the local route through the city of Staunton (US 11) contains 12 traffic signals, so unplanned detour traffic on this corridor causes massive delays at these intersections. In contrast, the planned detour route (Rt. 262) is largely limited access with significantly higher capacity. Although Case Study 1 shows that Rt. 262 experienced a measurable increase in travel time during detour events, its high-capacity design allows it to absorb the volume without the significant increase in congestion that would otherwise cause an operational degradation across the local signalized network. Consequently, this investment will justify itself even more rapidly, likely within 1 to 2 years of operation.

Qualitative Benefits

Beyond direct economic metrics, the implementation of permanent emergency routing signage provides several critical qualitative benefits that enhance the overall resilience of incident management:

- Improved responder safety. By eliminating the need for personnel to manually deploy signage during active incidents, VDOT reduces responder exposure to traffic and hazardous conditions.
- Enhanced driver assurance. Unlike manual flip-down systems that may be inconsistently deployed, permanent signs provide continuous guidance, which could help foster motorist trust, reduce the stress associated with being detoured, and minimize the likelihood of drivers becoming lost.
- Reduced legal risk. The use of standardized, MUTCD-compliant permanent signage ensures that detour operations are legally defensible. By providing a consistently signed detour route, VDOT minimizes the risk of negligence claims stemming from inadequate temporary traffic control.

ACKNOWLEDGMENTS

The authors are grateful to the following VDOT technical review panel members for their guidance and support: Matthew Shiley, Project Champion; Roy Reid and Darin Simpson from the Staunton District; Rashmi Patel, Traffic Operations Division; and Benjamin Cottrell, VTRC. The authors also thank David Morris, Sandy Wyrick, and Neil Murray from the Staunton District, as well as Allan Yue and Simona Babiceanu from the Traffic Operations Division for sharing data and providing constructive feedback throughout the study. Recognition is also due to Ron Hobson of the Traffic Operations Division for his efforts in coordinating field data collection. Finally, the authors gratefully acknowledge Kevin Wright, VTRC Research Implementation Coordinator, and the VTRC Research Implementation Program for providing the funding necessary for the sign procurement and installation.

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