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Forensic Engineering Technology Solutions for Highway Work Zone Temporary Traffic Control Investigations

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Abstract

Incidents or collisions involving pedestrians, bicyclists, motorcycles, automobiles, heavy trucks, or tractor-trailers frequently occur in roadway or roadside areas affected by highway construction projects. When such events arise, the ensuing claims or litigation processes often concern whether or not the temporary traffic control (TTC) system in place at the time was compliant with the applicable standard of care. Due to the short-term and constantly changing nature of construction projects and work zones, the hardest challenge for the forensic engineer is often to determine what was in place at the time and location of the incident. This paper will introduce and expound on the application of modern technology solutions to address these questions. Methods for extraction of useful information from the raw data will be addressed, along with examples demonstrating the engineering application of this data to the underlying legal questions.

Keywords

Forensic engineering, temporary traffic control (TTC), maintenance of traffic (MOT), highway construction work zones, transportation engineering, highway safety, traffic control devices, photogrammetry, animation

Introduction

Construction and maintenance activities occur frequently throughout our nation's transportation network in order to improve function and safety, aid traffic flow, provide new benefits, or keep existing facilities at an adequate level of service:

- As our nation's travel demands grow, roadways continue to be expanded or upgraded. Aging roadways and bridges require rehabilitation and renewal projects.
- Construction of new roadways involves connections with the existing adjacent facilities.
- Expansion of transit systems impacts the surrounding vehicular and pedestrian routes.
- Private property construction activities affect the abutting public roadways and pedestrian routes.
- Our public infrastructure requires routine maintenance activities that alter the normal flow of traffic.
- Utility construction and maintenance work occurs within the public right-of-way.

In these situations (and others), the work to be completed provides an engineering benefit to the public, but a consequence of achieving the project's goals is a temporary alteration to the normal function of the public roadways or private roads open to public travel. These impacts on the transportation environment may include mobile and intermittent operations that are constantly moving, short- and intermediate-term events lasting from minutes to three days, or long-term projects that occupy a portion of roadway or sidewalk for weeks or months.

According to the *Manual on Uniform Traffic Control Devices* (MUTCD), anytime the normal function of a roadway (or private road open to public travel) is suspended by work activities, there needs to be an appropriate implementation of temporary traffic control (TTC) in order to provide continuity of movement for motor vehicles, motorcycles, bicycles, pedestrians, commercial vehicles, and transit (Manual on Uniform Traffic Control Devices 2009). The primary function of

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this TTC system is to provide for the reasonably safe and effective movement of road users through or around the work zones while reasonably protecting road users, workers, responders to traffic incidents, and equipment.

As with any permanent transportation facility, a variety of incidents may potentially occur within a TTC area:

- A pedestrian may trip and fall while walking through a temporary pedestrian detour.
- A bicyclist may encounter a pavement discontinuity around a drainage feature.
- A motorcyclist may encounter a vertical height difference within a milling and paving project.
- A passenger vehicle may have an intersection collision with another vehicle, or may depart from the roadway into the work zone and strike a piece of equipment.
- A commercial vehicle may collide with queued vehicles at a flagging station.

There are a nearly infinite variety of potential scenarios for incidents within a work zone or TTC area. Some of these may be coincidental, and have no relationship to the location where the event occurred. Others may have a direct relationship to the work zone, such as a lack of proper advanced warning or devices that were placed incorrectly by the workers (Hintersteiner 2008).

When a collision or incident does occur within a work zone area, it is not uncommon for claims or litigation processes to ensue. These types of cases often involve multiple interested parties, such as the claimants, other motorists, the governmental entity, owner of the project, the engineer designer of record, the prime contractor for the project, traffic control subcontractors, subcontractors conducting specific elements of the project related to the incident, and construction engineering / inspection (CEI) professionals. Though each party has different levels of involvement in the actual incident, all are typically interested in determining whether or not the TTC in place at the time of the incident was consistent with the standard of care and whether or not there was any connection between the existing TTC and the causation of the event. As such, any entity involved in the claim or litigation can benefit from a thorough and detailed forensic engineering evaluation to address the causation of the incident at hand and to help prevent similar incidents.

Despite the breadth of incident types (and the complexity of the highway construction industry), forensic engineers can follow a consistent process to complete an independent analysis of any incident and the TTC issues related to that event:

1. Forensic determination of what TTC system was actually in place at the date and time of the subject incident, including the selection and location of individual traffic control devices and the historical development of the TTC leading up to the date of the incident.
2. Engineering study to determine the applicable guidelines or standards for the work activity that was taking place, including a review of federal, state, local, and project-specific documents and publications.
3. A forensic engineering comparison between the existing TTC and the recommended TTC to identify any deficiencies or discrepancies.
4. If deficiencies or discrepancies existed, identification of the parties involved in the project and their relative responsibility for the condition in question.
5. Coordination of the TTC findings with a forensic engineering collision reconstruction effort, in order to evaluate whether any deficiencies or discrepancies are causally related, or unrelated, to the subject event.

Though Steps 2 through 5 of the methodology are outside the scope of this paper, all of the steps are predicated on first being able to determine (to a reasonable degree of engineering certainty) what was actually in place for the transportation system at the time of the incident. However, the scope of investigation needed for a TTC case is both extensive and complex:

- Geography of data needed: A TTC zone can be as small as a single driveway or sidewalk. Alternately, the areas affected by construction, including advanced warning areas, detours, and TTC devices, can extend for many miles, making the relevant "scene" of the incident larger than in most forensic engineering cases.

- Quantity of data needed: A thorough investigation would ideally identify and document all aspects of the TTC, including roadway geometry, lane usage, roadside conditions, pedestrian routes, permanent signs, temporary signs, permanent pavement markings, temporary pavement markings, channelizing devices, delineators, barriers, tapers, traffic signalization, sight lines, and any other relevant transportation engineering issue.

- Temporary nature of data needed: The ephemeral nature inherent to TTC zones has long presented difficult obstacles for forensic engineers. Some conditions exist only for a few minutes or hours. In contrast, notice of claims or litigation may not be provided until months or years have passed. In many forensic engineering assignments, the analyst is not contacted until well after the project is completed or has at least transitioned to another stage or phase of construction.

As modern technology develops, there are new techniques and resources that can be utilized to address these fundamental and critical questions for forensic engineering evaluation of TTC projects. Four categories are presented for data acquisition and information-gathering methods:

Engineering Solution 1: Field Investigation

When an involved party becomes aware of a major incident or potential claim situation, the immediate retention of a forensic engineering expert can be extremely beneficial for documentation and data preservation. A rapid response to the scene by the engineering data collection team allows the analyst to capture a snapshot of the TTC system before it has been changed by the ongoing flow of work activities. Specific technology applications for rapid response data collection include:

- Laser mapping (**Figure 1**) — Total station mapping can document the points in 3D space to identify the roadway geometry and locations of key TTC components directly in the area of the collision or incident. This serves as the basis for a scene diagram. However, this technology is not ideal for documenting all advanced warning and devices over miles of roadway.

Figure 1
Laser mapping of scene.

- Photography (**Figure 2**) — Visual documentation of the type, location, and orientation of all TTC devices is imperative. This task includes going back far enough to identify the beginning of the work zone for every direction of travel of an involved vehicle or pedestrian. As the roadway is likely to change as construction continues or is completed, it can be helpful to document photographs with permanent landmarks.

Figure 2
Photographs of scene.

- GPS coordinate data (**Figure 3**) — Collecting GPS coordinates of all TTC devices, along with major landmarks and roadway features, is a useful way to document locations and distances for future reference. This is especially helpful when major projects are going through large changes over time, which will eventually eradicate most visual landmarks or reference points.

Figure 3
GPS coordinates of key data.

- Videography (**Figure 4**) — Drive-through videos can be a useful method of documenting all of the advanced warning, channelizing devices, and information conveyed by the work zone to motorists or pedestrians for each approach to the scene of the incident. Traffic observational study videos can document how motorists are behaving within the work zone and responding to the traffic control setup.

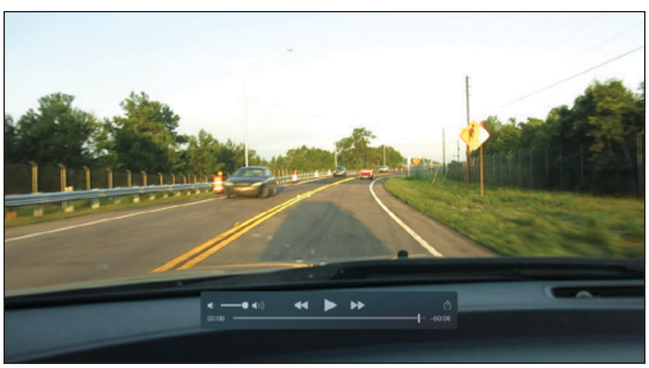


Figure 4
Scene drive-through video.

- Measurements – When relevant, the heights, widths, offsets, and sizes of TTC devices, work equipment, or sight line obstructions should be documented.

- 3D scanning (**Figure 5**) – Given the size and complexity of TTC systems, a full 3D scan of the entire environment can be an appropriate method for documenting all of the devices and

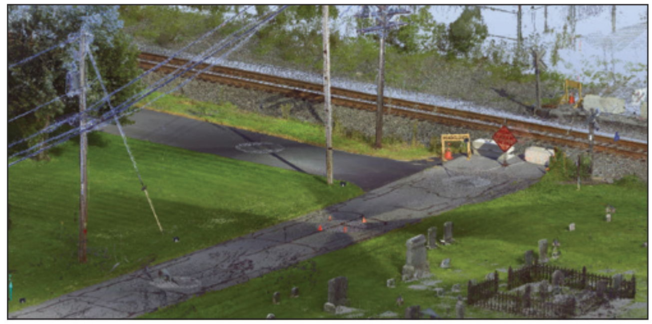


Figure 5
3-dimensional scanning.

roadway features. Modern 3D scanners create a cloud with millions of data points, which can be utilized for analysis or visualization.

- Aerial photography (**Figure 6**) — Some highway construction work zones, such as on major freeways in congested urban areas, cannot be safely documented with other methods. In such circumstances, an airplane or helicopter service (providing aerial photography with high resolution images) can be a source of data collection for roadway layouts and TTC devices (Dilich and Goebelbecker 1996) (Whelchel 2003). This is an especially useful method for projects that are very large or have many miles of TTC system.

Figure 6
Aerial photography of scene.

- Drones (**Figures 7** and **8**) — Remote-controlled high-resolution photography or videography can now be used in certain appropriate circumstances to document a TTC zone, offering many of the same advantages as piloted aerial

Figure 7
Drone photography.

Figure 8
Drone photography.

Figure 9
Imprint of sign.

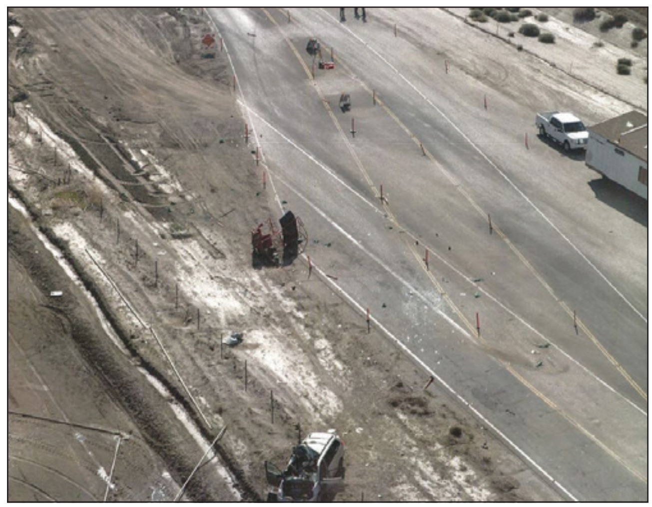


Figure 10
Obliterated lane lines.

photography. It is expected that this technology will continue to evolve in the near future.

In circumstances when the forensic engineer is notified after there have already been changes made to the temporary condition of the roadway and traffic control devices, field investigation can still prove fruitful. Mapping or 3D scanning of the permanent roadway, landmarks, markings, and signs are an important basis for diagramming the scene, and will be used in combination with later techniques. Often, evidence of previous stages can still be found in the roadway environment. For example, there may be a darkened asphalt area where the base of a drum had been, or dead grass in the area of a portable changeable message sign (PCMS) trailer (**Figure 9**) had been. Obliterated pavement markings can usually be identified and mapped to determine their previous position (**Figure 10**). Station marking paint should also be documented for cross-reference with the project plans. A thorough field investigation may provide extensive insight into the previously existing TTC, even after the completion of the construction project.

Engineering Solution 2: Police and First Responder Materials

Police officers and other first responders have a unique opportunity to document the conditions of the construction project and TTC immediately after an incident occurs. However, the focus of their investigations usually is on the determination of criminal conduct and the provision of emergency and medical services. As such, there is a variety of detail and thoroughness to be found in the investigative materials of first responders.

The main difficulty faced, from a traffic engineering evaluation perspective, is that the first responders tend to be focused directly on the areas of impact and final rest — with little or no documentation of any advanced warning devices or the TTC in the area leading up to the incident location. In many cases, photographs are limited to the area within 100 feet upstream from the area of impact.

First responders sometimes actually create a greater challenge for the forensic engineer in determining the TTC that existed at the time of the incident because it is not uncommon for police or emergency services to either move the TTC devices to gain access with their vehicles and equipment or to move the work zone's TTC devices to provide traffic control around the incident investigation area. This should be considered when evaluating the TTC setup documented in first responder materials.

There may be important evidence and data captured in first responder materials, or there may be nothing of use. Some of the sources of data that can be extremely helpful, if they are available, include:

- Scene photography (**Figure 11**) — Some investigators thoroughly document an entire TTC system on approach, though this is not common. Even if the focus of the photograph is not on TTC, there may be documentation of the roadway and devices visible in the background.

Figure 11
Police scene photographs.

- Mapping and measurements (**Figure 12**) — Especially in serious injury or fatality cases, police investigators may use either a laser or wheel device to document the location of items, including lane markings, tapers, crash attenuators, barrier walls, signs, arrow panels, or channelizing devices. These can be incorporated into the forensic engineering diagram by tying in to a permanent landmark or reference points.

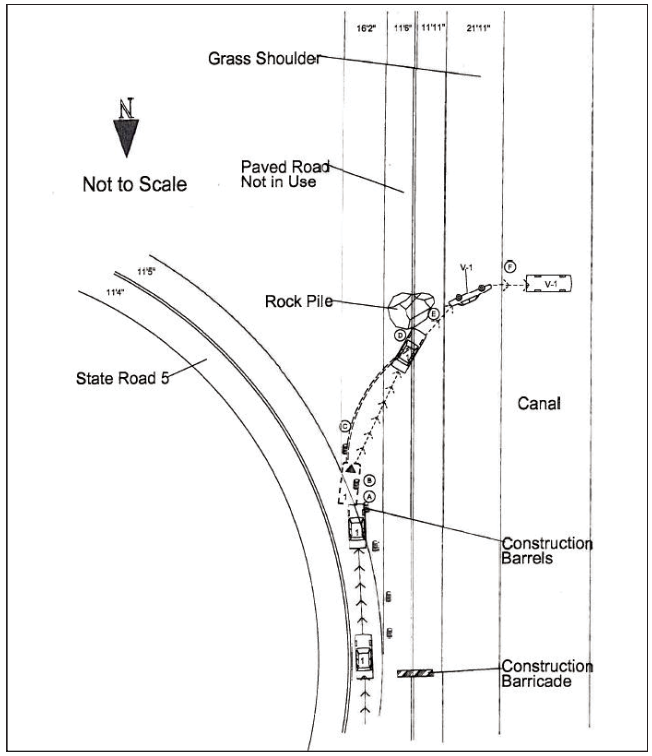


Figure 12
Police investigation measurements.

- Field notes — In some cases, police investigators may do a drive-through of the entire work zone and make written notes about the identification and location of various signs and devices. In other cases, there may be generalized references to signs and other TTC, but without specific locations provided.

- Dash cams (**Figure 13**) — If the police, fire, or emergency vehicles are equipped with a dashboard camera, they may inadvertently document the entire approach to the collision location as a side benefit. Some or all of the advanced warning signs, arrow panels, PCMSs, channelizing devices, taper locations, and other critical TTC information may be identified in the frames of the video as the vehicle proceeds. In some circumstances, the dash cam continues recording after the vehicle comes to a stop, and

Figure 13
Police dash camera footage.

might capture the post-incident relocation of existing TTC setups as first responders adjust to control traffic around the investigation area. One challenge with obtaining this type of documentation is getting a copy of the video footage before it is overwritten by future video.

Engineering Solution 3: Public Sources

With increases in the technologies adopted in our society, there has been a trend toward imagery becoming available from sources entirely unrelated to the subject incident. Many TTC cases have been forensically evaluated thoroughly, thanks to the fortuitous availability of video or photographic evidence. Though not comprehensive, these are some of the categories of public information sources that have been used to collect TTC data:

- Driver, witness, or passerby photography (**Figure 14**) — Whether with a digital camera, film camera, or cell phone, many incidents now have one or more photographs taken by someone other than law enforcement and first responders. Even if the focus of the photograph is not on TTC, there may be documentation of the roadway and devices visible in the background.

- News media (**Figure 15**) — Still photography or videography of an incident scene may be captured by media professionals and published in print, television, or online formats. A search for relevant news imagery may result in useful documentation of a temporary work zone TTC system. This is especially helpful when media crews use elevated camera positions or helicopter-based videographers to document large segments of the roadway.

Figure 14
Photo by unrelated passerby.

Figure 15
Photograph taken by media.

- Surveillance videos and dash cams (**Figure 16**) — Many private businesses and residences are equipped with security or surveillance cameras that may be pointed in a direction of interest for documenting the collision scene or roadway approach. Many commercial and private vehicle owners are choosing to install video camera data recorders in their vehicles, which can be manually triggered or can automatically trigger a recording when internal accelerometers indicate a collision event. Some units have multiple camera views, such as both forward and rearward. The video footage captured may

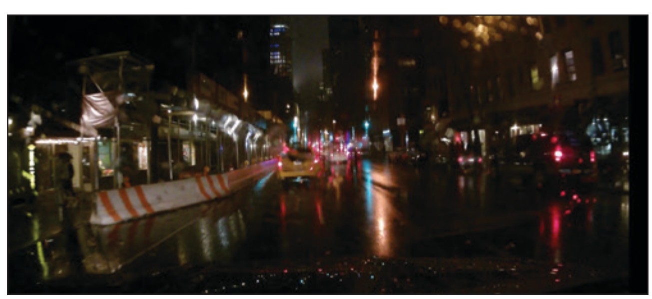


Figure 16
Surveillance / dash cam footage.

inadvertently document the entire approach to the collision location. Some or all of the advanced warning signs, arrow panels, PCMSs, channelizing devices, taper locations, and other critical TTC information may be identified in the frames of the video as the vehicle proceeds.

- Historical dated aerials (**Figure 17**) — Rectified aerial photographs of roadway environments are available from numerous public sources, including Google Earth, Microsoft Bing, TerraServer, and local government agencies (Wirth et al. 2015). Published research has indicated that these sources are typically adequately precise for taking scaled measurements. As most images are dated, it is possible to either find an aerial that captured the sequence of construction and the TTC in place for that phase, or at least to bracket the date of the incident with aerials from both before and after. Depending on the resolution of the imagery, it can be difficult in satellite aerial imagery to identify the legends of specific signs, but usually the pavement markings, channelizing devices, and large devices such as PCMS or arrow panels are well documented.

Figure 17
Dated aerial image.

- Historical dated photographs (**Figure 18**) — Services including Google and Bing also continue to publish photographs that are not from directly overhead, but instead from an orthogonal angle or from street level. These images, many of which are dated, provide a better opportunity to view the faces of signs and the locations of traffic signal heads, while also documenting the pavement markings, roadway geometry, and other TTC devices.

Figure 18
Dated street view image.

- Social media (**Figure 19**) — Occasionally, a private individual posts photos or videos of a roadway on social media sites such as YouTube. Sometimes passersby are documenting the incident aftermath. In one case, a motorcyclist videotaped his drive-through along a segment of roadway that happened to occur on the same day as a collision event. That video was not intended to investigate the TTC, but it captured each sign location along the way.

Figure 19
Social media footage.

Engineering Solution 4: Project Documents and Resources

Numerous documents are typically produced and retained as part of ongoing highway construction or building construction projects. Many of these documents also provide useful information in a forensic engineering context. Whether gathered directly from a client or through the court-directed production process, a thorough study of the documents should be conducted to glean engineering data. Items of interest may include the stage of construction, the duration of a work phase, the location of work activities, the identity of individuals involved in specific tasks or inspections, the timing of TTC implementation, and the specific devices and locations for the TTC system. The following sources may provide engineering data relevant to the investigation:

- Contractor emergency response (**Figure 20**) — Some highway construction companies, construction engineer / inspection (CEI) firms, or governmental agency engineers respond to the scene of a major incident if they are aware of it occurring within their work zone. These individuals may photograph the location of the incident and the surrounding roadway environment in order to develop safety improvements and countermeasures — and in order to preserve this information in case of later claims or litigation.

Figure 20
Contractor emergency response image.

- Contractor drive-through videos (**Figure 21**) — Some contractors or governmental agencies routinely videotape drive-throughs of their large projects to document the ongoing work activities and TTC devices.

- Contractor progress aerials (**Figure 22**) — For major construction projects, an aerial photography company may be hired to conduct weekly or monthly routine progress aerials, documenting the stage of construction as well as the TTC system.

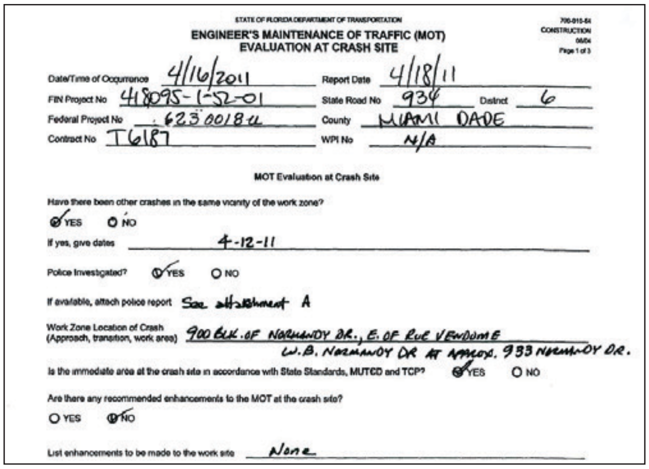
Figure 21
Contractor drive-through video.

Figure 22
Progress aerial.

- Contractor work photographs (**Figure 23**) — When issues arise with a construction activity, or major accomplishments are completed, some contractors or subcontractors will choose to photograph their work for documentation. If the TTC is visible in the background, these photos can be helpful as well for the forensic engineer.

Figure 23
Contractor work photographs.

- Post-collision reports (**Figures 24**) — Some state agencies require an investigation to be conducted following a known incident within a work zone. For example, the Florida Department of Transportation (FDOT) issues a standard form called "Engineer's Maintenance of Traffic Evaluation at Crash Site," which should be completed by the state's project engineer or their retained CEI professional. This document can include diagrams, measurements, data logs, or narrative descriptions.


STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
ENGINEER'S MAINTENANCE OF TRAFFIC (MOT)
EVALUATION AT CRASH SITE

700-010-84
CONSTRUCTION
06/04
Page 1 of 3

Date/Time of Occurrence 4/16/2011 Report Date 4/18/11
FIN Project No 418095-1-52-01 State Road No 934 District 6
Federal Project No 6230018 U County MIAMI DADE
Contract No T6187 WPI No N/A

MOT Evaluation at Crash Site

Have there been other crashes in the same vicinity of the work zone?
YES NO
If yes, give dates 4-12-11

Police Investigated? YES NO

If available, attach police report See attachment A

Work Zone Location of Crash (Approach, transition, work area) 900 BLK. OF NORMANDY DR., E. OF RUE VENDOME
W.B. NORMANDY DR AT APPROX. 933 NORMANDY DR.

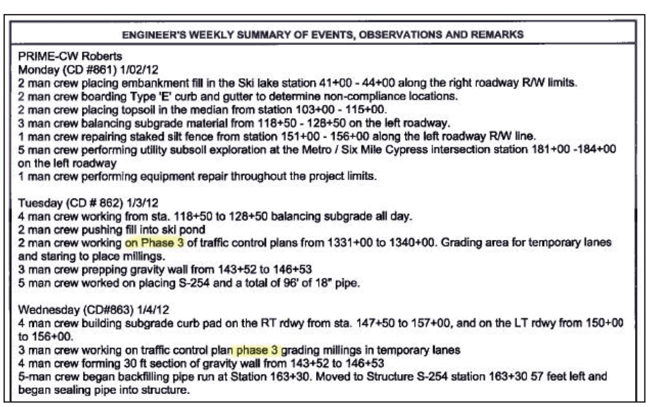
Is the immediate area at the crash site in accordance with State Standards, MUTCD and TCP? YES NO

Are there any recommended enhancements to the MOT at the crash site?
YES NO

List enhancements to be made to the work site None

Figure 24
Construction project post-collision evaluation.

- Daily reports of construction or daily time sheets (**Figure 25**) — Most governmental agencies require daily accounting of the work activities by all contractors, subcontractors, and equipment. This usually includes the location of work (either with general descriptions or station numbering), a description of the work, a numerical tabulation of quantities, and information about any discrepancies or unusual situations encountered.


ENGINEER'S WEEKLY SUMMARY OF EVENTS, OBSERVATIONS AND REMARKS

PRIME-CW Roberts
Monday (CD #861) 1/02/12
2 man crew placing embankment fill in the Ski lake station 41+00 - 44+00 along the right roadway R/W limits.
2 man crew boarding Type 'E' curb and gutter to determine non-compliance locations.
2 man crew placing topsoil in the median from station 103+00 - 115+00.
3 man crew balancing subgrade material from 118+50 - 128+50 on the left roadway.
1 man crew repairing staked silt fence from station 151+00 - 156+00 along the left roadway R/W line.
5 man crew performing utility subsoil exploration at the Metro / Six Mile Cypress intersection station 181+00 -184+00 on the left roadway
1 man crew performing equipment repair throughout the project limits.

Tuesday (CD # 862) 1/3/12
4 man crew working from sta. 118+50 to 128+50 balancing subgrade all day.
2 man crew pushing fill into ski pond
2 man crew working on Phase 3 of traffic control plans from 1331+00 to 1340+00. Grading area for temporary lanes and staring to place millings.
3 man crew prepping gravity wall from 143+52 to 146+53
5 man crew worked on placing S-254 and a total of 96' of 18" pipe.

Wednesday (CD#863) 1/4/12
4 man crew building subgrade curb pad on the RT rdwy from sta. 147+50 to 157+00, and on the LT rdwy from 150+00 to 156+00.
3 man crew working on traffic control plan phase 3 grading millings in temporary lanes
4 man crew forming 30 ft section of gravity wall from 143+52 to 146+53
5-man crew began backfilling pipe run at Station 163+30. Moved to Structure S-254 station 163+30 57 feet left and began sealing pipe into structure.

Figure 25
Contractor daily report of construction.

- Project plans and specifications (**Figure 26**) — In situations with temporary detours or temporary roadway construction, the project plans can provide information about the roadway geometry of the temporary facility even if the temporary asphalt has been destroyed prior to being documented by the forensic engineer. The project plans also provide insight into the general phasing of the construction project, the traffic control setup intended by the design engineer, and context for the forensic engineer to consider when evaluating the overall TTC system.

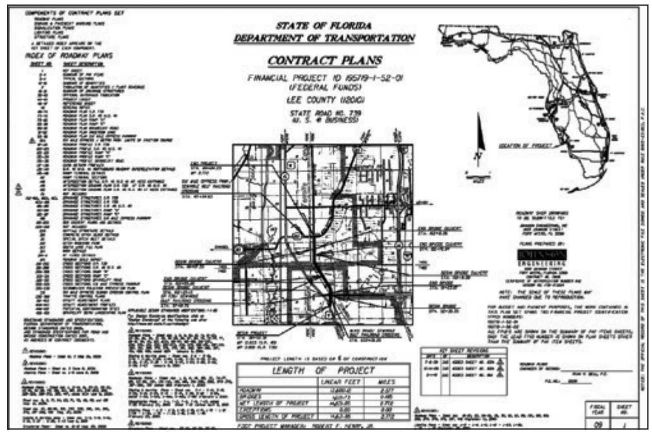


Figure 26
Project plans and specifications.

Analyzing the TTC Data

As described in the introduction, the purpose of the forensic engineering data collection efforts is to generate a comprehensive understanding of the transportation system that existed for users at the time of a past incident. In order to be able to evaluate the information available to motorists, the effectiveness of the traffic control devices — and the appropriateness of the overall TTC system — the forensic engineer needs to complete a tabulated list of TTC devices and a graphical representation of the roadway environment. The goal is a thorough and accurate scaled diagram, depicting all of the aspects of the transportation system through the TTC zone (**Figure 27**).

After gathering data using the engineering solutions listed above, engineering processing and analysis of the data is still necessary to convert raw data into a usable format. For example, photographs of roads and signs are useful data, but they need to be processed to convert the information into spatial coordinates. Some photographic data is easily incorporated into a scene diagram based on permanent landmark references or

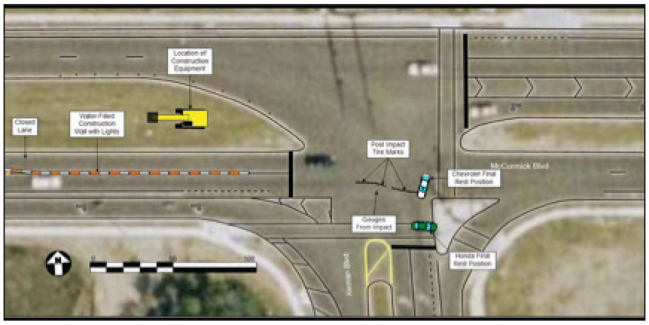


Figure 27
Scaled diagram of TTC zone.

photo-matching methods. In complex scenes, greater precision can be accomplished utilizing one of multiple photogrammetry techniques (Fenton and Kerr 1997) (Hicks 1999) (Ziernicki 2000) (Fenton et al. 2001) (Danaher and Ziernicki 2007) (Randles et al. 2010). Many forms of photogrammetry are reliant upon known locations of existing structures in the photographs and videos. Examples of these existing structures include lane lines lengths and widths, trees, permanent signage, or buildings. Once the positions of known objects within a photograph or video are determined, the TTC devices that were temporary and no longer available for documentation can still be located within 3-dimensional space. There are numerous computer programs that will assist an analyst in performing the photogrammetry analysis, such as Photomodeler (from Eos Systems Inc.) or iWitness (from DCS Inc.), or the analysis can be done in some circumstances by hand, utilizing parallel lines and similar triangles. In especially complicated cases, the entire geometry of a temporary roadway, which may have existed only for a short period of time during one phase of a construction project, can be re-created in 3-dimensional space utilizing photogrammetry processing.

After all the photographic, coordinate, and narrative data has been compiled from all available sources, the final product is a to-scale scene diagram. This creates the overall visual reference for subsequent steps of the forensic engineering analysis of the TTC system, including evaluating whether safety countermeasures can be developed, and whether the work zone was in compliance with applicable plans, guidelines, and standards at the time of the incident. First, the diagram should include "re-building" the roadway geometry as it was at the time of the incident, including historical aerials in the background. The diagram should extend sufficiently far in every direction to incorporate the relevant transportation engineering context, and should include related items such as hills, curves, intersections, interchanges, sight distance obstructions, and roadside obstacles. Additional data that can be added to the diagram, if available, include police measurements, to-scale police diagrams, and laser scene mapping of roadway geometry and temporary traffic control devices. Coordinates of items developed through photogrammetry analysis of photos or videos can be added as another layer of data, including signs and markings, channelizing devices, traffic signals, or other TTC devices. If coordinating with a collision reconstruction, the transportation engineer can include pertinent information from the subject collision in the overall diagram, such as points of impact, sight lines, critical decision points, and a distance-time line to evaluate the information available to each motorist as they traversed the work zone prior to impact. In addition to assisting with the analysis process for the engineer, a completed diagram serves as a visual communications tool for educating clients, juries, attorneys and claims personnel regarding the roadway environment and TTC system as it existed on the date of the subject incident.

Another communication technique that can be especially effective for these temporary roadway conditions is a 3-dimensional recreation of the scene, either as a static image 3D rendering or in the form of a real-time moving animation (**Figure 28**). In many cases, this is the only way to visually depict the actual TTC condition as it existed at the time of the incident, since everything was changed prior to documentation. An animation brings together the vehicle motions from the collision reconstruction with the forensic engineering evaluation of the TTC setup, and places the viewer in a position to see a realistic perspective from various viewpoints in real time (**Figure 29**). For example, the animation may depict the viewpoint of an involved driver as he or she passes by each of the advanced warning signs and continues without slowing down before ultimately crashing into a queue of stopped vehicles ahead. The type of animation selected will vary widely based on case-specific facts, but can be a very effective tool for demonstrating the final opinions and conclusions of the forensic engineer when based on a thoroughly documented process described above for collecting and analyzing data from new technology sources.

Figure 28
3D Visualization of TTC zone.

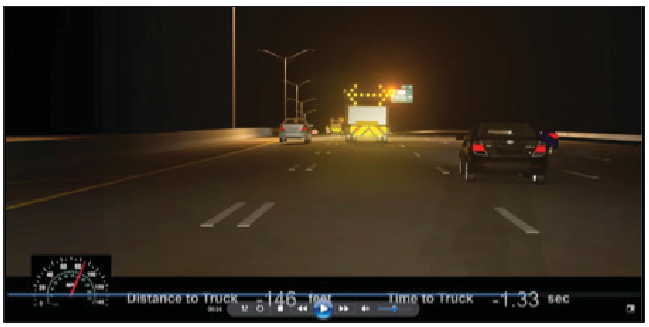


Figure 29
3D Visualization of TTC zone.

Conclusion

Forensic engineering cases involving the evaluation of temporary traffic control issues are inherently challenging due to the changeability and short-term nature of the scenes. They are further complicated by the large-scale geography, complexity, and multi-party aspects of the claims. However, many of the new technological developments that were presented throughout this paper can be leveraged to the advantage of the forensic engineer in order to gather data, process geospatial information, and accomplish a thorough re-creation of how the roadway environment and TTC system existed at the time of the subject incident. Use of these technologies improves opportunities to develop safety improvements, identify deficiencies, or develop professional engineering conclusions regarding the work zone's role in a specific incident.

Additional technologies and methodologies have also been developed to aid in the engineering analysis and the final communication of opinions and conclusions. Moving forward, it is likely that more sources of video and still imagery will proliferate, making these techniques critical for the effective forensic engineering evaluation of transportation safety incidents.

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