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Pilot Evaluation of the Use of Contract Towing and First Responder Strategies in the Virginia Department of Transportation's Staunton District

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I-81 in Shenandoah County was chosen for the pilots based on historical incident data and the number of incidents involving heavy vehicles with lane blockage. The purpose of the study was to evaluate before and after data to determine the effectiveness of each pilot separately. For the contract towing pilot, the evaluation analyzed lane clearance, incident duration, traffic impacts, and benefit-cost ratios. For the first responder pilot, the evaluation analyzed lane clearance, incident duration, and benefit-cost ratios. In addition, stakeholder interviews were conducted to document qualitative assessments and lessons learned.

The results indicated that contract towing operations reduced average lane clearance time, queue dissipation time, and user delay costs while increasing average incident duration and regain time. Conclusions regarding the effectiveness of the contract towing pilot could not be determined because all results were statistically insignificant because of the small sample sizes. First responder operations resulted in statistically significant reductions in average lane clearance time (10.58 minutes at $\alpha = 0.05$) and incident duration (7.75 minutes at $\alpha = 0.10$), thereby providing conclusive evidence of the effectiveness of the first responder pilot.

The study recommends that opportunities be explored to continue with the first responder program in the Staunton District and expand the program to other districts of the Virginia Department of Transportation. Opportunities should also be explored for targeted deployment of contract towing operations.

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FINAL REPORT

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ABSTRACT

This study evaluated the contract towing and first responder pilot projects in the Virginia Department of Transportation's Staunton District. The evaluation included before and after studies of incident duration and comparisons of clearance time. Both pilots were operational stimultaneously during the period from May 1 to October 31, 2016, on I-81 from mile marker 264 in Shenandoah County to mile marker 302, including the I-81/I-66 interchange in Frederick and Warren counties. The first responder initiative was also piloted within this segment of I-81 during the period from August 1 to October 31, 2015.

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INTRODUCTION

In 2016, the Virginia Transportation Research Council (VTRC) published a report by Dougald et al. titled *Traffic Incident Management Quick Clearance Guidance and Implications*.[1] The first recommendation in the report was that the Virginia Department of Transportation's (VDOT) Operations Division and regions implement one or more of the four pilot projects developed in the study:

1. towing and recovery incentive programs
2. zone-based towing
3. emergency relocation
4. rural incident response teams.

The purpose of the "pilot" designation was to help facilitate the initiation of short-term quick clearance strategies not currently used in Virginia.

The second recommendation in the report[1] was that VTRC assist in evaluating the pilot projects to include "before" and "after" studies of incident durations and clearance time comparisions. In support of the study recommendations, VDOT's Operation Division and the Statewide Traffic Incident Management (TIM) Committee authorized the intiation of two pilots for VDOT's Staunton Distict: (1) emergency relocation, and (2) rural incident response teams.

Emergency relocation (referred to as "contract towing" herein) involves contracting with towing companies within specific zones to respond immediately with appropriate equipment when dispatched and clear travel lanes by relocating crashed vehicles to a safe place off the road. The premise that this strategy can reduce incident durations is predicated on faster response times because of a dedicated single zone towing contract and faster clearance times because of the immediate dispatch of appropriate equipment. Once lanes are cleared, vehicle owners can work with the towing companies of their choice or the Virginia State Police (VSP) will use the next towing company on the VSP rotation list for recovery. Rural incident response teams (referred to as "first responders" herein) composed of trained VDOT personnel were deployed immediately 24 hours a day 7 days a week (24/7) to assist with incident command and decision-making for all incidents, including the dispatch of towers for the contract towing pilot incidents.

Both pilots were operational simultaneously during the period from May 1-October 31, 2016, on I-81 from Mile Marker (MM) 264 in Shenandoah County to MM 302, including the I-81/I-66 interchange in Frederick and Warren counties (see Figure 1). The first responder initiative was also piloted within this segment of I-81 from August 1-October 31, 2015. I-81 in Shenandoah County was chosen for the pilots based on historical incident data and the number of incidents involving heavy vehicles with lane blockage.

The contract towing pilot covered three zones that matched VSP zones: Zone 4 from MMs 302-289; Zone 5 from MMs 289-276; and Zone 6 from MMs 276-264. The contract required incident response with a minimum equipment availability of a 50-ton rotator and a supplemental availability of a rubber tire loader and a Class 8 recovery capability on an as-needed basis. The contract also required a response time of within 45 minutes to the zone affected by an incident. VDOT's Staunton District was responsible for overseeing and managing the contract towing pilot and documenting relevant incident data each time contract towing services were rendered.

The first responder pilot used trained VDOT volunteers equipped with fire and rescue pagers and a half-ton unmarked pickup truck with strobe deck lights. The pagers enabled rapid notification of incidents and prompted timely coordination with other emergency responders.

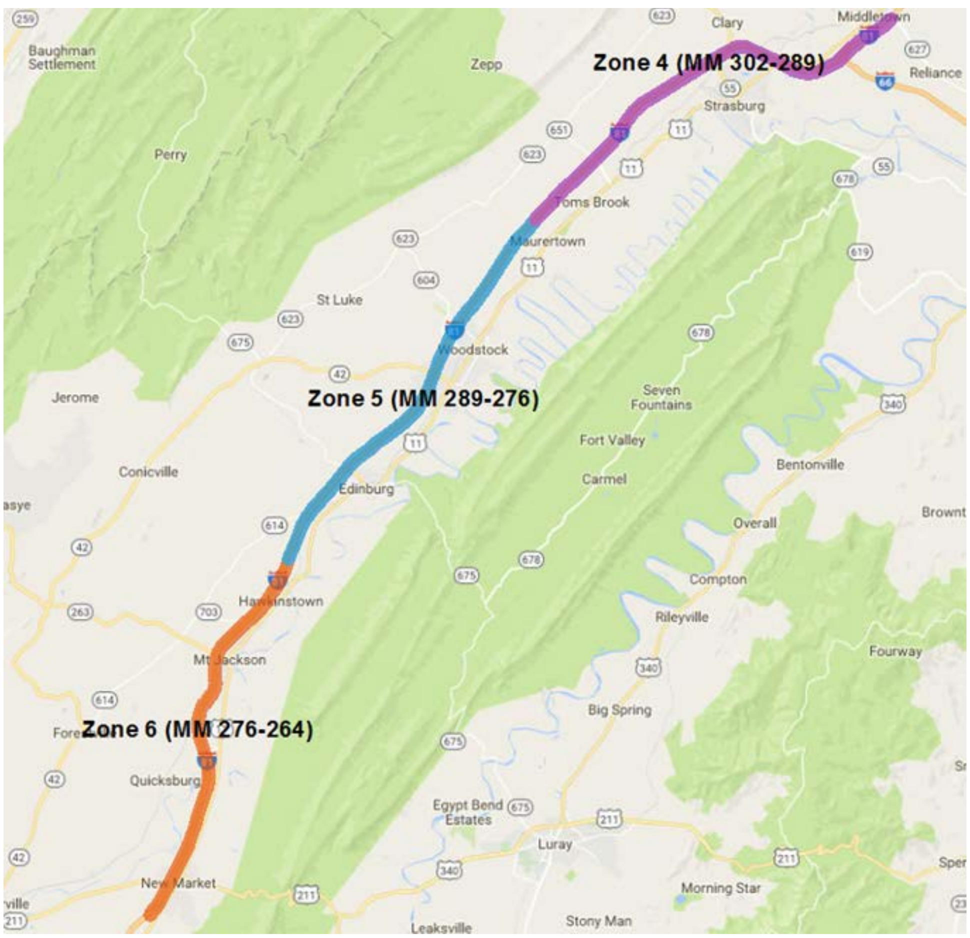


Figure 1. Location of Contract Towing and First Responder Pilots. MM = mile marker.

The on-call first responder was to be available 24/7 with the capability of reaching the interstate within 10 minutes. The primary role was to dispatch to the incident scene immediately upon notification; assess the scene and needed resources; work with other responders within the incident command structure; and initiate the contract towing based on initial alert information. The first responder was not responsible for traffic control, as this is a role for VDOT's Safety Service Patrol and/or the VDOT-managed interstate maintenance contractor.

VTRC staff worked with Staunton District staff to obtain data and information related to each pilot. This report documents a before and after evaluation to help gauge the benefits of the pilots measured in terms of reduced lane clearance times, incident durations, and traffic impacts.

PURPOSE AND SCOPE

The purpose of this study was to implement a research recommendation[1] to perform quantitative before and after analyses and cost-benefit evaluations of the Staunton District's contract towing and first responder pilots. The scope of the pilots was limited to the I-81 corridor in Shenandoah and Frederick counties from MMs 264-302. Additional spatial extents were analyzed as needed, to include queue spillbacks from the incidents. The "after period" included the actual contract towing pilot period from May 1-October 31, 2016, and the first responder pilot periods from August 1-October 31, 2015, and May 1-October 31, 2016. The before period included the same months as the after period from 2013-2015 for the contract towing pilot and from May 1-October 31 (2013-2014) and May 1-July 31, 2015, for the first responder pilot. The evaluation analyzed lane clearance, incident durations, traffic impacts, and benefit-cost (B/C) ratios. In addition, stakeholder interviews were conducted to document qualitative assessments and lessons learned.

METHODS

The following tasks were performed to achieve the study objectives:

1. Identify data sources.
2. Collect and filter incident data.
3. Develop evaluation metrics.
4. Compute and analyze evaluation metrics.
5. Document internal qualitative and quantitative assessments.

Identify Data Sources

A primary objective of the contract towing and first responder initiatives is to decrease overall incident and lane clearance durations by enhancing response and clearance protocols. It is important to note that the two pilots were not mutually exclusive, as the first responder pilot was initiated for a wide range of incidents including all contract towing–initiated incidents (primarily tractor-trailer crashes). Figure 2 shows a typical incident timeline and responder activities within five TIM categories: detection, verification, response, clearance, and recovery. The first responder pilot places emphasis on response but also engages in clearance activities such as evaluating the scene, coordinating with other responders, and summoning the contract tower (or working with VSP to summon a wrecker on the VSP towing rotation list). The contract towing pilot places emphasis on clearance but by the nature of the proximity of tower locations to towing zones and arrival time requirements, response is an important component of the pilot.

In order to develop evaluation metrics, data sources that provided information on each category in Figure 2 needed to be identified. For the purposes of this study, the primary data sources used to evaluate the before and after data were Virginia Traffic (VaTraffic) and the Regional Integrated Traffic Information System (RITIS).[2]

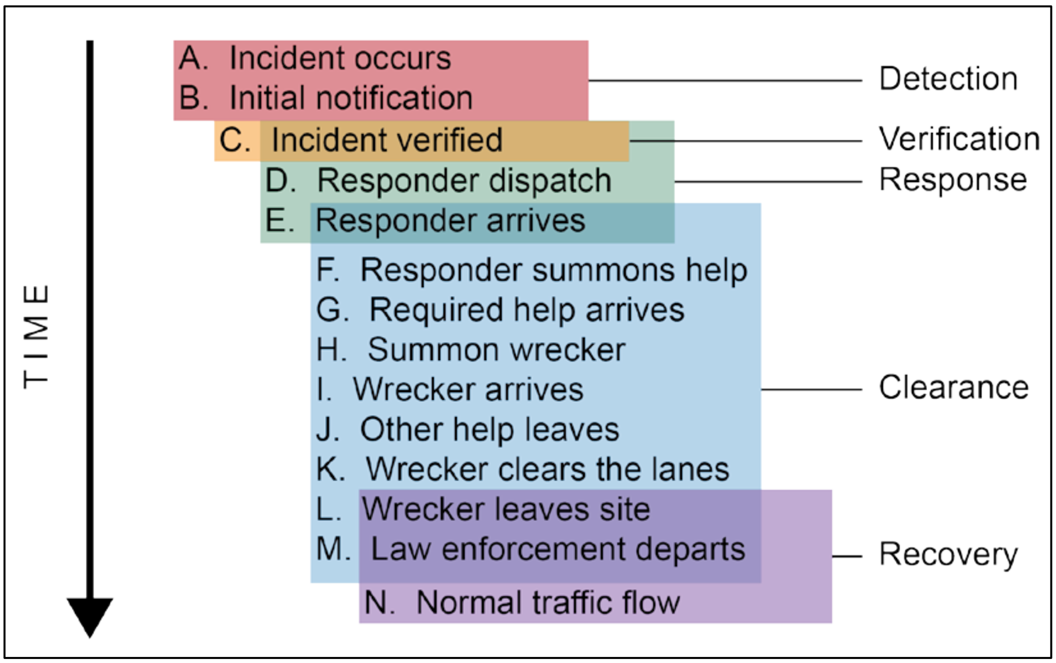


Figure 2. Traffic Incident Management Timeline

VaTraffic

To obtain information on incident detection, verification, response, and clearance times (the first four categories in Figure 2), VaTraffic data needed to be analyzed. VaTraffic is a web-based data management and reporting system into which all known abnormal road and traffic conditions are entered and fed to VDOT's 511 system. All road closures, whether work zones, incidents, or emergency closures because of weather, are reported in VaTraffic by the traffic operations centers (TOCs), district staff, and contractors. For incidents, VaTraffic text logs contain detailed event information such as type, severity, location, lane closures, and approximate traffic queue lengths. The logs also contain timestamps for incident start, verified, cleared, and closed times; lane openings and closures; and responder arrival times. All of these data were used for evaluating incidents in the before and after pilot periods.

RITIS

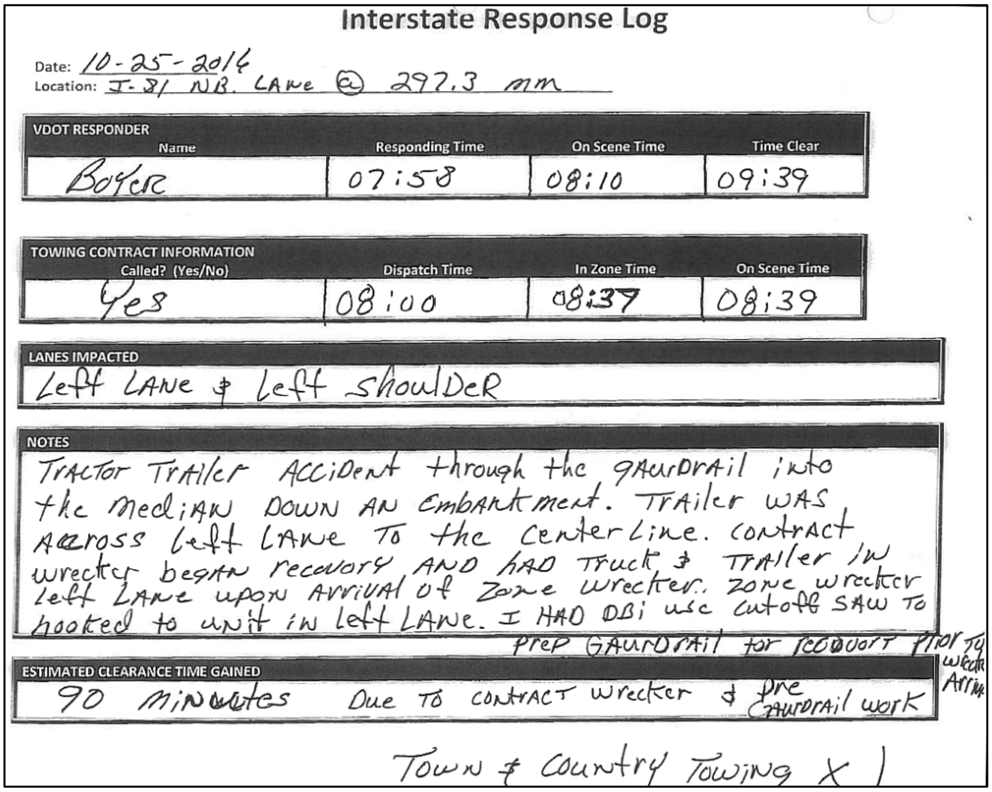
To obtain roadway recovery information (last category in Figure 2), traffic data including average travel speed and traffic volumes needed to be analyzed. VDOT procures 1-minute, Traffic Message Channel (TMC)–based average travel speeds from INRIX for the entire state. TMC is the industry standard spatial unit in which INRIX provides speeds (further details on TMC nomenclature are provided in *I-95 Vehicle Probe Project II INRIX Interface Guide*[3]). These data were available from RITIS Vehicle Probe Project (VPP) Suite (VPP is now called the Probe Data Analytics Suite) for each TMC of interest on I-81 in the project area in 15-minute average intervals. There is a total of 26 TMCs each in the northbound and southbound directions in the study area, as indicated in Table 1. RITIS VPP Suite also provides a platform for obtaining delay costs based on travel speeds, average annual daily traffic (AADT), truck and passenger vehicle percentages, and hourly cost rates for trucks and passenger vehicles. This feature allows for an analysis of the monetary implications of time to recovery.

Table 1. TMCs in I-81 Northbound and Southbound Travel Lanes of Project Area

Direction	Tmc	Intersection	Length (Miles)		Direction	Tmc	Intersection	Length (Miles)
Northbound	110+05363	US-11/VA-259/EXIT 257	6.18		Southbound	110-05375	VA-277/EXIT 307	2.53
	110P05363	US-11/VA-259/EXIT 257	0.45			110N05375	VA-277/EXIT 307	0.53
	110+05364	VA-211/EXIT 264	6.49			110-05374	VA-627/EXIT 302	4.25
	110P05364	VA-211/EXIT 264	0.49			110N05374	VA-627/EXIT 302	0.34
	110+05365	VA-730/EXIT 269	3.73			110-05373	I-66/EXIT 300	1.57
	110P05365	VA-730/EXIT 269	0.38			110N05373	I-66/EXIT 300	0.49
	110+05366	VA-703/EXIT 273	4.04			110-05372	US-11/EXIT 298	1.56
	110P05366	VA-703/EXIT 273	0.48			110N05372	US-11/EXIT 298	0.47
	110+05367	VA-614/EXIT 277	3.44			110-05371	VA-55/EXIT 296	1.16
	110P05367	VA-614/EXIT 277	0.22			110N05371	VA-55/EXIT 296	0.58
	110+05368	VA-675/EXIT 279	1.49			110-05370	VA-651/EXIT 291	4.76
	110P05368	VA-675/EXIT 279	0.62			110N05370	VA-651/EXIT 291	0.5
	110+05369	VA-42/EXIT 283	3.47			110-05369	VA-42/EXIT 283	7.68
	110P05369	VA-42/EXIT 283	0.42			110N05369	VA-42/EXIT 283	0.44
	110+05370	VA-651/EXIT 291	7.69			110-05368	VA-675/EXIT 279	3.56
	110P05370	VA-651/EXIT 291	0.46			110N05368	VA-675/EXIT 279	0.5
	110+05371	VA-55/EXIT 296	4.66			110-05367	VA-614/EXIT 277	1.53
	110P05371	VA-55/EXIT 296	0.46			110N05367	VA-614/EXIT 277	0.26
	110+05372	US-11/EXIT 298	1.3			110-05366	VA-703/EXIT 273	3.33
	110P05372	US-11/EXIT 298	0.46			110N05366	VA-703/EXIT 273	0.52
	110+05373	I-66/EXIT 300	1.7			110-05365	VA-730/EXIT 269	4.12
	110P05373	I-66/EXIT 300	0.77			110N05365	VA-730/EXIT 269	0.37
	110+05374	VA-627/EXIT 302	1.23			110-05364	VA-211/EXIT 264	3.73
	110P05374	VA-627/EXIT 302	0.33			110N05364	VA-211/EXIT 264	0.45
	110+05375	VA-277/EXIT 307	4.29			110-05363	US-11/VA-259/EXIT 257	6.56
	110P05375	VA-277/EXIT 307	0.54			110N05363	US-11/VA-259/EXIT 257	0.46

Collect and Filter Incident Data

Staunton District staff maintained responder logs that provided incident details for all first responder activity during the 2016 pilot period. A screenshot of one of the logs is shown in Figure 3. A total of 95 incident logs were provided for analyses. The initial task was to separate the logs that involved contract towing indicated by “Yes/No” in the Towing Contract Information field in the logs. Once this was accomplished, two groups of first responder logs were created: (1) those that involved contract towing, and (2) those that involved only first responders. The information contained within the logs was then used to cross-reference data in VaTraffic. This section describes the data collection and filtering processes for each pilot evaluation in the before and after periods.



Interstate Response Log

Date: 10-25-2016
Location: I-81 NB. Lane @ 297.3 mm

VDOT RESPONDER Name	Responding Time	On Scene Time	Time Clear
Boyer	07:58	08:10	09:39

TOWING CONTRACT INFORMATION Called? (Yes/No)	Dispatch Time	In Zone Time	On Scene Time
Yes	08:00	08:37	08:39

LANES IMPACTED
Left Lane & left shoulder

NOTES
Tractor Trailer Accident through the gaurdrail into the median down an embankment. Trailer was across left lane to the centerline. contract wrecker began recovery and had truck & trailer in left lane upon arrival of zone wrecker. zone wrecker hooked to unit in left lane. I had DBi use cutoff saw to prep gaurdrail for recovery prior to wrecker arrival

ESTIMATED CLEARANCE TIME GAINED
90 minutes due to contract wrecker & pre gaurdrail work

Town & Country Towing X)

Figure 3. Example of First Responder Log

Contract Towing

First responder log information including date, location, direction, mile marker, timestamps, and incident type was cross-referenced with VaTraffic data to match incidents. Additional incident details from VaTraffic that were not captured in the logs were also documented such as responding agency information and timestamps for incident detection/verification, lane closures, roadway clearance, and incident duration. Once all responder logs and VaTraffic incidents were matched in the after period, the next step was to extract incidents from VaTraffic in the before period. For the analysis results to be meaningful, crashes in the before period were to be comparable in scope and type to crashes in the after period. To ensure this was the case, the types of before crash data extracted included the following:

- only tractor-trailer and multi-vehicle crashes
- only lane-blocking crashes
- only crashes that required wreckers.

If a travel lane was blocked at any time during the incident timeline in the VaTraffic database, that crash was deemed a lane-blocking crash.

Before Data

There was a total of 365 unique crashes in the VaTraffic database in the before period from May 1-October 31, 2013-2015; the extraction process resulted in the identification of 26 comparable crashes. All incidents were located within the pilot zone of MMs 264-302. Upon further analysis of the data, 5 incidents had occurred in the overnight period with very little traffic impact; therefore, these incidents were removed to limit statistical skew. The resulting dataset included 21 incidents, of which 17 were tractor-trailer crashes and 4 were multi-vehicle crashes. The incident-related details obtained from VaTraffic for the 21 crashes are available from the authors.

After Data

Filtering the first responder logs for contract towing calls during the pilot period from May 1-October 31, 2016, resulted in 27 records. Of those 27, there were 10 records where contract towing was called but not used and 1 record where contract towing was used but the incident was located on the Route 55 ramp. These 11 records were removed, leaving 16 incidents for which contract towing was initiated and used. Of those 16 incidents, 2 northbound incidents on September 19, 2016, were very close in time (3:29 P.M. and 3:41 P.M.) and space (MMs 289.6 and 290). The impacts of these two incidents could not be isolated, and therefore the incidents were combined and considered a single contract towing event. The total number of incidents analyzed after the data were filtered was 15 and included 2 multi-vehicle, 7 tractor-trailer, and 6 single/combination vehicle crashes. These incidents were then matched with VaTraffic data to obtain specific timestamps needed for analyses. The incident-related details obtained from VaTraffic for the 15 crashes are available from the authors.

Before and After Data Summary

Table 2 is a summary of the number and type of incidents evaluated in the before and after periods, and Table 3 shows the crash frequency by roadway direction, day of week, and time of day. The number of incidents evaluated in the before period was higher because the before period spanned 3 years whereas the after period was 6 months. Also of note is that there were no single/combination vehicle incidents in the before period and there were six in the after period. The data extraction rules as described previously for the before period included only multi-vehicle and tractor-trailer incidents where there were lane closures and wreckers used for recovery. The initial intent of the contract towing pilot was to provide a response primarily to these types of incidents; however, crash circumstances dictated the deployment of the contract towing operator for some single/combination vehicle crashes. Isolating similar types of single/combination vehicle crashes in the before period would have been challenging, as choosing incidents based on severity would have introduced an element of subjectivity.

Table 2. Number and Type of Incidents in Before and After Periods for Contract Towing Pilot Evaluation

Incident Type	Before	After	Total
Multi-vehicle	4	2	6
Tractor-trailer	17	7	24
Single/combination vehicle	0	6	6
Total	21	15	36

Table 3. Frequency of Incidents by Direction, Day of Week, and Time of Day for Contract Towing Pilot Evaluation

Period	Direction		Day of Week		Time of Day	
	NB	SB	Weekday	Weekend	6 A.M.-10 P.M.	10 P.M.-6 A.M.
Before	8	13	17	4	21	0
After	7	8	11	4	13	2

NB = northbound; SB = southbound.

First Responder Pilot

In order to evaluate the first responder pilot it needed to be treated as a separate operation from the contract towing pilot (even though the two were operationally joined). Therefore, all before and after incidents used for the contract towing evaluation were excluded from the first responder evaluation. Matching first responder incidents from logs in the after period to VaTraffic data was not possible because there were no logs maintained during the initial pilot that occurred in 2015. In addition, there were difficulties matching some incidents from logs during the pilot period in 2016 because of timestamp discrepancies. First responders were dispatched to a much larger number of incidents, and a much broader classifications of incident types added further difficulties to exact matching. Therefore, VaTraffic data were used to evaluate both the before and after data for the first responder pilot. Extraction rules were developed based on the types of incidents in the logs that involved first responder dispatch. These rules included the following:

- Only incidents with a travel lane blockage.
- Only incidents with a duration between 10 and 180 minutes. To mirror VDOT TIM Dashboard methods, all incident durations of less than 10 minutes were removed from the analysis. This reduced the probability of incorporating incidents with timestamp errors and incidents to which first responders typically are not dispatched. In addition, all incidents with a duration greater than 180 minutes were removed as these were considered outliers and would promulgate statistical skew.

Before Data

There was a total of 296 unique incidents in the VaTraffic database in the before period from May 1-October 31 (2013-2014) and May 1-July 31 (2015). Six of these incidents were analyzed as two separate events because they affected two separate travel ways: either both directions of I-81 or both ramp and mainline. The data were then filtered to remove 147 incidents that did not involve a lane blockage, 21 incidents used for the contract towing comparisons, and 4 overnight incidents that had no traffic impacts. In addition, the data were filtered to remove 13 incidents that incurred durations of less than 10 minutes and 7 that incurred durations greater than 180 minutes. The resulting dataset included 109 incidents, of which there were 2 multi-vehicle crashes, 21 tractor-trailer crashes, 81 single/combination vehicle crashes, and 5 vehicle fires.

After Data

There was a total of 244 unique incidents in the VaTraffic database in the after period from August 1-October 31 (2015) and May 1-October 31 (2016). Five of these incidents were analyzed as two separate events because they affected two separate travel ways. The data were then filtered to remove 112 incidents that were non–lane blocking, 16 contract towing incidents, 13 incidents that incurred durations of less than 10 minutes, and 4 incidents that incurred durations greater than 180 minutes. The resulting dataset included 104 incidents, of which there were 8 multi-vehicle crashes, 15 tractor-trailer crashes, 66 single/combination vehicle crashes, and 14 vehicle fires.

Before and After Data Summary

Table 4 shows the incident frequencies by incident type evaluated in the before and after periods, and Table 5 shows the incident frequencies by roadway direction, day of week, and time of day. The tables show comparable uniformity in the before and after datasets in most categories.

Table 4. Number and Type of Incidents in Before and After Periods for First Responder Pilot Evaluation

Incident Type	Before	After	Total
Multi-vehicle	2	8	10
Tractor-trailer	21	15	36
Single/combination vehicle	81	66	147
Vehicle fire	5	15	20
Total	109	104	213

Table 5. Frequency of Incidents by Direction, Day of Week, and Time of Day for First Responder Pilot Evaluation

	Direction		Day of Week		Time of Day	
Period	NB	SB	Weekday	Weekend	6 A.M.-10 P.M.	10 P.M.-6 A.M.
Before	57	52	66	43	95	14
After	54	50	67	37	87	17

NB = northbound; SB = southbound.

Development of Evaluation Metrics

To analyze the effectiveness of each pilot, evaluation measures needed to be developed for before-after comparisons. Five categories of measures were considered based on available data from VaTraffic and RITIS: (1) lane clearance time, (2) incident duration, (3) regain time, (4) queue dissipation time, and (5) user delay costs. Incident response time is an important component of the pilots and is defined as the time interval from first notification to arrival on scene. However, because of the lack of available response time data in the before period, comparisons could not be made with the after period. Incident duration time does encompass response time and, therefore, is implicitly captured in the data comparisons.

Lane Clearance Time

Lane clearance time (similar to the "roadway clearance time" measure in the literature[1]) is defined as the time interval from the first timestamp when any lane is closed to the time all travel lanes are declared open. VaTraffic data were used to obtain this measure for both pilot evaluations. Roadway clearance time[1] is defined as "the time between the first recordable awareness of an incident (detection, notification, or verification) by a responding agency and the first confirmation that all lanes are available for traffic flow." This standard definition does not properly account for lane closures if the crashed vehicles are off the road but their recovery requires lane closures.

For the contract towing pilot, vehicles were cleared from the road and moved to shoulders or medians; therefore, the timestamp when travel lanes were open is of significance for this measure. A query was performed to extract VaTraffic lane closure details for each of the 21 incidents in the before period and the 15 incidents in the after period.

For the first responder pilot, a similar query was performed for each of the 109 incidents evaluated in the before period and the 104 incidents evaluated in the after period. An example of lane closure detail in VaTraffic is shown in Figure 4. From this example, North Normal #1 (only "normal" lane type was of interest for this study, and not shoulders) was closed at 08:02 and reopened at 09:36; therefore, lane clearance time was calculated as 94 minutes. The next step involved developing a Python script to calculate lane clearance time for all the incidents. The coding for the Python script is provided in Appendix A.

```
Lane Closures:
North Shoulder  #0; Closed 10/25/2016 08:02
North Normal    #1; Closed 10/25/2016 08:02
North Normal    #2; Open 10/25/2016 08:02
North Shoulder  #3; Open 10/25/2016 08:02
South Shoulder  #4; Open 10/25/2016 08:02
South Normal    #5; Open 10/25/2016 08:02
South Normal    #6; Open 10/25/2016 08:02
South Shoulder  #7; Open 10/25/2016 08:02
North Shoulder  #0; Open 10/25/2016 09:36
North Normal    #1; Open 10/25/2016 09:36
North Normal    #2; Open 10/25/2016 09:36
North Shoulder  #3; Open 10/25/2016 09:36
South Shoulder  #4; Open 10/25/2016 09:36
South Normal    #5; Open 10/25/2016 09:36
South Normal    #6; Open 10/25/2016 09:36
South Shoulder  #7; Open 10/25/2016 09:36
```

Figure 4. Screenshot of VaTraffic Lane Closure Detail

Incident Duration

Incident duration (sometimes referred to as incident clearance time[1]) is defined as the time from first notification to the time the last responder leaves the scene (often the VSP). VaTraffic data were used to obtain this measure for both pilot evaluations by obtaining the difference between the "Verified Date/Time" timestamp and the "Cleared Date/Time" timestamp for each incident.

For the contract towing pilot, incident duration includes the additional time required for the VSP-dispatched rotational towers to recover relocated vehicles completely. Because the responder logs were able to be matched with incidents in VaTraffic, the calculation of this measure was performed using the extracted data for the 21 incidents in the before period and the 15 incidents in the after period.

For the first responder pilot, a query was performed to extract VaTraffic incident summary details for each of the 109 incidents evaluated in the before period and the 103 incidents evaluated in the after period. An example of a VaTraffic incident summary detail is shown in Figure 5. The next step involved calculating incident duration using MS Excel.

```
----------------
VaTraffic_INNW3086978-10252016
Shenandoah (County) - I-81N - 297.3 - North - the ramp from Rt. 55 - Traffic - Tractor Trailer Accident - 10/25/16
511 Text:On I-81 North at mile marker 297.3 in the County of Shenandoah, motorists can expect potential delays due to a
tractor trailer accident.;
Event Type:Incident
Event SubType:Tractor Trailer Accident

Detection Source:SSP
Start Date/Time:10/25/2016 08:02
Verified Date/Time:10/25/2016 08:02
Cleared Date/Time:10/25/2016 09:36
Closed Date/Time:10/25/2016 10:13
District: Staunton
Jurisdiction:Shenandoah (County)
Physical Jurisdiction:Shenandoah (County)
Region:Northwestern Region
Road Name:
Route Number:I-81N
Direction:North
Milemarkers:297.3-297.3
Start lat/long:39.01432,-78.350872
End lat/long:39.01432,-78.350872
Total lanes:8
Lanes affected:0
Special facility name:
Bridge tunnel name:
Cross roads:the ramp from Rt. 55-the ramp from Rt. 55
Nearest Intersection:the ramp from Rt. 55
Road condition:
Delay Type:Potential (Unknown)
Severity level:Level III
Priority description:
Queue miles:0

Updates:
--
10:13 -- Per DBi the back up has cleared.
10:10 -- Per Google map that back up is at 3 miles.
09:36 -- Per DBi, the scene is clear.
09:35 -- Per DBi, 6 mile back up.
09:12 -- Per R Getz the tractor trailer has been recovered.
09:07 -- Per DBi, two rotators are on scene.
09:06 -- Per DBi, 4 mile back up
08:55 -- Per J Boyer wrecker is on location.
08:49 -- Per DBi, 3 mile back up.
08:32 -- Per R Getz the tanker is empty, zone wrecker is responding.
08:24 -- Accident is within the I-81 NB MM 297.2 right shoulder workzone. Per Brian wtih Landford Brothers, personal and
equipment within the workzone is not effected.
08:19 -- VDOT J Boyer on location.
```

Figure 5. Screenshot of VaTraffic Incident Summary Detail

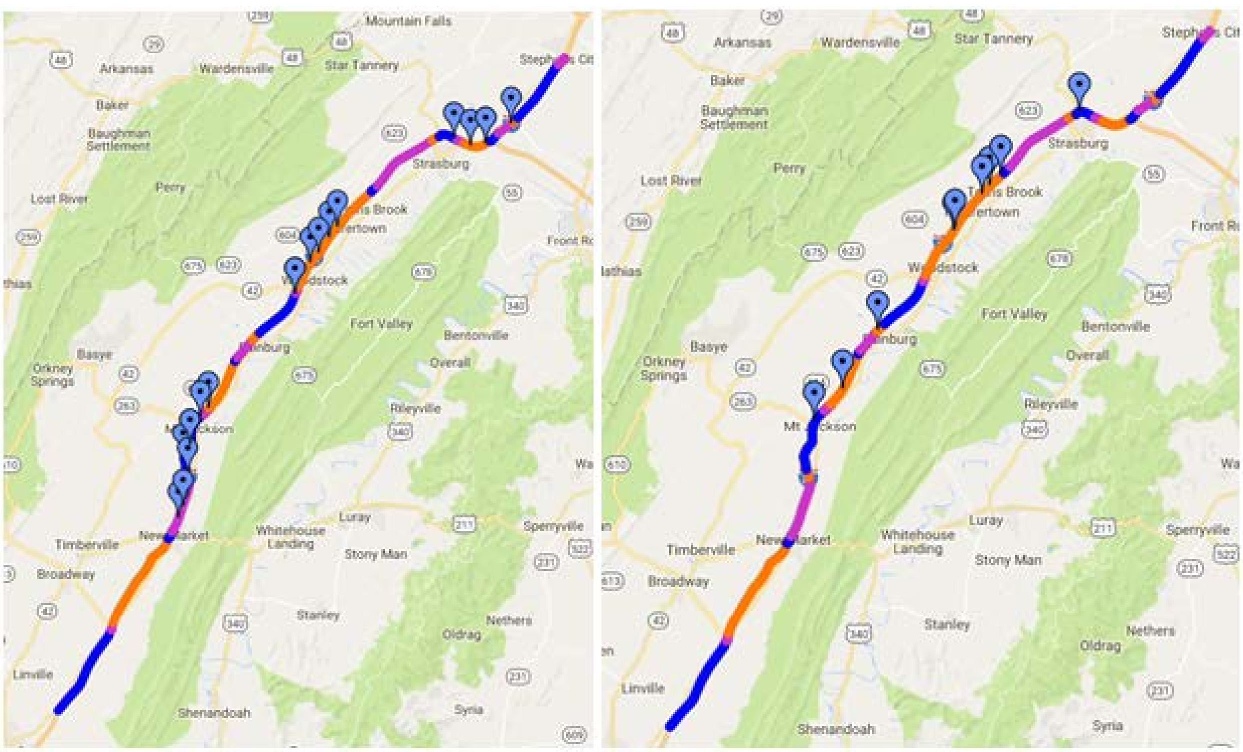
Regain Time, Queue Dissipation Time, and User Delay Costs

Because of the quicker lane clearance objective of contract towing, an analysis of traffic impacts was deemed prudent for this pilot. To accomplish this, regain time, queue dissipation time, and user delay costs were evaluated; each measure is discussed in this section. RITIS VPP Suite, Microsoft Excel, Python programming language, and Tableau were the main tools used for the analyses. These performance metrics were not evaluated for the first responder pilot because the tools currently available can analyze only one incident at a time and are inadequate for analyzing hundreds of incidents. In addition, first responders were dispatched to a much broader classification of incidents with varying levels of traffic impacts.

Regain Time

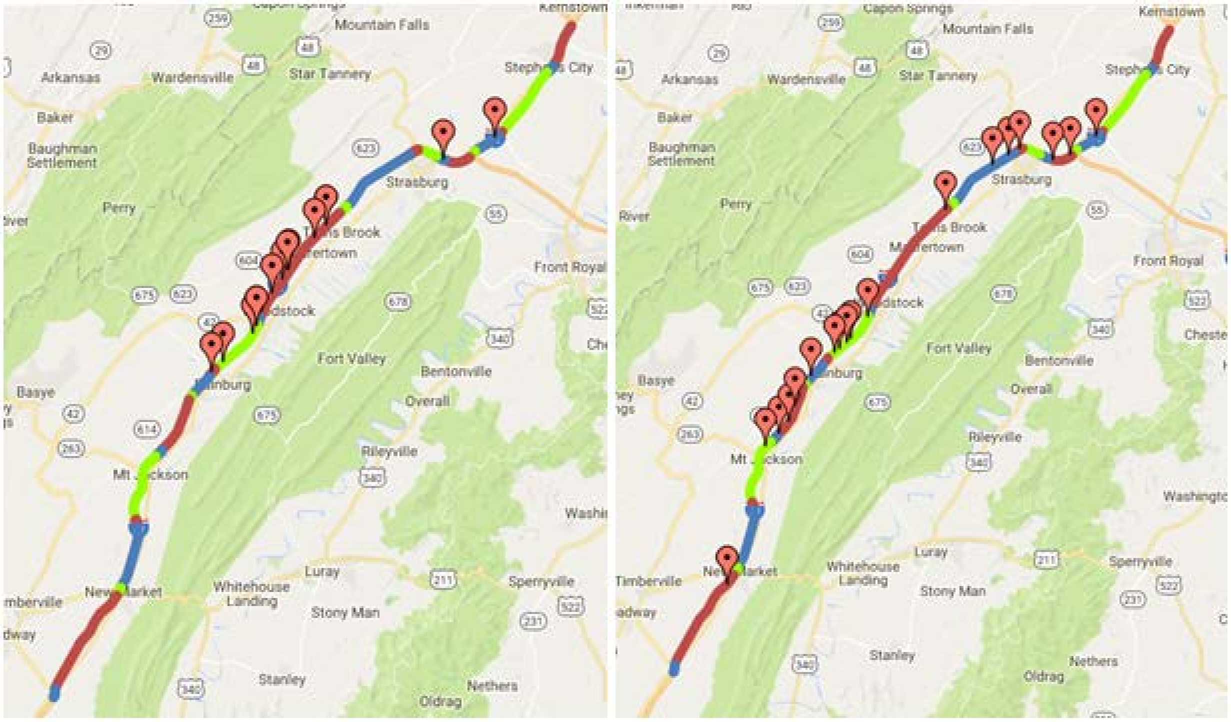
Regain time is defined as the elapsed time from first notification of an incident to traffic speeds returning to normal at the location of the incident. Theoretically, this measure is directly correlated with lane clearance times because once travel lanes are open, the elapsed time to regain normal travel speed at the incident location should be minimal. However, because contract towing does not fully remove the incident from the scene, the measure may not be directly associated with lane clearance times because vehicles relocated to shoulders or medians may still have an effect on motorist speed because of the gawking or "rubbernecking" effect. Therefore, regain time is considered to be directly correlated with incident duration as opposed to lane clearance.

To obtain regain time, the initial tasks were to plot all before and after incidents on a map using latitude/longitude data and then superimpose the TMC line segments to identify the TMC at which each incident occurred (Figures 6 and 7 show northbound and southbound plots, respectively). Using data from RITIS, average 15-minute speeds were then calculated for each TMC by year, day of week, and season to obtain typical or normal traffic speeds (i.e., baseline speeds).



(a) **(b)**

Figure 6. Northbound Incident Plots in (a) Before Period and (b) After Period



(a) **(b)**

Figure 7. Southbound Incidents in (a) Before Period and (b) After Period

Day of week was separated into five groups based on the typical travel days of Monday, Tuesday-Thursday, Friday, Saturday, and Sunday. The months of May-August and September-October were grouped together as summer and fall seasons, respectively. Concurrently, the average 15-minute speed for each TMC was calculated for each incident date, allowing baseline and incident speeds to be compared. When the speed at an incident site recovered to within 5 mph of the baseline speed over a 15-minute interval, normal operations were considered to be regained.[4,5]

Tableau tools were used as a platform to help visualize and analyze temporal and spatial speed characteristics within each TMC. As an example, Figure 8 shows 15-minute speed profiles of an incident for which contract towing was dispatched that occurred on October 25, 2016. The incident occurred in the northbound lanes at approximately 8 A.M. within TMC 110+05732. The traffic impacts of the incident (measured in terms of speed reduction) propagated upstream approximately 6 miles into TMC 110P05370. Based on the speed profile of this particular day, regain time appeared to occur at approximately 10:30 A.M.

The next step was to develop normal speed profiles to identify day-to-day traffic anomalies (i.e., recurring congestion) and compare them to the incident day traffic speeds. To obtain normal traffic speeds, speed data were averaged over a particular year, season, and day of the week.

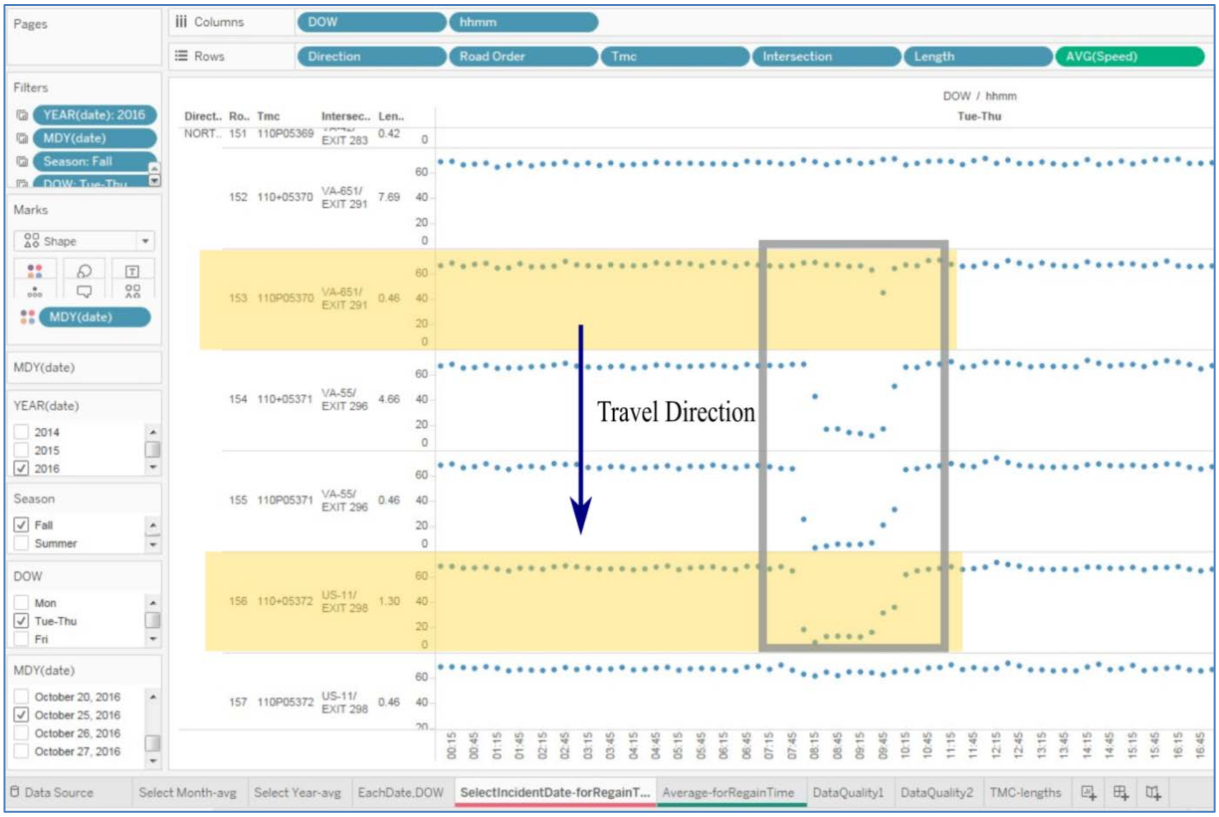


Figure 8. Tableau Speed Profile Screenshot of Incident on October 25, 2016

For example, Figure 9 shows the normal speed profiles to which the October 25 incident day was compared. The leftmost column shows that the year (2016), season (fall), and day of week (Tuesday-Thursday) were all selected; thus, within each 15-minute bin, speeds were averaged over all Tuesdays through Thursdays during the fall months of September and October 2016. Both the incident day and normal speed data were then exported to Excel and programmed to output differences greater than negative 5 mph (subtracting normal speeds from incident day speeds) for each TMC and 15-minute time bin.

Figure 10 shows the resulting spreadsheet used for the analysis of regain time. All blank cells in the figure are positive speed differences; all cells shaded yellow are speed differences greater than −5 mph. The particular incident shown occurred at 8:02 A.M. and was cleared at 9:36 AM. Therefore, the incident duration was 94 minutes. Traffic resumed to normal flow in the TMC at 10:30 AM. Therefore, the regain time for this incident was 148 minutes. As discussed earlier, the queue backed up approximately 6 miles to TMC 110P05370 and is shown in the uppermost cell shaded yellow.

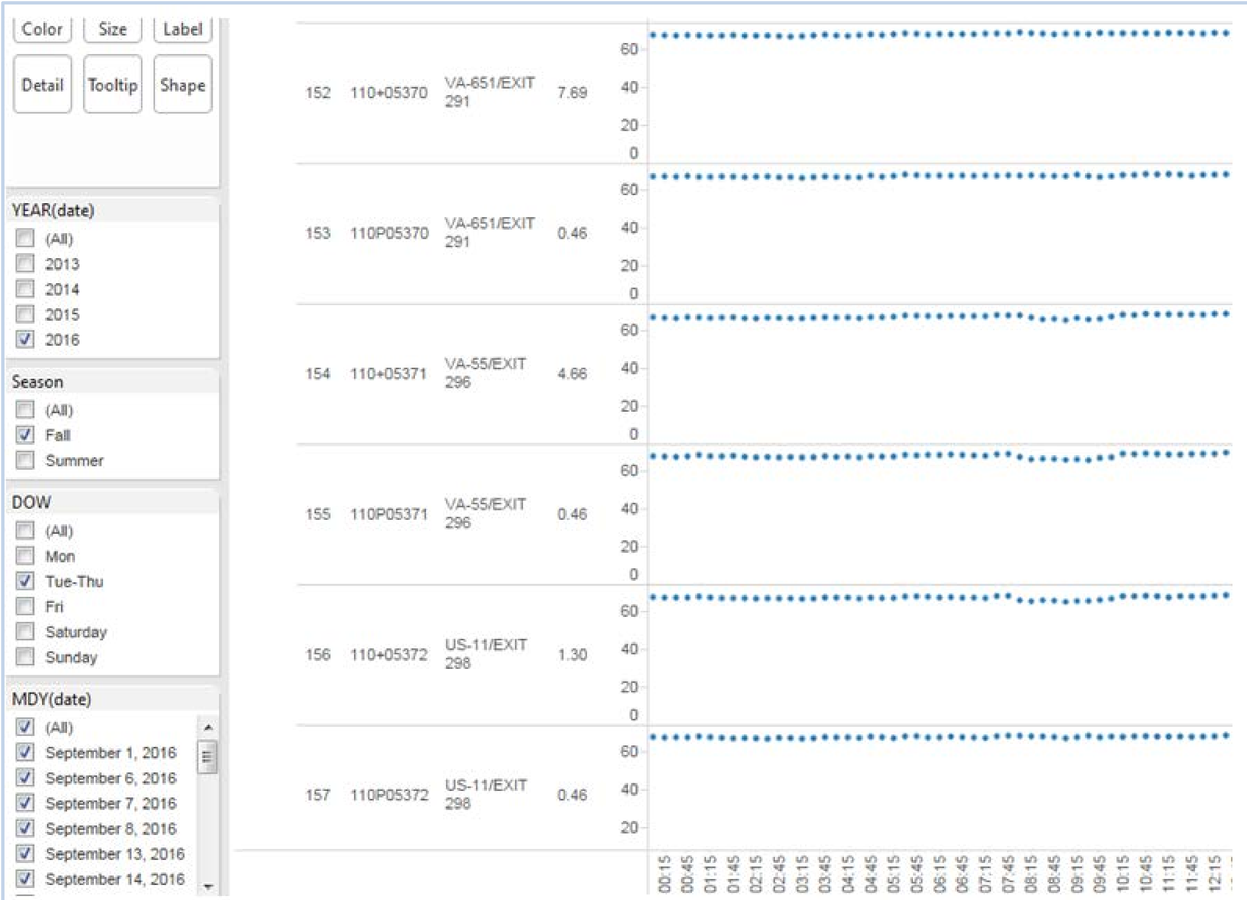


Figure 9. Tableau Screenshot of Normal Speed Profiles Used for October 25, 2016, Incident Comparison

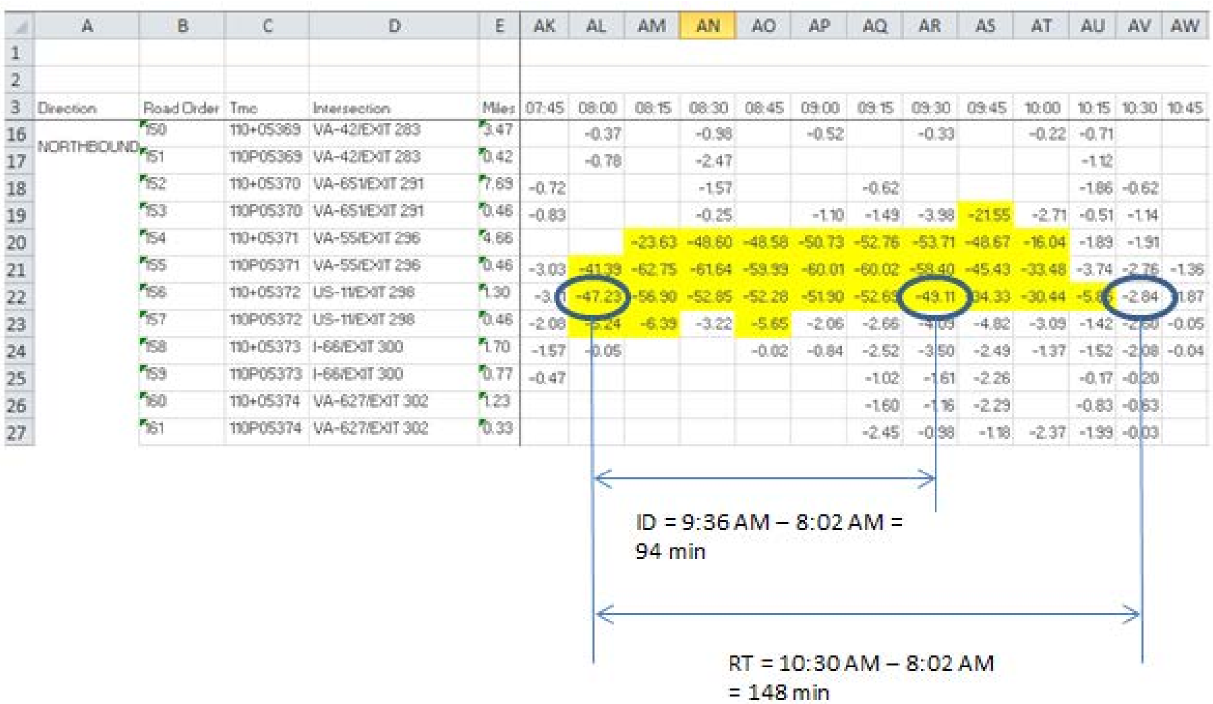


Figure 10. Speed Data Spreadsheet Used to Evaluate Regain Time. ID = incident duration; RT = regain time.

Queue Dissipation Time

Queue dissipation time is defined as the elapsed time from the end of an incident (end timestamp of incident duration) to normal traffic flow across all affected, upstream TMCs. This measure can be considered a surrogate for queue length in miles and duration, as the pilot corridor is homogeneous in the number of lanes, access, and alternate detour routes. As with regain time, queue dissipation time is directly correlated with traffic volume and motorist delay. With contract towing operations, the hypothesis is that the faster the lanes are opened, the shorter the queue length and motorist delay.

In the case of the October 25 incident, the difference in regain time (10:30 A.M.) and the incident end time (9:36 A.M.) resulted in a queue dissipation time of 54 minutes. In some cases, upstream TMCs do not regain normal traffic speeds until after the regain time at the incident location. This typically occurs when there is a transition in traffic volumes during the incident period such as mid-day volumes to peak period volumes. Figure 11 shows the case of an incident that occurred at 3:36 P.M. and ended at 4:30 P.M. on September 12, 2016. The regain time at the incident site occurred at 5:45 P.M.; however, because of the additional traffic demand at that time of day, the queues extended to TMC 110-05370 and the regain time of that TMC occurred at 6:15 P.M. Therefore, the difference in regain time of the upstream TMC (6:15 P.M.) and the end time of the incident (4:30 P.M.) resulted in a queue dissipation time of 105 minutes.

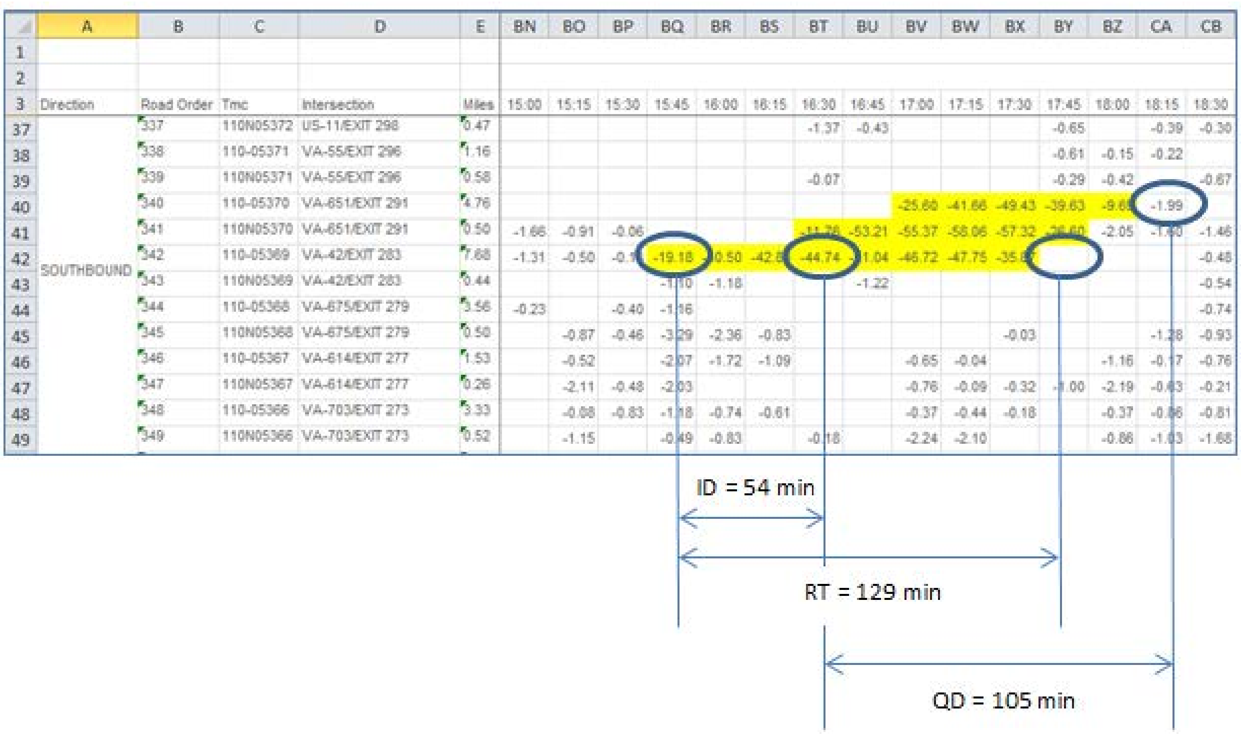


Figure 11. Speed Data Spreadsheet Used to Evaluate Queue Dissipation Time. ID = incident duration; RT = regain time; QD = queue dissipation.

User Delay Costs

RITIS VPP Suite was used to calculate user delay costs. User delay costs are measured by monetizing incident-related motorist traffic delays in the before period compared to the after period, using value of time. RITIS incorporates INRIX speed data; average hourly costs for passenger and commercial vehicles ($16.79 for passenger vehicles and $86.81 for commercial vehicles)[6]; VDOT traffic volume data; and the ratio of passenger vehicles to trucks along the pilot corridor (77 percent passenger vehicles and 23 percent trucks).[7] Any speed below the free flow speed was considered congested for delay calculations. Median user delay costs for season (summer and fall), time of day, day of week, and location extents were calculated for each incident and considered the baseline. (Median values were used because, unlike average values, they are less likely to be skewed by extreme incident events and planned events such as work zones.) The total incident delay cost was then calculated by subtracting the baseline user delay costs from the user delay costs incurred during the specific crash. A Python script (shown in Appendix B) was developed to calculate median delay and associated costs by inputting the Excel files used in the analyses for obtaining regain time as well as files that incorporated the starting and ending hour of analysis for each incident.

Figure 12 shows the RITIS output for user delay costs for a subset of days in September 2016. For the incident on September 12 (described in the previous section), the incident occurred at 3:36 P.M. and the queue dissipated at 6:15 P.M.; therefore, the dollar amounts in Table 6 from 3 P.M. to 7 P.M. were added together to obtain total user delay costs for that particular incident. In this case, the user delay costs totaled $52,021.

	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM
9/01/16	$1	$0	$0	$0	$1	$1	$1	$0
9/02/16	$0	$1	$0	$1	$0	$133	$1	$0
9/03/16	$0	$2	$1	$22	$0	$0	$12	$33
9/04/16	$3	$1	$37	$5	$0	$2	$0	$18
9/05/16	$2	$0	$42	$9	$22	$15	$6	$1
9/06/16	$0	$0	$0	$1	$6	$0	$1	$7
9/07/16	$2	$8	$0	$0	$0	$185	$7	$21
9/08/16	$1	$2	$1	$1	$0	$4	$6	$21
9/09/16	$2	$0	$29	$10	$1	$0	$2	$15
9/10/16	$1	$16	$9	$1	$5	$39	$2	$4
9/11/16	$1	$0	$25	$3	$2	$0	$1	$16
9/12/16	$1	$0	$0	$550	$23,134	$28,220	$117	$7
9/13/16	$0	$1	$0	$0	$19	$5	$0	$3
9/14/16	$0	$0	$0	$1	$0	$0	$6	$0
9/15/16	$1	$1	$0	$0	$0	$0	$0	$28
9/16/16	$5	$0	$18	$0	$0	$1	$0	$1
9/17/16	$8	$18	$14	$0	$34	$1	$2	$12
9/18/16	$0	$18	$2	$1	$6,159	$28,920	$333	$1
9/19/16	$1	$1	$0	$2	$1	$0	$0	$5

Figure 12. RITIS Output for User Delay Costs of Incident on September 12, 2016

Summary of Computation and Analysis of Evaluation Metrics

A summary of the evaluation measures for each pilot is shown in Table 6. The aggressive lane clearance function for larger incidents with contract towing was the impetus to evaluate traffic impact measures. First responders were dispatched to a higher number and broader mix of incident types where traffic impact measures in the before and after periods would be difficult to compute.

Prior to the calculation of each metric, traffic volumes were downloaded from the nine VDOT continuous count stations in the project area (where data were available) for all the time periods of interest in order to analyze the traffic volume changes over the before and after pilot years. Changes in traffic volumes would affect the traffic impact measures used for the contract towing evaluation. Figure 13 shows the daily traffic volumes from May 2013-October 2016 for links within the corridor. Although there are fluctuations, the volumes over the study period remain similar.

Table 6. Summary of Evaluation Metrics for Each Pilot

Metric	Contract Towing	First Responder
Incident duration	✓	✓
Lane clearance time	✓	✓
Regain time	✓	
Queue dissipation time	✓	
User delay costs	✓	

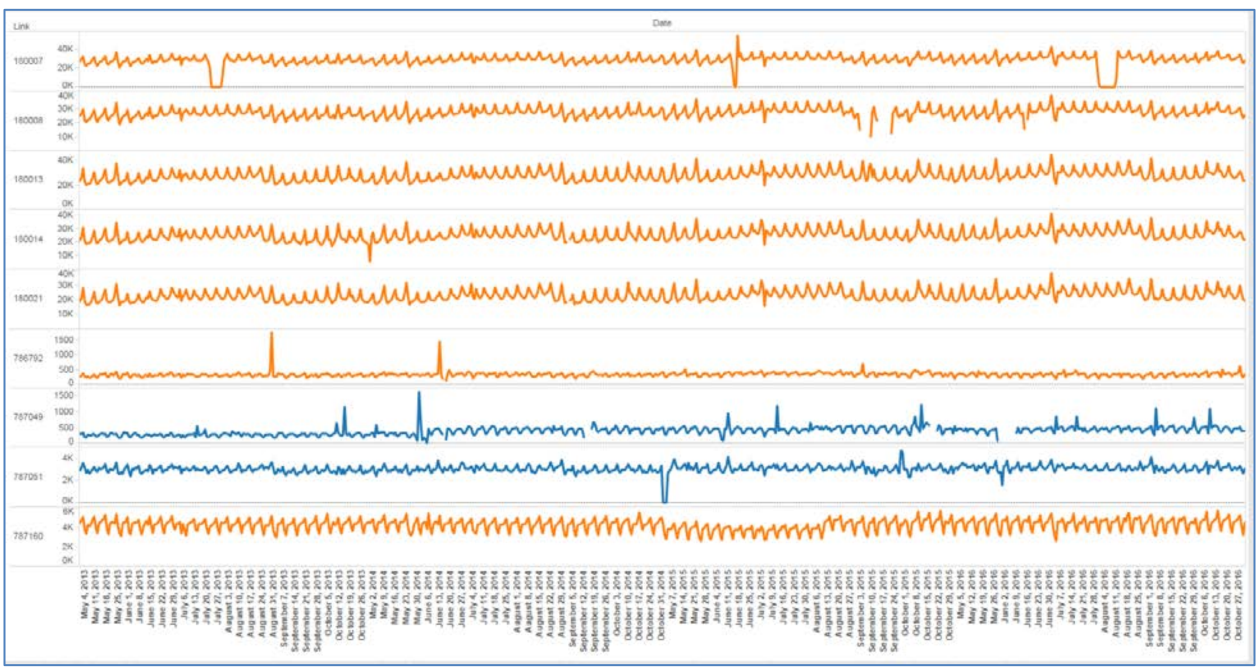


Figure 13. Daily Traffic Volumes Along Project Corridor From May 2013-October 2016

For all the performance metrics analyzed in each pilot, independent samples pooled *t*-tests[8] were performed assuming unequal variance using the following equation where the degrees of freedom are taken as the smaller of $n_1 - 1$ and $n_2 - 1$:

$$E = t_{\propto/2}\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}$$

where

E = confidence interval
t = cumulative probability under the T distribution
$\alpha = 0.05$, level of significance at the 95 percent confidence interval
s_1 = standard deviation of before data
s_2 = standard deviation of after data
n_1 = number of observations in the before period
n_2 = number of observations in the after period.

In addition, because individual crashes in the before and after periods varied significantly in scope and severity, and aggregate crash statistics provide only one point of reference, cumulative distribution functions were developed for each metric In all graphs, the blue curve represents the before period and the red curve represents the after period. The slope of the line indicates the level of variability in the data, and the horizontal spread indicates the range in the data. If data points were consistently similar, the lines would be more vertical, and if the pilot project was beneficial, the blue line would be to the right of the red line.

RESULTS AND DISCUSSION

Contract Towing Pilot

Small sample sizes in the before and after periods (21 and 15 incidents, respectively) coupled with the innate variability in the complex incidents for which contract towing was used resulted in high standard deviations and broad confidence intervals across each performance metric. Small sample sizes create “instability” with the data, where a single high-duration crash can skew the statistics considerably. The following provides the cumulative density function, descriptive statistics, and *t*-test results for each performance metric.

Lane Clearance Time

Figure 14 shows the cumulative density function for lane clearance time. The goal of contract towing is faster clearance time, and the plots clearly show an improvement as the red line (after data) is shifted to the left of the blue line (before data). However, both datasets exhibit high variability and range.

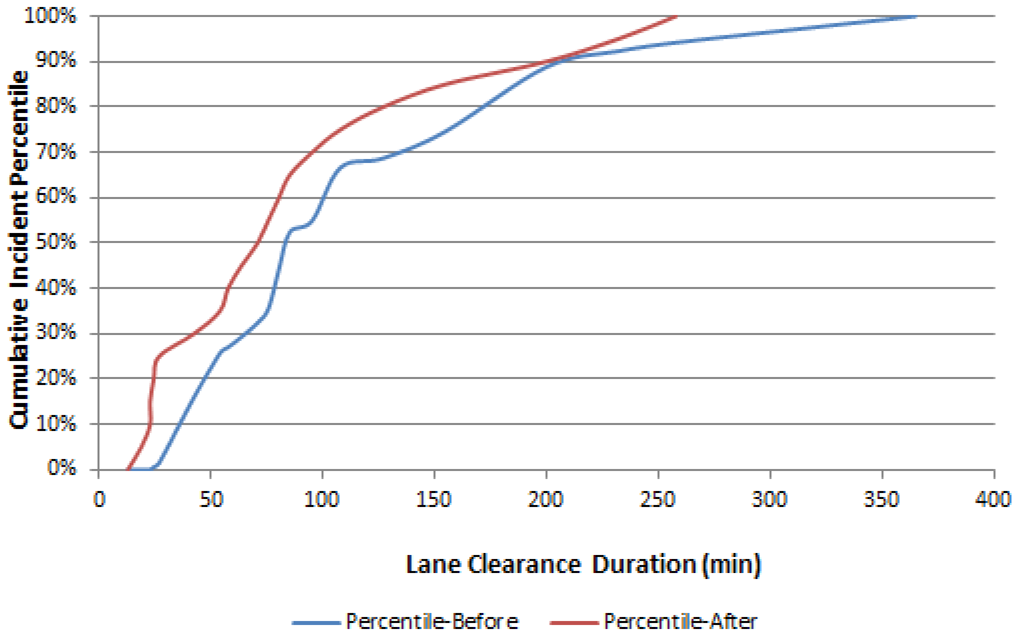


Figure 14. Cumulative Density Function of Lane Clearance Time for Contract Towing

Table 7 shows the lane clearance descriptive statistics for the before and after data. The average lane clearance time in the before period was 111 minutes and in the after period was 95 minutes, for a difference of 16 minutes. Because of high standard deviations in the before and after data (85 and 73 minutes, respectively), the 95 percent confidence interval for the difference of the average clearance times was ±56 minutes; therefore, the result was not statistically significant and conclusions about this performance metric cannot be made with confidence.

Table 7. Lane Clearance Descriptive Statistics for Contract Towing

Statistic	Before	After
Count	21	15
Average (min)	111 [a]	95 [a]
Median (min)	84	79
Standard deviation (min)	85	73

[a] Difference in before and after data = 16 minutes with a 95% confidence interval of ±56 minutes.

Incident Duration

Figure 15 shows the cumulative density function for incident duration. The plots show an increase in incident duration in the after period, as the red line (after data) is shifted to the right of the blue line (before data). Both datasets exhibit high variability and range. Contract towing is not involved in recovery and, therefore, even if lane clearance times improve, the improvement does not necessarily translate to shorter incident durations because the cleared timestamp for an incident occurs when recovery is completed.

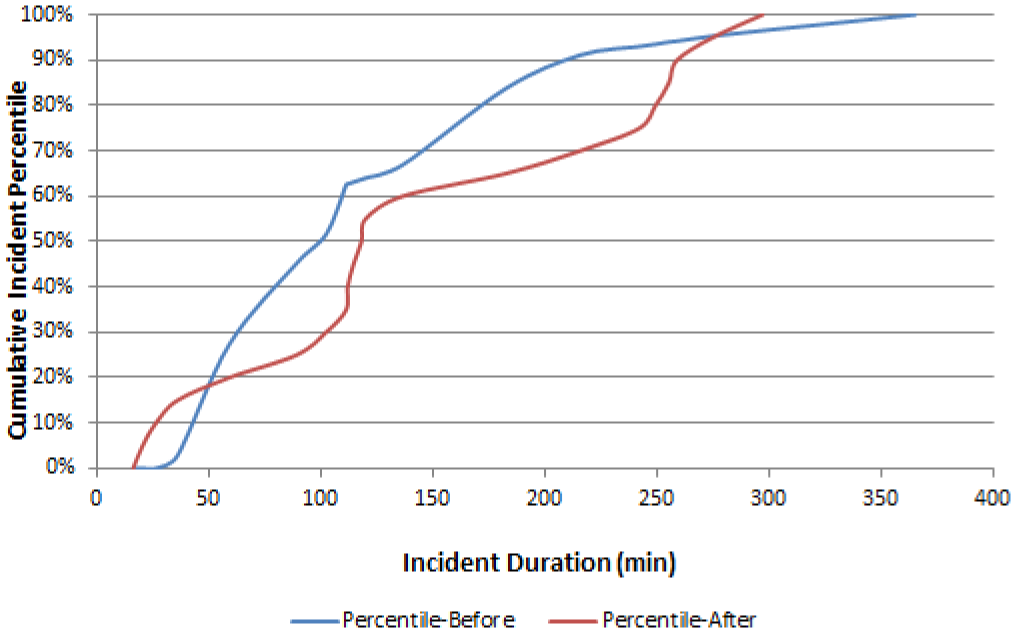


Figure 15. Cumulative Density Function of Incident Duration for Contract Towing

Table 8 shows the incident duration descriptive statistics for the before and after data. The average incident duration in the before period was 116 minutes and in the after period was 145 minutes, for a difference of 29 minutes. Because of high standard deviations in the before and after data (84 and 91 minutes, respectively), the 95 percent confidence interval for the difference of the average incident duration was ±63 minutes; therefore, the result was not statistically significant and conclusions about this performance metric cannot be made with confidence.

Table 8. Incident Duration Descriptive Statistics for Contract Towing

Statistic	Before	After
Count	21	15
Average (min)	116 [a]	145 [a]
Median (min)	93	118
Standard deviation (min)	84	91

[a] Difference in before and after data = 29 minutes with a 95% confidence interval of ±63 minutes.

Regain Time

Figure 16 shows the cumulative density function for regain time. The plots show an increase in regain time in the after period, as the red line (after data) is shifted to the right of the blue line (before data). Both datasets exhibit high variability and range. As was the case with incident duration, faster opening of travel lanes does not necessarily translate to improved regain time at the incident location. In most instances, incidents are relocated by the contract tower to the adjacent shoulder or median and passing vehicles may not reach the regain time threshold of −5 mph to the normal speed as long as incident-related response activity exists. Therefore, it is plausible that regain time is closely associated with incident duration time.

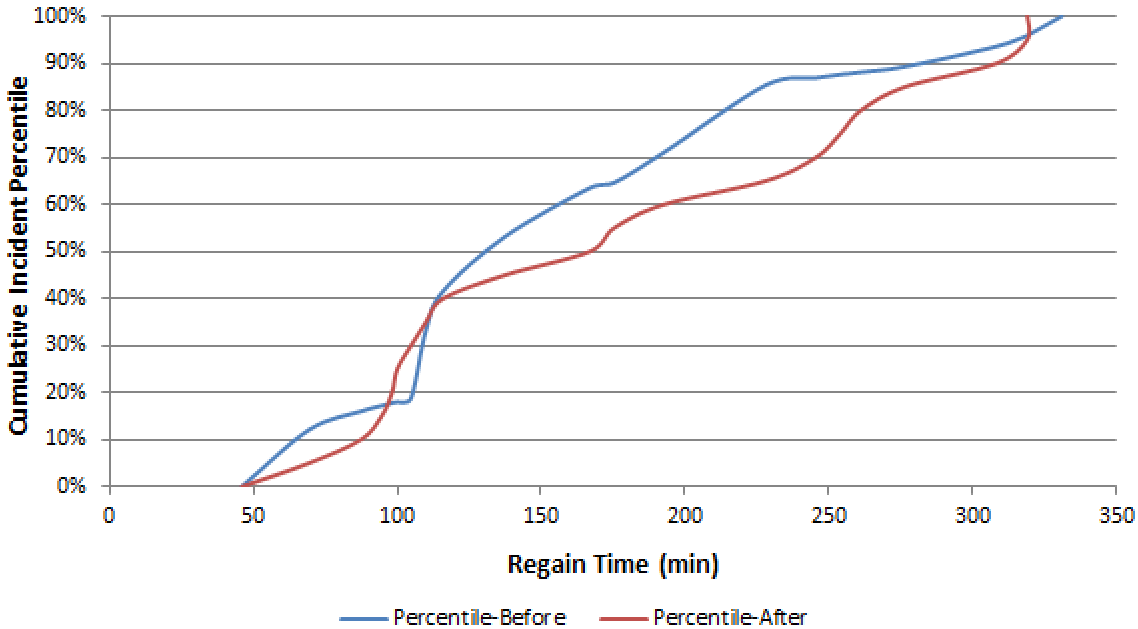


Figure 16. Cumulative Density Function of Regain Time for Contract Towing

Table 9 shows the incident duration descriptive statistics for the before and after data. The average regain time in the before period was 155 minutes and in the after period was 174 minutes, for a difference of 19 minutes. Because of high standard deviations in the before and after data (83 and 87 minutes, respectively), the 95 percent confidence interval for the difference of the average regain times was ±61 minutes; therefore, the result was not statistically significant and conclusions about this performance metric cannot be made with confidence.

Table 9. Regain Time Descriptive Statistics for Contract Towing

Statistic	Before	After
Count	21	15
Average (min)	155[a]	174[a]
Median (min)	127	161
Standard deviation (min)	83	87

[a] Difference in before and after data = 19 minutes with a 95% confidence interval of ±61 minutes.

Queue Dissipation Time

Figure 17 shows the cumulative density function for queue dissipation time. The plots show an improvement in queue dissipation time in the after period, as the red line (after data) is shifted to the left of the blue line (before data). Both datasets exhibit high variability and range. This result may be expected as queue dissipation time is directly correlated with lane clearance time. Even though regain time increased in the after period, it is plausible to assume that higher volumes of traffic are moving past the incident location, thereby dissipating the queue at a faster rate.

Table 10 shows the incident duration descriptive statistics for the before and after data. The average queue dissipation time in the before period was 65 minutes and in the after period was 42 minutes, for a difference of 23 minutes. Because of high standard deviations in the before and after data (60 and 43 minutes, respectively), the 95 percent confidence interval for the difference of the average queue dissipation times was ±36 minutes; therefore, the result was not statistically significant and conclusions about this performance metric cannot be made with confidence.

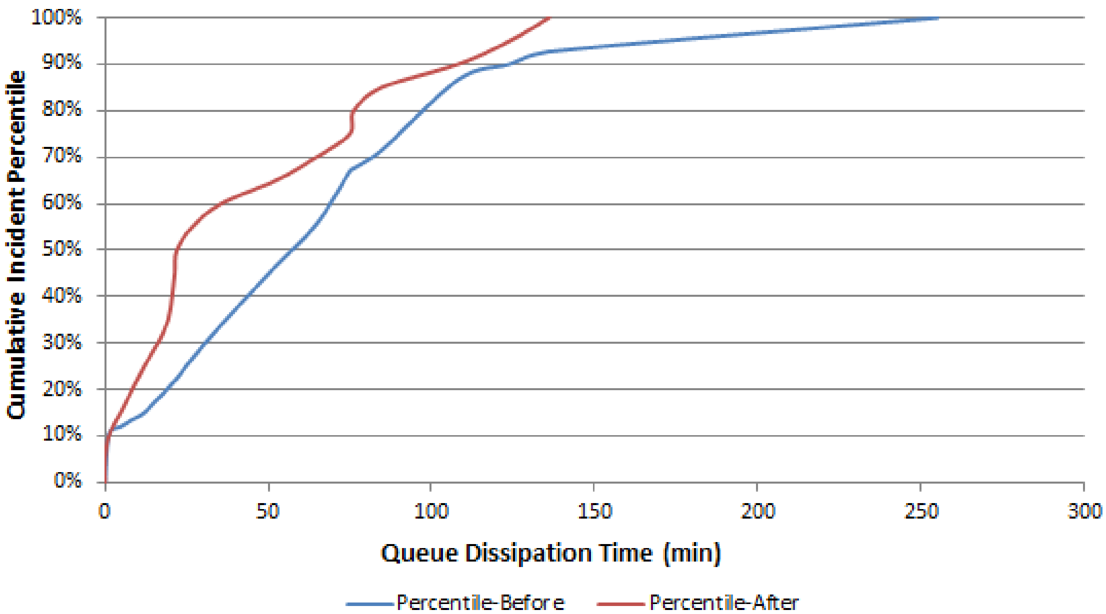


Figure 17. Cumulative Density Function of Queue Dissipation for Contract Towing

Table 10. Queue Dissipation Time Descriptive Statistics for Contract Towing

Statistic	Before	After
Count	21	15
Average (min)	65[a]	42[a]
Median (min)	61	22
Standard deviation (min)	60	43

[a] Difference in before and after data = 23 minutes with a 95% confidence interval of ±36 minutes.

User Delay Costs

Figure 18 shows the cumulative density function for user delay costs. For incidents resulting in lower overall delay costs of less than $170,000 (approximately 83 percent of incidents evaluated), the plots show an increase in user delay costs in the after period, as the red line (after data) is shifted to the right of the blue line (before data). For larger incidents with higher overall delay costs of more than $170,000 (approximately 2 to 4 incidents evaluated), the plot shows a decrease in user delay costs in the after period, as the red line is shifted to the left of the blue line. Both datasets exhibit high variability and range. User delay costs are strongly correlated with traffic volumes, and this measure has the potential for extreme variability with such low sample sizes. With larger sample sizes, data segmentation can be performed to account for time-of-day and day-of-week analyses.

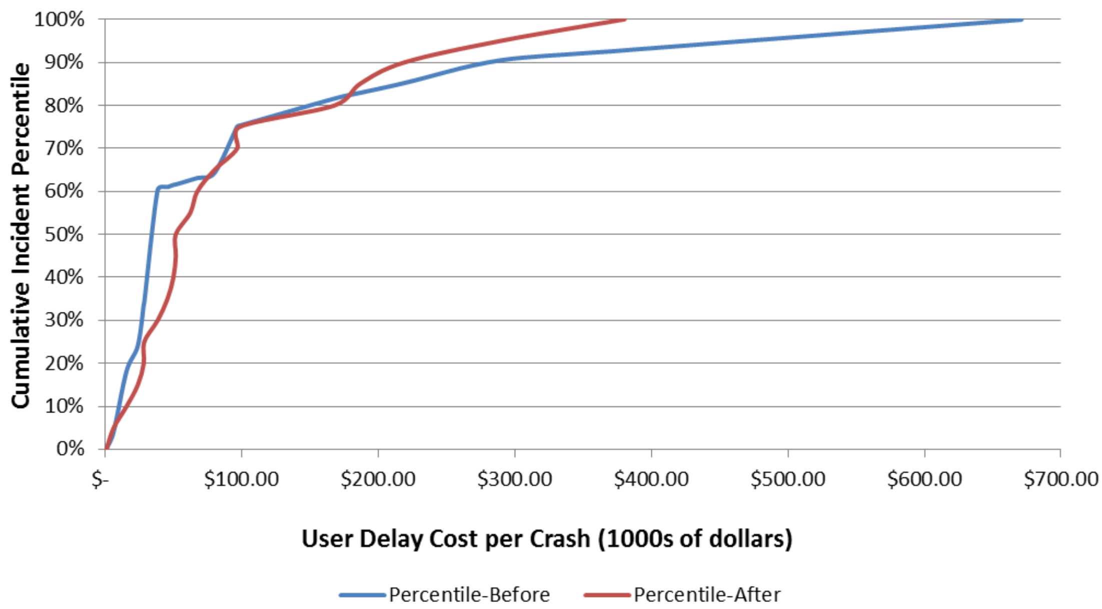


Figure 18. Cumulative Density Function of User Delay Costs for Contract Towing

Table 11 shows the incident duration descriptive statistics for the before and after data. The average user delay cost in the before period was $105,747 and in the after period was $98,374, for a difference of $7,637. This difference shows an improvement, but because of high standard deviations in the before and after data ($167,730 and $109,261, respectively), the 95 percent confidence interval for the difference of user delay costs was ±$97,701; therefore, the result was not statistically significant and conclusions about this performance metric cannot be made with confidence.

Table 11. User Delay Cost Descriptive Statistics for Contract Towing

Statistic	Before	After
Count	21	15
Average	$110,753[a]	$98,374[a]
Median	$33,518	$51,469
Standard deviation	$170,176	$109,261

[a] Difference in before and after data = $12,379 with a 95% confidence interval of ±$98,582.

Benefit-Cost Analysis

Based on the information available at the time of first incident notification, contract towing was dispatched for a total of 27 crashes, of which contract towing was used for 16 crashes. For the 11 unworked crashes, the contract towing operator was turned back because incidents were not found or the VSP zone rotation tower was already on scene. In each of these cases where contract towing was not used, VDOT paid a minimum of 2 hours pay ($1,800). The total cost to VDOT from the payout to the contract tower during the pilot was $40,850. This value was used as the “cost” in the benefit-cost analysis. The “benefit” was the dollar amount from the user delay cost analysis. To explain further the effect of small sample sizes on the stability of the results, a sensitivity analysis was performed.

Table 12 shows three rows of user delay cost data where the first row incorporates all of the data used in the analyses (21 incidents in the before period and 15 incidents in the after period). Scenario A was calculated by removing the single highest user delay cost incident in the after period. Scenario B was calculated by removing the single highest user delay cost in the before period. The results are not statistically significant at $\alpha = 0.05$ and show very large differences, including a negative number, further indicating data instability with small sample sizes.

Table 12. Sensitivity Analysis on Benefit-Cost (B/C) Ratio for Contract Towing

Scenario	Avg. Before	Avg. After	Difference	Benefit	Cost	B/C Ratio
All data	$110,753.31	$98,374.12	$12,379.19	$185,687.91	$40,850.00	4.5
Scenario A	$110,753.31	$78,240.17	$32,513.14	$487,697.08	$40,850.00	11.9
Scenario B	$82,710.80	$98,374.12	$(15,663.31)	$(234,949.72)	$40,850.00	-5.8

Scenario A = removing the single highest user delay cost incident in the after period; Scenario B = removing the single highest user delay cost incident in the before period.

First Responder Pilot

The first responder sample sizes in the before and after periods were much larger than in the contract towing pilot (109 and 104 incidents, respectively), thus providing more statistical stability in the data groups. The following provides the cumulative density function, descriptive statistics, and *t*-test results for each performance metric evaluated.

Lane Clearance

First responders collaborate with other responders with scene management including making lane clearance decisions and helping to relocate lane-blocking vehicles to the shoulder when possible. Figure 19 shows the cumulative density function for lane clearance time, and the plots show an improvement, as the red line (after data) is shifted to the left of the blue line (before data). Also of note is that the slopes of the lines are more vertical (indicating less variability) and the range of the data for approximately 95 percent of the incidents is tighter (clearance times were within approximately 120 minutes).

Table 13 shows the lane clearance descriptive statistics for the before and after data. The average lane clearance time in the before period was 52.96 minutes and in the after period was 42.38 minutes, for a difference of 10.58 minutes. The standard deviations for the before and after periods were similar (31.37 and 29.47 minutes, respectively), indicating low variation between the datasets. The 95 percent confidence interval for the difference of the average clearance times was ±8.27 minutes; therefore, the result was statistically significant.

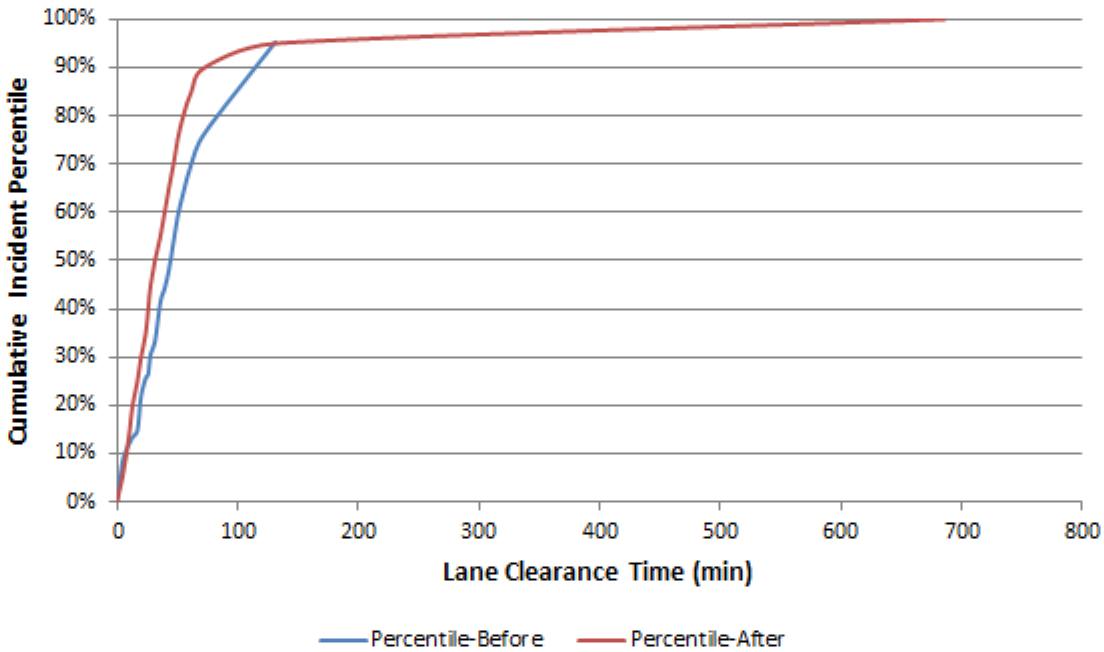


Figure 19. Cumulative Density Function of Lane Clearance Time for First Responder Pilot

Table 13. Lane Clearance Time Descriptive Statistics for First Responder Pilot

Statistic	Before	After
Count	109	104
Average (min)	52.96[a]	42.38[a]
Median (min)	46.00	38.00
Standard deviation (min)	31.37	29.47

[a] Difference in before and after data = 10.58 minutes with a 95% confidence interval of ±8.27 minutes.

Incident Duration

Figure 20 shows the cumulative density function for incident duration. The plots show an improvement in incident duration, as the red line (after data) is shifted to the left of the blue line (before data). As was the case with lane clearance, the slopes of the lines are more vertical (indicating less variability) and the range of the data for approximately 90 percent of the incidents is tighter (incident durations were within approximately 150 minutes).

Table 14 shows the incident duration descriptive statistics for the before and after data. The average incident duration in the before period was 58.37 minutes and in the after period was 50.62 minutes, for a difference of 7.75 minutes. The standard deviations for the before and after periods were similar (32.24 and 32.46 minutes, respectively), indicating low variation between the datasets. The 95 percent and 90 percent confidence intervals for the difference of the average clearance times were ±8.80 and ±7.36 minutes, respectively; therefore, the result was not statistically significant at a 95 percent confidence level but was statistically significant at a 90 percent confidence level.

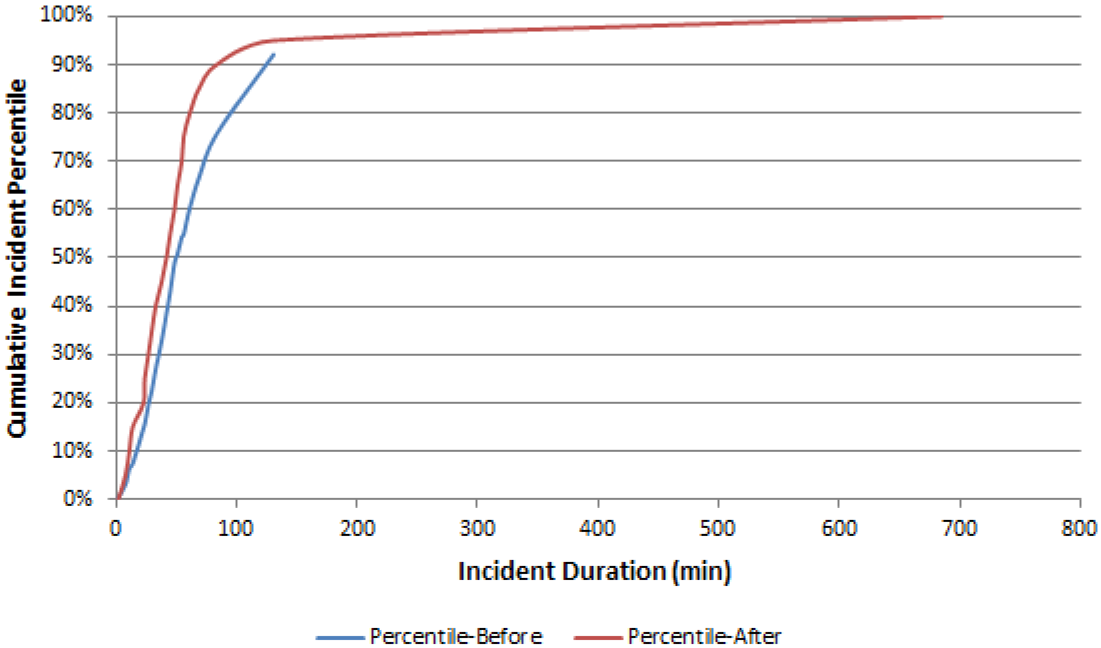


Figure 20. Cumulative Density Function of Incident Duration for First Responder Pilot

Table 14. Incident Duration Descriptive Statistics for First Responder Pilot

Statistic	Before	After
Count	109	104
Average (min)	58.37[a]	50.62[a]
Median (min)	51.00	44.50
Standard deviation (min)	32.24	32.46

[a] Difference in before and after data = 7.75 minutes with 95% and 90% confidence intervals of ±8.80 and ±7.36 minutes, respectively.

Benefit-Cost Analysis

Two naïve methods are presented to calculate the B/C ratio of the first responder pilot. Method 1 considers lane clearance time savings using 1 minute of lane blockage equaling 4 minutes of traveler delay after lane clearance.[9] Method 2 considers incident duration savings using the incident response analysis methodology from *WSDOT's Handbook for Corridor Capacity Evaluation*,[10] in which the cost of delay per minute of incident duration for lane blocking incidents was estimated as $345.

Method 1

For Method 1, the following equation was used to obtain the benefits measured in terms of estimated user delay cost savings:

Estimated user delay cost savings = (Average lane clearance time saved)*(4 minutes of delay per 1 minute of lane blockage)*(Average vehicle/truck delay costs)

The calculation inputs included the following:

- Average commercial truck delay cost per hour = $86.81[6]
- Average passenger car delay cost per hour = $16.72[6]
- Average annual daily traffic = 24,000[7]
- Average truck percentage along the pilot corridor = 23 percent[7]
- Average passenger car percentage along the pilot corridor = 77 percent[7]
- Average lane clearance time savings per crash = 10.58 minutes
- Average traveler delay for one minute of lane blockage = 4 minutes[9]

where

Average delay cost per hour = $16.79*0.77 + $86.81*0.23 = $32.90
Average user delay cost savings per crash per vehicle = 10.58*4*32.90/60 = $23.21
Average traffic demand[7] on the pilot corridor in 10.58 minutes = 10.58/1440*24000 = 176.3 vehicles.

The total benefit was calculated as:

Average user delay cost savings per crash per vehicle*Average traffic demand in 10.58 minutes = 23.21*176.3 = $4,091.92.

For program costs, the following values were used:

- Overtime paid to first responder volunteers: $11,218.17
- Vehicle lease over pilot period = $8,250
- Vehicle gas over pilot period = $600
- STAR radio equipment (6 months annualized over 5 years) = $1,400
- 95 incidents (this includes contract towing responses)

where

First responder program cost per crash = [$11,218.17 (overtime) + $10,250 (equipment and gas)]/95 = $225.98.

Based on this method, therefore, the B/C ratio was calculated as $4,091.92/225.98 = +18.1.

Method 2

In contrast to Method 1, which used average lane clearance time savings, Method 2 uses average incident duration savings. If this approach is used, where the estimated cost of delay per minute of incident duration for lane blocking incidents is $345,[10] the following calculation is performed to obtain the average benefits per crash:

Average benefits per crash*Average incident duration savings = $345*7.75 = $2,673.75.

Based on this method, the B/C ratio was calculated as $2,673.75/$225.98 = +11.8.

Internal Qualitative and Quantitative Assessments

During the pilot project implementation, VDOT district staff and the research team were in regular contact to document fully the lessons learned for this study. After completing the pilot project, the research team met with the VDOT incident management team and the contract tower to capture their qualitative experiences. VDOT district staff also reached out to VSP and fire and rescue to elicit their feedback about both the first responder and contract towing pilots. This section summarizes the findings from those meetings and preliminary evaluations performed by the Staunton District.

First Responder Pilot

The Staunton District's incident management team, VSP, fire and rescue, and the contract tower were unanimous in their praise for and the perceived value from the first responder pilot project.

- All TIM partner agencies acknowledged improvement in the 3Cs (Communication, Cooperation, Coordination).

- By reducing the incident durations, the chances of secondary incidents are decreased any time of the day, irrespective of the traffic demand. Thereby, the hazard exposures of both motorists and responders are decreased and safety is improved with the first responder initiative.

- The VDOT team mentioned that "other responders have become used to VDOT being at the scene to support incident management."

- The first responder dispatched the contract tower; communicated with VSP and fire; and provided incident details and pictures to rotational towers so that the right equipment was brought to the scene.

Pilot Project Details

- The first responder was dispatched to any incident to which fire and rescue responded. The pilot was operational 24/7.

- Program costs included about 10 hours of overtime per week and a $500 bonus per responder for the 6 months of the pilot.

- Sometimes the VSP Computer Aided Dispatch (CAD) feed is down and the TOC does not have detailed incident information. VDOT first responders provide detailed information over the telephone supplementing the closed-circuit television (CCTV) and CAD feeds.

Equipment

- A half-ton pickup truck was leased for the duration of the pilot project (see Figures 21 and 22). This vehicle is equipped with two deck lights on the front dash and amber strobe lights in the back.

Figure 21. First Responder Vehicle

Figure 22. Deck Lights on First Responder Vehicle

— First responders were initially issued vehicles with a standard work zone lighting package; however, at an incident site with limited traffic control devices, VDOT deemed this standard work zone lighting inadequate and added more conspicuous deck lighting.

— First responder vehicles do not have push bumpers. They have the capability to drag a vehicle.

— VDOT staff mentioned that the vehicle size was appropriate for the purpose, but with a heavier vehicle (¾ to 1 ton) with push bumpers, the first responder would be able to push a disabled passenger vehicle from a travel lane to the shoulder. They would still need to obtain VSP permission to push, but that could save additional time in some cases compared to waiting for the tower.

— During an emergency response, VDOT does not need VSP permission to use the shoulder, and there are no liability concerns. Towers must obtain VSP permission to use the shoulder.

- The first responder does not carry traffic management equipment such as cones, arrow boards, etc. The Safety Service Patrol and Turnkey Asset Maintenance Services (TAMS) contractor manage the traffic with traffic cones and arrow boards. VDOT preferred this approach so that the first responder is not distracted from the focus on the 3Cs and travel lane clearance.

- For dispatch of a first responder, fire and rescue pagers were used to enable faster communication compared to a telephone call. In VDOT's Northwestern Regional Operations (NWRO), VDOT incident responders have experienced as much as a 30-minute delay between the time that fire / emergency medical services is dispatched and the TOC is notified of the incident. The use of emergency service pagers by VDOT was chosen to reduce the notification lag time.

- Two STAR communication radios were purchased (but the units did not arrive in time for use in this pilot implementation).

Personnel

- The two main VDOT employees responsible for the project have extensive prior experience as fire and rescue responders. A third first responder was trained during the program. The training material is delivered in person by experts, rather than via computer.

- Training is provided through VDOT University (see Figures 23 and 24 for descriptions of VDOT Incident Responder and SHRP-2 National TIM Responder Training Program modules), tabletop exercises, and on-the-job training working with experienced personnel. VDOT noted that incident management skills and abilities are usually not high among VDOT field staff and that training is necessary. Interest, aptitude, and buy-in into VDOT's quick clearance mission were the factors used by VDOT for screening personnel selected for the pilot project. Three members of the applicant pool were eventually chosen to participate in the 2016 program.

- Personnel selected as first responders have other primary VDOT roles. Therefore, they are considered volunteers, although they were paid overtime when they responded to incidents outside the regular workday. VDOT management noted that the volunteers who participated in 2015 were "burning out" with excess work. For this reason, formalizing this role and adjusting the other work schedules of these personnel as necessary to sustain their well-being should be considered and implemented. Rotating the lead responder by time period is one such possibility.

- The distance of residences from the interstate incident management zones is an important factor in determining who can participate in the program, as first responder staff must be with their vehicle at all times when on call.

VDOT Incident Responder
Event . VDOT - Maintenance Training Academy . 6 hours . $0.00

The primary goal of the training is to engage the VDOT responder into the Incident Scene, becoming part of a safe and active participant in reducing incident times.

The VDOT Incident Responder course is designed to enhance the VDOT responder's opportunity to be an integral and vital partner at an Incident Management Scene. The primary focus of the course is Communication, Cooperation and Coordination with other incident Responders. The VDOT responder will be exposed to: Situational Awareness, Responder Safety, Responder duties, Scene management, Scene reporting, Scene support and overall scene management. Further the VDOT responder will be exposed and participate in table top exercises where VDOT will be an active partner in the scene.

Target Audience: Anyone who has a role in VDOT incident response.

Figure 23. Description of VDOT Incident Responder Training Module

SHRP-2 National TIM Responder Training Program
Event . Federal Highway Administration . 4 hours . $0.00

SHRP 2 (The Second Strategic Highway Research Program (SHRP 2)) was created by Congress to address the challenges of moving people and goods efficiently and safely on the Nation's highways. This short-term research program addresses four strategic focus areas:•Safety – The role of human behavior in highway safety.
•Renewal – More efficient highway project delivery.
•Reliability – Congestion reduction through improved travel times.
•Capacity – Improved integration of community, economic, and environmental considerations for new highway capacity.Training ObjectivesThe new multi-agency National Traffic Incident Management Training Program equips responders with a common set of core competencies and assists them in achieving the TIM National Unified Goal of strengthening TIM programs in the areas of:•Responder safety.
•Safe, quick clearance.
•Prompt, reliable, and interoperable communications.Flexible delivery approaches for full-scale implementation of the TIM training courses are also under development.Program Strengths•Promote more effective multi-agency, coordinated, and planned incident response.
•Improves responder safety.
•Improves travel-time reliability for person and freight trips on the Nation's highways by improving incident clearance time.
•Reduces congestion, collisions, and delays caused by secondary crashes.Key to SuccessIn order to effectively strengthen TIM activities, the training courses must reach a majority of the Nation's TIM responders. You can effect change by encouraging the deployment of the new National TIM Training Program in your State.

Figure 24. Description of SHRP-2 National TIM Responder Training Program Module

Additional Notes

- VDOT's Northwestern Region Operations management is interested in supporting this program and expanding it to other VDOT districts and counties. District administrators and regional operations directors (RODs) are interested in the detailed evaluation findings.

- Initially, VDOT district staff planned a two-person team. The plan was for one person to go directly to the incident scene while another went to the yard and picked up the crash cushion, etc. However, with the experience gained, district staff realized early on that the second person was not adding much benefit and changed their plan to a one-person response.

- Detailed responder logs were very helpful in understanding the 3C dynamics and matching the incidents with VaTraffic logs. The exact data fields captured in the logs can be seen in Figure 3.

- First responders mentioned that when they inform a TOC operator that a lane is cleared on scene, sometimes that information does not get entered into VaTraffic immediately, perhaps because of other tasks that operators may be working on in parallel. This delay in entering information could result in inaccurate lane closure / opening timestamps.

- VDOT management noted that it would be useful if the first responders could use a drone to obtain an overall scope of the incident scene and share it with the TOC. VDOT executive management in the districts and the central office want to receive visual media with their notifications. CCTVs provide some details to the TOC but are limited by equipment location and incident characteristics.

- According to VDOT staff, traffic queue management has been a top priority for the last 7 years; therefore, they were concerned that significant queue dissipation benefits attributable to the incident management pilot projects (this applies to both pilots) might not be visible when compared to data from recent years.

- Training is very important because the first responder focuses on team building and unified command. Most new first responders have no concept of the roles and responsibilities of VSP, fire, and VDOT on an incident scene.

Contract Towing Pilot

VDOT staff expressed high praise for the specific contract tower used in 2016, for dedication and professionalism, flexible accommodation of needs, and friendly personality.

- Feedback from other agency responders (VSP and fire) was mixed. Whereas some supported the contract towing initiative (see the letter from the chief of the Shenandoah County Department of Fire and Rescue in Appendix C), noting that it aided in quick clearance of highways and enhanced safety of responders, some mentioned that they saw no benefit or were not impressed by the program, and one respondent did not have any experience with contract towing on any of his or her incidents.

- Other feedback was that there was possible duplication of efforts in dispatching for wreckers and it was confusing as to which wrecker was recovering which crash vehicles when multiple crashes occurred one day.

- One respondent was “not impressed with the wrecker company used.”

Pilot Project Details

- The pilot was operational 24/7.

- The contract tower was dispatched by and worked directly for VDOT.

- The contract tower considered VDOT their number one customer when they were awarded the contract.

- VDOT management noted that for a successful contract towing program, the first responder program is critical. The former cannot be implemented without the latter.

- The contract tower was proactive in reaching out to the first responder for incident information.

- VDOT divided the 28-mile stretch on I-81 into three zones for the pilot to match the VSP zones closely, with the goal of saving lane clearance times. However, the contractor observed that there are not enough wreckers in the area to meet the contract requirements in all three zones. These goals and realities should be considered together in determining zones.

Equipment

- The contract tower purchased fire and rescue pagers for all their staff when they were awarded the pilot contract.

- The pilot contract included a 50-ton rotator as a requirement. The contract tower pointed out a number of reasons for including a 25-ton rotator as a primary equipment requirement with a backup of a 50-ton rotator: (1) a 25-ton rotator is sufficient for most incidents; (2) a 50-ton or even an 85-ton rotator is often unable to pick up a loaded tractor-trailer intact;(3) a heavier rotator cannot reach beyond the guardrail to pick up a car; (4) more wreckers have a 25-ton rotator available in their inventory; (5) a 50-ton rotator is more costly to procure and maintain; and (6) higher, often unnecessary costs will reflect directly in the contract tower's bid.

- The contract tower recommended including a skid loader to the contract, in addition to the rubber tire loader, because the former is 3 times faster.

- The contract tower recommended including some hazmat capabilities, such as booms, absorbent pads, a spill containment pool, and fuel tank putty.

Personnel

- The contract tower has prior experience as a fire and rescue responder.

- Most of the training for the wreckers is obtained in-house, within the wrecker company. Some personnel have certifications; however, hands-on training and experience are observed to be relatively more important.

Additional Notes

- Initially, the contract tower was dispatched immediately after the VDOT first responder received incident notification. Since the tower was not needed at all incident scenes, depending on the incident severity, the protocol was changed to the first responder assessing the incident severity following the pager notification before dispatching the contract tower.

- Contract towers and VSP rotational towers must be connected through the first responder to enable efficient collaboration.

- In one instance, when the contract tower was en route to a crash, the tower was re-routed to another crash to help with victim extrication. The contract tower, VDOT first responder, and fire personnel communicated and decided to use the contract tower for emergency safety needs first. Such flexibility is not available outside the contract towing program.

- The initial contract required the contract tower to be within the incident zone within 45 minutes of notification (their business operations did not have to be located physically within the zone). The first invitation for bid (IFB) received no responses for the southernmost zone. The second IFB for this zone received one bid with very high costs of around $8,000/hour. Therefore an extension was issued to the successful bidder for the other two zones to include the southernmost zone. The successful bidder subcontracted with another tower physically located in the southernmost zone. VDOT staff mentioned that in the future, they would prefer to award the contract directly to a tower who has a full presence within the incident tow zone and not subcontract.

- For a future pilot, VDOT would like to add a light duty vehicle with a flatbed to the contract.

- VDOT assumes liability for any possible damage to vehicles and/or goods during relocation. The contract tower works for VDOT but must still carry his or her own liability insurance.

- Legislation needs to be in place for funding and for setting up minimum standards for the towing industry.

Preliminary VDOT Evaluation During the Pilot Implementation

VDOT district staff internally evaluated the benefits from the pilot projects as the implementation was in progress by measuring and estimating time savings at each incident site. The data gathered provided useful feedback mechanisms for management to obtain a preliminary understanding of the pilot impacts and potentially to improve any aspects of the pilot. The evaluation methods, results, and limitations are documented in this section.

The first responders that managed each incident scene provided measured and estimated benefits in the incident logs (see Figure 3). The measured and estimated benefits included a number of aspects such as (1) the clock time difference between when the contract tower arrived at the incident scene and when the rotation list wrecker arrived there; (2) the clock time difference between when the first responder asked the motorist to move the vehicle over to the shoulder and when the VSP officer arrived on scene; and (3) estimated time savings attributable to the 3Cs among all responding agencies and collaborative decision making. Results from this evaluation method are summarized in Figure 25.

District staff mentioned that these measurements and estimates of time savings were conservative because they did not include any time savings estimation because of contract tower actions or support to the rotation list wrecker. However, three important limitations exist. First, all savings estimations attributable to improved 3Cs might be estimated differently by different responders, based on their own experiences, thereby leading to subjectivity. Second, it is not clear if the VSP process for dispatching zone wreckers was exactly the same in the before and after periods. VDOT field staff mentioned that they did not see any difference in the VSP processes and that the rotational tower gets notified whenever VSP calls the dispatcher. However, VDOT field staff also mentioned that the VSP paperwork seems to have increased during the pilot period (unrelated to the pilot itself) given the extra time they spent on scene after the vehicles were cleared. Third, if the contract tower arrived later than the rotational tower the clock was not reversed, hence indicating no negative impact on the incident duration. One potential concern with this approach is that the contract towing will always be seen as resulting in only a positive B/C ratio, irrespective of their efficiency/inefficiency, appropriateness of equipment, etc.

- Total number of incidents responded to = 95
- Total number of incidents with documented time savings = 68 (71.5% of calls responded to)
- Total number of incidents where VDOT tow contractor was dispatched = 29
- Total number of incidents towing contractor saved time = 16 (contractor was not used for the remaining 13 incidents)
- Total amount invoiced by the contractor = $40,850.00
- Total number of incidents first responder saved clearance time = 52
- Time saved by using VDOT first responder = 838 min. (13 hr 58 min)
- Time saved by using VDOT tow contract = 510 min (8 hr 30 min)
- Total clearance time saved = 1,348 min (22 hr 28 min)

Figure 25. Staunton District Measurement and Estimation of Time Saved From Pilots

CONCLUSIONS

- *The effectiveness of the contract towing pilot could not be determined because all results were statistically insignificant because of the small sample sizes.* This conclusion is complemented by the mixed comments from the stakeholders. Qualitatively, VSP and fire noted that the incident duration did not change much whereas VDOT noted some improvements in lane clearance time. Both of these observations were reflected in the quantitative analyses (even though they were not statistically significant).

- *VDOT's first responder pilot produced statistically significant improvements to both lane clearance time (at a 95 percent confidence level) and incident duration (at a 90 percent confidence level).* This conclusion is complemented by the unanimous positive comments from stakeholders across the board.

RECOMMENDATIONS

1. *VDOT's Staunton District should continue with the first responder program.* Significant improvements in lane clearance time and incident duration were achieved during the pilot.

2. *VDOT's Operations Division should explore opportunities to implement the first responder program in other districts.*

3. *VDOT's Operations Division should explore opportunities for targeted deployment of a contract towing pilot(s).* This study found potential for improvements in lane clearance times and traffic impacts with this initiative, but the study was limited in terms of sample size. An additional pilot(s) that provided an adequate sample size would help in improving understanding of the effectiveness of this initiative.

CONSIDERATIONS FOR FUTURE IMPLEMENTATION

Contract Towing Pilot

- A VDOT first responder presence is essential for implementing a contract towing initiative.

- More samples are needed for an effective evaluation. To increase sample size, pilots could be implemented for a longer time period and/or across larger geographic areas if applicable.

- The number of zones for a roadway should reflect both the desired lane clearance objectives and the availability of towers. A discussion with the towing community before the letting of bids might be helpful.

- Some VSP and fire respondents noted that incident durations had not decreased. Although incident durations may or may not decrease, depending on the nature of the incident, the focus of contract towing is to decrease lane clearance times significantly. This message needs to be communicated clearly with VSP and fire in order to set appropriate program expectations.

- VSP noted some confusion in the handling of the contract towing and its relation to the existing rotation towing. Increased outreach to VSP should be considered going forward.

- The contract tower was called out but not used in some instances. Some of these incidents were unfounded and limited information was available to VDOT in some cases. Responders and managers should explore means to minimize these dry runs in the future.

- VDOT should discuss equipment needs with the towing community prior to developing contract specifications. These specifications should reflect the common equipment needs for incident clearance; the availability of the equipment in the region; and the costs for procuring, maintaining, and operating the equipment. Rarely needed equipment should continue to be listed as supplemental rather than required.

- The contract tower suggested adding some hazmat cleaning/containing capabilities in the contract towing specifications.

- VDOT should consider the advantages and disadvantages of awarding zone contracts exclusively to towers with a physical presence in each zone versus permitting contract towers to subcontract with other towers.

First Responder Pilot

- The training and screening approach followed for this pilot were deemed efficient and practical.

- First responders provided incident photographs and direct information to the contract and rotational towers. These comprise a very useful tool for ensuring the towers bring the right equipment to the scene.

- First responders provided additional situational awareness and details regarding incidents and their clearance to the TOC. Such details are essential for accurate evaluations.

- The use of fire and rescue pagers was deemed to improve information flow for the first responder dispatch function compared to telephone calls.

- Vehicle conspicuity was improved with the additional lighting package that included strobe and dash lights. VDOT deemed the standard work zone lighting inadequate.

- VDOT field staff commented that the vehicle leased for this pilot was the proper size. However, a heavier vehicle with push bumpers is preferred to enable the pushing of disabled vehicles off the travel lanes, wherever possible, to gain additional improvements in lane clearance times.

- The first responder logs were very helpful in documenting incident details. These logs should be continued for program analyses.

Data

- VaTraffic logs have some issues that need to be rectified. Ramp openings are currently not recorded in many cases. They should be recorded. In addition, accurate recordings of lane closure and opening times are critical for evaluations. VDOT field staff mentioned that in some cases the recording could have been delayed 15 minutes or more.

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APPENDIX A

PYTHON SCRIPT FOR CALCULATING LANE CLEARANCE TIMES FROM VATRAFFIC

```
# Lane clearance time analysis for the Clear Roads Project
import pandas as pd
import numpy as np

# importing data and establishing an order of the lane closing/opening action at each event, by direction, lane
df = pd.read_csv(r'C:\Temp\LaneClearanceRawData.txt')
df.sort_values(['IncID','Direction','Lane Number','Date'], inplace=True)
df.reset_index(inplace=True, drop=True)
df['order'] = df.index

# isolating lane closings; removing lane openings and shoulder actions
# joining with the original file so that each closing and its next event is in one row
df2 = df[(df['Lane Status']=='Closed') & (df['Lane Type'] != 'Shoulder')]
df2['order2'] = df2.order+1
df3 = pd.merge(df2, df, left_on=['IncID','Direction','Lane Number','Lane Type','order2'],
right_on=['IncID','Direction','Lane Number','Lane Type','order'])
df3['order3'] = df3.order_y+1

# isolating those rows that were either lane closings or subsequent lane actions (either closing or opening)
df4 = df2['order'].append(df3['order2'])
df5 = df[df['order'].isin(df4)]
df6 = df5.groupby(['IncID','Direction','Lane Type','Lane Number'])

# determining the first closing and the first immediate opening per lane
# lane clearance is the difference of these two timestamps
df7 = df6['Date'].agg([np.min, np.max])
df7.reset_index(inplace=True)
df7['amin'] = pd.to_datetime(df7['min_time'])
df7['amax'] = pd.to_datetime(df7['max_time’])
df7['Each Lane Closed Time'] = (df7.max_time - df7.min_time).astype('timedelta64[s]')/60

df8 = df5.groupby(['IncID','Direction','Lane Type'])
df9 = df8['Date'].agg([np.min, np.max])
df9.reset_index(inplace=True)
df9['min_time’] = pd.to_datetime(df9['min_time’])
df9['max_time'] = pd.to_datetime(df9['max_time'])
df9['All Lane Closed Time'] = (df9.amax - df9.amin).astype('timedelta64[s]')/60

unanalyzed_inc = sorted(set(df['IncID'].unique()) - set(df7.IncID.unique()))
all_inc_list = pd.DataFrame(df['IncID'].unique())

df9.to_csv(r'c:/Temp/LaneClearanceTimes.csv', index=False)
```

APPENDIX B

PYTHON SCRIPT FOR CALCULATING AVERAGE AND MEDIAN DELAY COSTS

```
import pandas as pd
import glob
from datetime import timedelta
#import numpy as np

#function to group day of week into Weekday, Friday, Saturday and Sunday
def dow_to_dow2(dfx):
    if dfx['dow'] in (0,1,2,3):
        return 'Weekday'
    elif dfx['dow'] == 4:
        return 'Friday'
    elif dfx['dow'] == 5:
        return 'Saturday'
    else:
        return 'Sunday'

#function to check if a specific hour under consideration is of interest for calculating impacts or not
def impact_checker(dfx):
    if dfx['impact_start_time'] <= dfx['impact_end_time']:
        if dfx['impact_start_time'] <= dfx['hour'] <= dfx['impact_end_time']:
            return 'true'
        else:
            return 'false'
    else:
        if dfx['impact_start_time'] <= dfx['hour'] and dfx['dow2'] == dfx['dow2_start']:
            return 'true'
        elif dfx['hour'] <= dfx['impact_end_time'] and dfx['dow2'] == dfx['dow2_end']:
            return 'true'
        else:
            return 'false'

#function to determine the date of the impact hour for overnight crashes
def end_date_finder(dfx):
    if dfx['impact_start_time'] <= dfx['impact_end_time']:
        return dfx['crash_date']
    else:
        return dfx['crash_date']+timedelta(days=1)

#importing a table from spreadsheet that contained the start/end date/hour for impact of each incident
xl = pd.ExcelFile('c:/Temp/TIM-CR/DelayCostsLookUp2.xlsx')
delay_cost_lookup = xl.parse('Sheet1')
del delay_cost_lookup['Baseline_comments']
del delay_cost_lookup['Delay_comments']
delay_cost_lookup['crash_date'] = pd.to_datetime(delay_cost_lookup['crash_date'])
delay_cost_lookup['crash_date_end']=delay_cost_lookup.apply(end_date_finder, axis=1)
delay_cost_lookup['dow'] = delay_cost_lookup['crash_date'].dt.weekday
delay_cost_lookup['dow2_start'] = delay_cost_lookup.apply(dow_to_dow2, axis=1)
delay_cost_lookup['dow_end']=delay_cost_lookup['crash_date_end'].dt.weekday
delay_cost_lookup['dow_start'] = delay_cost_lookup['dow']
delay_cost_lookup['dow'] = delay_cost_lookup['dow_end']
delay_cost_lookup['dow2_end'] = delay_cost_lookup.apply(dow_to_dow2, axis=1)
```

```
#reading cost file of each incident and determining the median and average for the specific day of week group, for
each hour of the day.
file_list = glob.glob('c:/Temp/ClearRoads/ ' + '/*.xlsx') # Get folder path containing text files
final_med = None
final_ave = []
crash_days = []
for file in file_list:
    df = pd.ExcelFile(file).parse('Total cost - All')    #for cost analysis
#    df = pd.ExcelFile(file).parse('Vehicle-hrs of delay - All')   #for delay hours analysis
    df2 = df[2:-2]
    df2['incid'] = df2.columns[0]
    df2.columns = ['datex'] + list(range(25)) + ['incid']
    df2['datex'] = pd.to_datetime(df2['datex']) #+ timedelta(days=1) this part was necessary before, because RITIS
output dates were off by one. Not needed as of 01/25/2017
    df2['dow'] = df2['datex'].dt.weekday
    del df2[24]

    for column in range(24):
        df2[column] = pd.to_numeric(df2[column])

    df2['dow2'] = df2.apply(dow_to_dow2,axis=1)
    df3a = pd.merge(df2, delay_cost_lookup, how='inner', left_on=['incid','datex'], right_on=['OID','crash_date'])
    df3b = pd.merge(df2, delay_cost_lookup, how='inner', left_on=['incid','datex'], right_on=['OID','crash_date_end'])
    df3 = pd.merge(df3a, df3b, how='outer')

    ave = df2.groupby(['incid','dow2']).mean().reset_index()
    med = df2.groupby(['incid','dow2']).median().reset_index()
    del med['dow']
    del ave['dow']
    if final_med is None:
        final_med = med
        final_ave = ave
        crash_days = df3
    else:
        final_med = final_med.append(med)
        final_ave = final_ave.append(ave)
        crash_days = crash_days.append(df3)

final_ave2 = pd.melt(final_ave, id_vars=['incid','dow2'], var_name='hour', value_name='cost')
final_ave2['hour'] = pd.to_numeric(final_ave2['hour'])
final_ave2['type']='average'
final_med2 = pd.melt(final_med, id_vars=['incid','dow2'], var_name='hour', value_name='cost')
final_med2['hour'] = pd.to_numeric(final_med2['hour'])
final_med2['type']='median'
#final benchmark file for all the incidents, containing both the average and median costs (or delay hours)
final_base = pd.merge(final_ave2, final_med2, how='outer')

crash_days.drop(['datex', 'dow_x', 'dow_y'], axis=1, inplace=True)
crash_days2 = pd.melt(crash_days, id_vars=['incid','dow2', 'OID', 'crash_date',
    'impact_start_time', 'impact_end_time', 'crash_date_end', 'dow2_start',
    'dow_end', 'dow_start', 'dow2_end'], var_name='hour', value_name='cost')
crash_days2['type'] = 'crash day'

crash_days2['keep'] = crash_days2.apply(impact_checker, axis = 1)
```

```
#isolating benchmark data for the hours of interest for analyzing impacts of each incident
df12a = pd.merge(final_base, delay_cost_lookup, left_on=['incid', 'dow2'], right_on=['OID', 'dow2_start'])
df12b = pd.merge(final_base, delay_cost_lookup, left_on=['incid', 'dow2'], right_on=['OID', 'dow2_end'])
df12a['keep'] = df12a.apply(impact_checker, axis = 1)
df12b['keep'] = df12b.apply(impact_checker, axis = 1)

df12 = pd.merge(pd.merge(df12a, df12b, how='outer'), crash_days2, how='outer')

df13 = df12.loc[df12['keep'].isin(['true'])]

#aggregating the hourly costs/delays for each incident
df14 = df13[['incid', 'type', 'cost']]
df15 = df14.groupby(['incid', 'type']).sum().reset_index()

#determining additional costs/delays due to an incident (for all incidents) by subtracting the benchmark average or median; and setting to zero if no costs/delays noted.
#df16 = df15.stack('type')
df15['cost'] = pd.to_numeric(df15['cost'])
df16 = df15.pivot_table(values='cost', index=['incid'], columns="type").reset_index()
df16['crash_cost_ave'] = (df16['crash day'] - df16['average']) * (df16['crash day'] > df16['average'])
df16['crash_cost_med'] = (df16['crash day'] - df16['median']) * (df16['crash day'] > df16['median'])

#writing the median, average, and additional costs of each incident to an excel file
writer = pd.ExcelWriter('c:/Temp/TIM-CR/costs1.xlsx', engine='xlsxwriter')
final_med.to_excel(writer, sheet_name='Median')
final_ave.to_excel(writer, sheet_name='Average')
df16.to_excel(writer, sheet_name='FinalCosts_med')
writer.save()
```

APPENDIX C

LETTER OF SUPPORT FROM THE CHIEF OF THE SHENANDOAH COUNTY DEPARTMENT OF FIRE AND RESCUE

Shenandoah County

Department of Fire and Rescue
600 N. Main Street, Suite 109
Woodstock, VA 22664

(540) 459-6167 voice
(540) 459-6192 fax

November 9, 2016

Edwin Z. Carter
Assist. Residency Administrator
VDOT-Edinburg Residency
14031 Old Valley Pike
Edinburg, VA 22824

Mr. Carter,

The Shenandoah County Department of Fire and Rescue would like to go on record in support of the VDOT 1st Responder program as well as the towing contract initiative. Both of these initiatives were beneficial during the pilot program to aid in quick clearance of our highways which in turn enhanced safety for our fire-rescue providers.

Please consider this a support letter for re-instating both of these programs on a permanent basis. If we can be of further assistance reference this matter, please don't hesitate to call upon us.

Thank you,

P. Timothy Williams, Chief
Shenandoah County Department of Fire and Rescue
600 N. Main St. Suite 109
Woodstock, VA 22664