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# Forensic Engineering Analysis of Roadway Geometry and Traffic Control

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## Abstract

*When evaluating evidence for causative factors contributing to a motor vehicle collision, consideration should be given to roadway geometric or traffic control factors. Roadway geometry, clear zone, safety features, visibility obstructions, and traffic control devices and their placement may influence drivers' behavior. Are the roadways involved properly designed and signed? The geometric design and traffic control requirements for special circumstances, such as highway construction zones, mixed-use paths, railway crossings, or low traffic volumes, may also present the potential for roadway issues. An evaluation of these potential contributing factors can open a Pandora's box of opportunities for errors when an improper engineering analysis follows. This paper explores the topics that guide proper engineering analysis of roadway geometry and traffic control, including determining which design standards, policies, or guidelines apply and the proper application of the semantics in these documents. Additionally, this paper addresses recommendations contained in research concepts or reports versus requirements for the designer, the constructor, or the roadway owner. The discussion includes examples from past cases addressing the topics presented, providing a systematic approach to evaluating permanent or temporary roadway geometric or traffic control design for factors contributing to a collision event.*

## Keywords

Roadway design, forensic engineering, civil engineering, forensic analysis, collision analysis, litigation, accident reconstruction, construction zone, temporary traffic control, road design, project development

## Introduction

Forensic engineers analyzing collision events typically focus on the evidence from the aftermath of an incident when evaluating the progression and timing of events. The forensic engineer oftentimes relies on evidence that may include final rest locations of vehicles, tire and gouge marks, debris fields, and electronically imaged data. The most frequently identified contributing factors involve driver actions, vehicle mechanical condition, roadway features, traffic control, and the environment. Contributing factors may also include confusing, missing, or misleading information or roadside safety features.

The authors provide a general overview of the project development process and discuss several national highway design manuals, highlighting how this information can have an important influence on a collision investigation. This paper begins with a high-level overview of the design process from initial programming to construction. Next, it

discusses the guiding documents provided to designers and agencies and how engineers use these standards and policies to make design decisions. The discussion then transitions to the semantics of the guiding documents, with the intent of highlighting where many forensic analyses go astray. The paper concludes with several case study examples in which design features, including both permanent and temporary ones, may contribute to collision events.

## Process — Programming to Construction Programming

Planning and programming of highway construction projects usually begin years, if not decades, before the first shovel breaks ground and normally involves individuals and agencies from the local level to the federal level.

Smaller local governments, regional agencies, and other stakeholders/groups with a vested interest in transportation combine to either form metropolitan planning

organizations (MPOs) or regional planning organizations (RPOs) at the local level. It is these MPOs and RPOs that are tasked with regional planning and programming for all modes of transportation. MPO and RPO operations are similar, with the major differentiator being population density and geographic boundaries (i.e., municipality, city, county, etc.) [1].

RPOs, according to the Federal Highway Administration (FHWA), can also be identified by other naming conventions, such as regional affiliations, councils of government, and others, but these organizations are generally referred to as RPOs. Currently, approximately 30 states have RPOs in place [2]. Regardless of the organization of local transportation planners, RPOs, and MPOs, they are tasked with working with state agencies to identify highway and transit projects.

From the federal level, the United States Department of Transportation (USDOT) oversees 11 operating administrations, including the FHWA, which “supports state and local governments in the design, construction, and maintenance of the nation’s highway system (Federal Aid Highway Program) and various federally and tribal owned lands.” [3] The FHWA provides financial and technical assistance to state and local governments.

A project must fulfill a need as defined by the National Environmental Policy Act (NEPA) for the identification and programming of the project to take place. Often, public welfare drives projects that aim to improve safety (e.g., when a roadway feature no longer functions as intended or newer technology becomes available). Whether traffic volumes exceed projections or a stop-controlled intersection, for example, is experiencing a high frequency of crashes, a need is identified, and a project is born.

### **Design**

Once a project has the general parameters determined, it is ready for the design phase. Projects can be designed in-house by the respective agency or designed by a consultant working under contract with the agency. A senior-level PE provides oversight for a specific discipline or manages the project in its entirety, while less experienced engineers typically perform detailed design. For this reason, a designer’s quality assurance/quality control (QA/QC) plan is fundamentally important for the production of transportation facilities that are safe enough for the traveling public.

The design process involves multiple submission and

review cycles to evaluate the design against established design criteria, established early in the design development process. Comments and feedback are provided that require sufficient review and attention before approval is received for the respective submission.

### **Design Resources**

Entry-level highway and traffic engineers graduate with a cursory understanding of national design guides and standards most frequently used in highway design. Very little, if any, of the baccalaureate academic career focuses on state-specific guides and standards. However, all state design guidance and standards are based on national standards, publications, guidance, and research.

This paper limits the discussion to three primary national documents that provide the policies or standards relied upon by highway design engineers:

- The American Association of State Highway Transportation Officials (AASHTO), *A Policy on Geometric Design of Highways and Streets* (Green Book)
- AASHTO’s *Roadside Design Guide* (RDG)
- FHWA’s *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD).

### **National Design Resources Geometric — Green Book**

The current version of the *Green Book* at the time of this paper’s writing is the 7th Edition, dated 2018 [4]. Founded in 1914, AASHTO, then known as the American Association of State Highway Officials (AASHO), met for the first time [5], but it wasn’t until 1965 that the first edition of the *Green Book* was published. However, prior to publishing the first *Green Book*, AASHO/AASHTO was involved in developing federal legislation from the group’s inception.

A Policy on Geometric Design of Highways and Streets, commonly referred to as the “*Green Book*,” is a publication produced by AASHTO that provides the policy by which states develop the standards for the design of roadways on the National Highway System (NHS). Each state may adopt the *Green Book* as standard, revise the *Green Book*, or develop its own that meets or exceeds the policy of the *Green Book*. Highway designers represent the target audience of the *Green Book* in the development of roadway geometric elements.

In the most recent versions of the *Green Book*, the text presents the concepts an engineer should understand regarding the relationships among the facets of geometric highway design, explains the development of the different concepts, and provides associated calculations. The *Green Book* also provides corresponding equations and adjustment factors for site-specific circumstances, such as grade. The results represent the minimum (or maximum) acceptable values that should be considered for design. For example, Table 3-1 provides the minimum design stopping distance for speeds ranging from 15 mph to 85 mph. With this type of presentation, the *Green Book* provides a pass/fail metric for evaluation, provided the person performing the evaluation properly applies the guidance.

With the *Green Book* developed for designers, the guidelines provide inherent challenges for the forensic engineer's evaluation of the as-built condition. The *Green Book* relies on holistic situational guidance requiring the engineer to evaluate a situation in a "connect-the-dots" systematic approach. The designer works from given parameters that define variables such as road type (freeway, arterial, collector, or local) and design speed, while the forensic engineer must determine the road type and consider the posted regulatory speed limit (PRSL). From there, the forensic engineer evaluates the design elements to determine whether the as-built conditions meet the design minimums (or maximums). It is also beneficial for a forensic engineer to be able to access and review project design records as part of the investigation, as discussed later in this paper.

### **Safety — Roadside Design Guide**

Just as the *Green Book* provides design guidance for the roadway itself, designers use the *Roadside Design Guide* (RDG) as a resource guide for applying the clear zone concept and shielding the traveling public from roadside obstructions. A simple way to differentiate between the *Green Book* and RDG is to think of the *Green Book* as containing design guidance for everything a vehicle is intended to touch, while the RDG contains design guidance for elements a vehicle is not intended to touch. AASHTO published the 4th Edition of the RDG in 2011 [6], the current version as of the time of this writing. The RDG may be referenced directly by individual highway agencies or used as a basis for developing their respective guidelines and standards, and it functions in conjunction with other design resources, such as the *Green Book*.

According to the FHWA, the first edition of the RDG

was adopted by FHWA and became effective on July 25, 1990 [7]. Many engineers may mistakenly refer to the RDG as a standard (as is the MUTCD discussed later) or policy (as is the *Green Book*), but it is neither. The RDG serves as a tool for designers, but ultimately the transportation agency soliciting the design should either maintain its own standard or adopt the document(s) as its standard. The RDG allows engineers and designers to establish a "clear zone" and identify obstructions located within.

The RDG includes a toolbox of options that designers and engineers can use for the selection of highway safety appurtenances to shield an obstruction. Transportation agencies can also use the RDG for developing their approved product list, respective design criteria, and standards. Many styles of roadside barrier, crash attenuators, end treatments, breakaway supports, and other options are presented in the RDG to facilitate establishing a proper clear zone.

As time progresses, it is inevitable that design standards and guidance are revised and updated, and the RDG is no different. A forensic investigation that includes an analysis of roadside grading and traffic barriers, for example, could identify features that may have been designed and installed appropriately and according to standards, but through time have lost the ability to meet the standards to which they were designed. Careful evaluation and documentation of the "non-traveled way" elements associated with an accident scene will aid a forensic investigation for causation.

### **Signage/Pavement Markings — Manual on Uniform Traffic Control Devices for Streets and Highways**

The first release of the *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) occurred in January 1927, as AASHO published the *Manual and Specifications for Manufacture, Display, and Erection of U.S. Standard Road Markers and Signs* [5]. At the time, however, the manual only included signage for rural areas. Signage for roadways located in urban areas was published by another agency. The rural and urban manuals were combined in 1932 when AASHO released the first official *Manual on Uniform Traffic Control Devices*. It wasn't until after the Highway Safety Act of 1966 that the FHWA became the agency responsible for the MUTCD, and it published its first version in 1971. Since 1971, FHWA has released updated versions of the MUTCD, with the most recent (11th edition) becoming effective on January 18, 2024.

The MUTCD was developed to establish a minimum standard that all transportation agencies must meet. Transportation agencies can either adopt the MUTCD as their standard, develop a state supplement to the MUTCD, or write their own version that meets or exceeds the federal MUTCD standards. The MUTCD provides standards for both permanent and temporary traffic control, but even with minimum standards defined, designers must use their engineering judgment and experience when applying them to each unique project or situation. States had until January 18, 2026, to adopt the 11th Edition of the MUTCD. It is important for engineers to know which edition the agency for which they are designing currently uses. As of the time of the writing of this report, 18 states have adopted the national MUTCD (2009 Edition), 22 states and two territories have adopted the national MUTCD (2009 Edition) along with a state supplement, and 10 states have adopted a State MUTCD (2009 Edition) [8].

The MUTCD functions very differently from the *Green Book* and RDG in how it provides information to designers. The MUTCD establishes minimum requirements for traffic control devices and provides additional commentary, including support, options, and guidance on when and where to use those devices. These semantics drive the use of the MUTCD and are discussed later in this paper.

Conversely, the AASHTO publications described in this paper define frequently encountered design situations and provide guidelines for developing and refining the design. For example, the *Green Book* provides the designer with guidance on how to balance the horizontal and vertical alignment by identifying the best locations for curves based on factors such as driver perception, comfort, and expectations. The *Green Book* builds upon that guidance and, in later chapters, provides minimum radii based on design speed, provides guidance on superelevation and rate, and so on. The *Green Book* provides flexibility such that multiple engineers may each have different solutions to a design, all of which may meet *Green Book* guidance. On the other hand, the MUTCD addresses site-specific features, such as signs and pavement markings. In the case of the horizontal curve design, the MUTCD will define under what conditions advance warning signs or additional pavement markings should be included.

### Design/Contract Documents

Highway design contracts include more than just roadway and temporary traffic control plan sets. Teams of engineers responsible for the design will compile the bid

package documents and submit them to the letting agency for contractor selection. Any number of items can be included in the bid package, and it is critically important that a designer understands the proper order (or hierarchy) of these documents. The order of the design documents may differ between transportation agencies. For example, according to the *2020 Standard Specifications for Construction*, the order of precedence for the Michigan Department of Transportation (MDOT) is as follows [9]:

1. All proposal material except the materials listed in subsections 104.06.B through 104.06.F;
2. Special provisions;
3. Supplemental specifications;
4. Project plans and approved working drawings;
5. MDOT standard plans; and
6. Standard specifications

The full list and most current order of MDOT documents should be referenced on MDOT's website.

It is important for engineers and designers to know the hierarchy of design documents. Likewise, a forensic engineer working to determine causation factors must understand this order when reviewing as-built or construction documents to determine which document controls in cases with conflicting information.

### Construction

Typically, for public design/bid/build projects, the most common public highway construction contract procurement method, the project owner releases the contract documents for review and bidding and selects the lowest bidding contractor that meets all contractual requirements. Once awarded, the contractor and owner sign the contract, and the project progresses into the construction phase. While other contract procurement methods are available (A+B bidding, design-build, performance contracting, etc.), engineers must understand that design changes do occur during construction. No matter the method of contract procurement, any such changes should be stored with the project records by the owner. Forensic engineers should refer to as-built or as-constructed plan sets, if available, to ensure any design changes made during construction are included. Using or relying on as-designed plans may not paint the full picture required by the forensic engineer.

## Waivers, Design Exceptions, and Variances

Designing for the natural environment can be challenging. Constraints, such as limited right-of-way, topographic changes, and sensitive environmental areas, are just a few examples of the many factors that can limit an engineer's design options, whether the design is a retrofit of an existing facility or an entirely new facility. In addition, when designing improvements to an existing facility, features that no longer meet current design criteria may need to be modified to meet current design standards and guidelines. In some situations, there may be no viable options within the scope of work that will allow an engineer to fully meet design requirements. The engineer must then, through his or her education, training, and experience, develop an engineering solution that best meets the requirements and document in the form of a design exception, variance, or waiver, how and why the selected design is optimal. The owner must maintain all approved waivers, variances, and/or design exception documentation with the respective project records.

Roadways of differing classifications and types may require different levels of waivers. For example, the FHWA requires a design exception to be developed and approved for any of 10 controlling criteria on National Highway System (NHS) roadways with a design speed greater than or equal to 50 mph [10]. The 10 controlling criteria follow:

1. Design speed,
2. Lane width,
3. Shoulder width,
4. Horizontal curve radius,
5. Superelevation rate,
6. Maximum grade,
7. Stopping sight distance,
8. Cross slope,
9. Vertical clearance, and
10. Design loading structural capacity.

While the FHWA requires the design exceptions for the listed criteria, other transportation agencies may require similar waivers or exceptions, or expand the listed

criteria, for roadways under their jurisdiction. The Pennsylvania Department of Transportation (PennDOT), for example, requires an 11th controlling criterion for acceleration and deceleration lane length [11]. Another example of a frequently used waiver/exception would be for pedestrian facilities such as sidewalks, pedestrian curb ramps, driveway aprons, etc. For more than a decade, the *Proposed Draft Accessibility Guidelines for the Public Right-of-Way* were used by highway agencies in developing standard drawings and engineers to design pedestrian facilities within the public right-of-way. On August 8, 2023, the United States Access Board published the final rule on the minimum accessibility guidelines for pedestrian facilities within the public right-of-way. Pedestrian curb ramps, for example, are notoriously difficult to design and construct. Many highway agencies maintain their own type of waiver when pedestrian facilities do not meet accessibility requirements, which has been a focus of many lawsuits [12]. Well-documented design decisions, especially design exceptions, provide the forensic engineer valuable insight into reasoning for the chosen options, which may not be readily apparent post-construction and post-incident.

## Semantics — “Words Have Meaning”

The subtitle “Words Have Meaning” summarizes the content of this section. The MUTCD divides its guidelines into four categories, with the definitions reprinted verbatim in the 2009 MUTCD [13]:

- **Standard** — a statement of required, mandatory, or specifically prohibitive practice regarding a traffic control device. All Standard statements are labeled, and the text appears in **bold** type. The verb “shall” is typically used. The verbs “should” and “may” are not used in Standard statements. Standard statements are sometimes modified by Options.
- *Guidance* — a statement of recommended, but not mandatory, practice in typical situations, with deviations allowed if engineering judgment or engineering study indicates the deviation to be appropriate. All Guidance statements are labeled, and the text appears in unbold type [italic]. The verb “should” is typically used. The verbs “shall” and “may” are not used in Guidance statements. Guidance statements are sometimes modified by Options.
- **Option** — a statement of practice that is a permissive condition and carries no requirement or recommendation. Option statements sometimes

contain allowable modifications to a Standard or Guidance statement. All Option statements are labeled, and the text appears in unbold type. The verb “may” is typically used. The verbs “shall” and “should” are not used in Option statements.

- Support — an informational statement that does not convey any degree of mandate, recommendation, authorization, prohibition, or enforceable condition. Support statements are labeled, and the text appears in unbold type. The verbs “shall,” “should,” and “may” are not used in Support statements.

Therefore, is a standard absolute? Not necessarily. Decisions must consider the situational context in which they are made. Section 1A.09 of the MUTCD [13] defines the following **Standard** text: **This Manual describes the application of traffic control devices, but shall not be a legal requirement for their installation.** *Directly followed by Guidance text stating: The decision to use a particular device at a particular location should be made on the basis of either an engineering study or the application of engineering judgment. Thus, while this Manual provides Standards, Guidance, and Options for design and applications of traffic control devices, this Manual should not be considered a substitute for engineering judgment. Engineering judgment should be exercised in the selection and application of traffic control devices, as well as in the location and design of roads and streets that the devices complement.*

It is unrealistic to expect a single guidance document or standard to be sufficient for all designs across the United States, and the MUTCD affords engineers flexibility to modify designs to fit specific situations. For example, sign placement guidelines from the MUTCD may be physically impossible to meet verbatim on a mountain road bounded by steep embankments. The designer then uses engineering judgment to determine an appropriate location. Note that appropriate documentation is important when deviating from any standard or guideline, as discussed earlier in this paper. In addition to decisions considering context, they must also be reviewed by qualified peers, as design typically requires a team process.

The MUTCD [13], [14] provides these definitions to convey very concise directives on when and how each term, Standard, Guidance, Option, and Support (SGOS) applies to the given topic. Even with these concise directives, disagreements in interpretation still develop. Se-

manics enters into discussion and lies as the root of many misinterpretations. Some examples include an engineer incorrectly interpreting guidance as a “must” rather than the defined “should,” or assuming that because an option allows an action, the action should occur. These two examples result in Guidance and Options being “promoted” to a “Standard.” Another common example occurs when no standard exists for a situation, and the engineer again “promotes” guidance to a standard. The editors of the MUTCD clearly defined the terms used and provided an allowance for engineering judgment. This promotion of guidance to standards often occurs when an engineer disagrees with the engineering judgment of a different engineer or does not fully understand the intention of the MUTCD authors’ nomenclature. Supporting one’s opinion with engineering principles may not be possible, making the “promotion” of Guidance or Options to a fictitious “Standard” the only option. The authors refer to situations in which an engineer makes a determination without directly citing supporting standards, as B.I.S.S. (Because I Said So). Keep in mind the forensic engineering analysis presents facts from a non-advocate position, and any B.I.S.S. statement appears to be from an advocatory position.

The SGOS structure of the MUTCD inherently leads engineers to grade traffic control with a common theme of “... should have done more,” or “if only this option had been added, then the incident would not have occurred.” A design either meets the MUTCD requirements or it does not. The grade is pass/fail — not A, B, C, D, F.

As stated previously, the presentation of the *Green Book* lends itself to a pass/fail analysis, while the MUTCD requires a much more “flowchart” (if-then) type of analysis. To further explain, Table 5-5 from the 2018 *Green Book* [4] presents minimum traveled way widths based on design speed and roadway volume, a very pass/fail, deterministic set of criteria.

The MUTCD includes prescriptive language but also contains inherent flexibility for engineers to customize designs to the specific location. Below the authors present Section 3B.01 Yellow Center Line Pavement Markings and Warrants from the 2009 MUTCD [13]:

**Standard:**

**Center line markings shall be placed on all paved urban arterials and collectors that have a traveled way of 20 feet or more in width and an ADT of 6,000 vehicles per day or greater. Center line markings shall also**

**be placed on all paved two-way streets or highways that have three or more lanes for moving motor vehicle traffic.**

*Guidance:*

*Center line markings should be placed on paved urban arterials and collectors that have a traveled way of 20 feet or more in width and an ADT of 4,000 vehicles per day or greater. Center line markings should also be placed on all rural arterials and collectors that have a traveled way of 18 feet or more in width and an ADT of 3,000 vehicles per day or greater. Center line markings should also be placed on other traveled ways where an engineering study indicates such a need.*

*Engineering judgment should be used in determining whether to place center line markings on traveled ways that are less than 16 feet wide because of the potential for traffic encroaching on the pavement edges, traffic being affected by parked vehicles, and traffic encroaching into the opposing traffic lane.*

The Standard “**shall**” contain a similar pass/fail, determinate set of criteria, while Guidance contains pass/fail criteria; the verb “*should*” applies to Guidance, which allows for engineering judgment to determine whether to install the centerline. Keep in mind that engineering judgment exceeds a single location and may require a holistic view. For example, consider the hypothetical situation of a 20-foot-wide, unstriped, two-way, collector roadway with 4,100 vehicles per day in a jurisdiction with three expensive new traffic signal installations scheduled and limited funds.

With the entirety of the information known, should a forensic analysis determine that the center lane markings were not required? The center line was not required (shall); it should be provided, and the budget situation explains the prioritization applied in the engineering judgment. Could any situation alter the findings? Regardless of the presented reasoning, the proper forensic analysis concludes the center line was not required. However, a proper analysis also notes that the MUTCD states the centerline should be installed. The forensic engineer may opine on the engineering judgment used to not install the centerline, but that guidance never becomes a standard. The trier of fact ultimately determines the sufficiency of the engineering judgment.

The engineering judgment used in making project decisions, even when well-documented and packaged with

project records, may remain unavailable, making research important to the forensic analysis. Depending on the circumstances of the case being investigated, researching the historic ADT may present valuable information. Continuing with the same example, has the ADT been increasing and recently passed the 4,000 mark? How recently? Was there a closure of a parallel road, making the added ADT “detour traffic”? How quickly should a jurisdiction react to changing ADT? Has ADT decreased? Possibly an improvement to a parallel road. The answers to each of these example questions provide valuable insight into the engineering judgment used to decide whether to apply centerline pavement markings, but the Guidance never becomes a Standard.

### **Forensic Considerations**

A forensic analysis of roadway design begins with the two primary factors, “when” and “where.” One must consider that an incident that occurs “today” may happen on a roadway that was designed and constructed decades prior. One must ask “when” the agency constructed the roadway, rather than applying the latest design standards to a facility built and not improved since 1950, for example. The forensic engineer must research the roadway’s construction history to determine whether and when the agency performed any intermediate improvements. The forensic engineer should also know the level of improvement to determine if the project triggered any additional modifications to be included in the improvement. Note: Recurring maintenance projects, such as pavement overlays, typically do not require updates to design features. The date of the latest improvement project provides the key to which design criteria apply to the design, thus also the analysis. The requirements for which features must be improved based on the work taking place in the construction process require an in-depth review of the design manuals in place at the time of design.

The “where” factor adds multiple components and must be broken down. First, consider the general location. As each state’s guidelines may differ. Within each state, each political subdivision (e.g., county and city) may also develop its own guidelines. The forensic engineer must first determine the political subdivision in which the incident occurred, then determine which guidelines that political subdivision codified. Note that the code also defines which edition (the “when”) of each guideline applies at the date of the design, as newly released guidelines may not have been adopted.

The next “where” factor considers the more precise

physical location and associated road classification. Roadway requirements differ significantly based on intended functionality. Consider low-volume rural roads, high-speed rural roads, urban residential streets, and urban arterials, each with its own functionality and requirements. Lane widths, cross-sectional elements, design speeds, alignments, and safety features differ significantly across different design speeds and traffic volumes, which relate to roadway functionality (classification).

Federal and state agencies continually seek to improve design to reduce the frequency and severity of vehicle collisions. With the discrete incremental introduction of design manuals, many state DOTs introduce new requirements through design memoranda that incorporate revisions in between releases of complete manuals. Along with design memoranda, agencies may seek to introduce new research into projects.

The introduction of current research requires very detailed engineering studies completed by the designers and/or the agency in control to implement new research. Consider the past evolution of roundabout design and the current evolution/implementation of continuous flow intersections. This concept introduces two important factors for the forensic engineer in these specific cases. First, the design criteria are in the design documentation, not necessarily in the published manuals. Second, the forensic engineer must not introduce new research not adopted by the agency in charge, nor introduce it into the design criteria through an engineering study. New research does not become a requirement until it is adopted.

## Case Studies

### *Truck Runaway Ramp*

The first case study involves an incident that occurred in the fall of 2018 with a semi-truck-trailer crashing into a structure located opposite a stop-controlled approach to an intersection. The intersection is located at the base of a long mountain downgrade. **Figure 1** displays a view of the route the truck had taken. As the semi entered the intersection, a security camera captured an image with visibly red-hot, overheated brakes. The forensic analysis consisted of several factors, including the design of the road reconstruction completed in the early 2000s, evaluation of the site for possible truck escape ramp (TER) locations, evaluation of the incident history, and review of other mitigation measures (i.e., signage and a brake check area).

With the construction taking place in the early 2000s, the 2001 *Green Book* and the 2001 MUTCD apply. The 2001 *Green Book* [16] (and still found in the 2018 *Green Book* [4]) references a technique called the “Grade Severity Rating System” (GSRS). The outdated DOS-based GSRS became unavailable in 1994. When reading the *Green Book* text: A technique for new and existing facilities available for use in analyzing operations on a grade, in addition to crash analysis, is the Grade Severity Rating System (45)..., the lack of availability of the GSRS becomes irrelevant as the *Green Book*'s intent is to determine the need for further evaluation. While the GSRS may have been useful for some situations, this specific project included an approximate 6-mile (approximately MP 492 to MP 498) downgrade average of 5.76% with no upgrades. A grade of this value and for this length should automatically trigger



**Figure 1**

Overview of route with milepost; re-construction project began at approximately MP 492 and ended at approximately MP 498 [15].

review for safety, specifically brake safety.

With the potential need for a TER established, evaluating the route for locations came next. The route contained 31 horizontal curves with the longest tangent between curves being 1,565 feet long. Note that at the time of design, Dagnet systems were in their infancy, and the 2002 *Roadside Design Guide* [17] included them only as temporary options, leaving an arrestor bed TER as the only option. The grade dictates the length of the bed required. An arrestor bed requires 1,120 feet of length on a 0.5% downgrade (bed grade) and 1,421 feet of length for a 6% downgrade (bed grade). The only two tangents exceeding 1,000 feet occur in this corridor within 3 miles of the summit, where a TER could not be effective due to the physical location being closer to the summit and not being near the bottom of the grade. Further review of the aerial identifies some potentially viable locations between mileposts 497 and 498, prior to the end of the construction project, for additional examination. The side of the road adjacent to the downhill lane in any potentially viable location contained relatively narrow widths outside the shoulder and long steep slopes where costs to build an embankment alone approached the cost of the entire project. Note **Figure 1** shows a current TER location in this area as the state installed a dragnet type TER post incident. No accident history or traffic/safety studies for the reconstruction project were made available for forensic review. The authors are aware of a safety study that fell under undisclosed information. In this case, one must not confuse the availability of a study with a study not being completed. Regardless of the safety study, no viable location existed.

The reconstruction project was completed approximately 15 years prior to the incident. Therefore, consideration must be given to whether the site should have been evaluated for a TER for safety reasons. What would trigger a safety evaluation? Similar and potentially repeatable accidents involving overheated brakes and/or commercial vehicles. A 10-year accident review found only one somewhat similar incident; however, that incident involved a pickup truck with a trailer, not a commercial vehicle. The other commercial vehicle incidents resulted from many different factors that eliminated them from inclusion — factors such as weather conditions, improper loading, and a local commercial vehicle (dump truck), not a long-haul vehicle. Therefore, no event triggered a safety analysis.

The final part of the forensic analysis involved evaluating other safety features. The controlling design

document (2001 Green Book [16]) contained the following regarding brake check areas.

*Turnouts or pull-off areas at the summit of a grade can be used for brake-check areas or mandatory-stop areas to provide an opportunity for a driver to inspect equipment on the vehicle and to ensure the brakes are not overheated at the beginning of the descent. ... A brake-check area can be a paved lane behind and separated from the shoulder or a widened shoulder where a truck can stop. ...*

The MUTCD contained no brake check area signage until the 2009 edition. The construction plans contain a widened shoulder at the summit and a full rest area, complete with truck parking spaces, within 1 mile of the summit. Therefore, the as-built condition met the design standards for a brake check area at the time of the reconstruction design. Witness testimony and legal filings also indicate that the semi driver used the widened shoulder area to pull his truck over at the summit.

Section 2C.11 of the 2000 Edition of the MUTCD [14] recommends the following regarding supplemental posting of the W7-1 Hill Advanced Warning Sign on extended grades:

*On longer grades, the use of the distance (W7-3a) plaque or the combination distance/grade (W7-3b) plaque at periodic intervals of approximately 1.6 km (1 mi) spacing should be considered.*

The subsequent 2009 Edition of the MUTCD [13] states the following in Section 2C.16 regarding the use of the W7-1, W7-1a and W7-2p signs on extended grades:

*On longer grades, the use of the Hill sign with a distance (W7-3aP) plaque or the combination distance/grade (W7-3bP) plaque at periodic intervals of approximately 1-mile spacing should be considered.*

The state agency placed supplemental postings of the W7-1 along the grade at approximately 1-mile intervals as recommended by the MUTCD. Guidance statements within the MUTCD do not carry requirements or mandates for posting, but *recommended* practices for posting related Hill (W7-3P) signs on a grade. The designer can exercise engineering judgment to determine if a different W7-2p

suggested, but not **standard** or *recommended*, sign should be posted. The state agency chose to reinforce USE LOW GEAR, which carries with it a greater and more specific message regarding the grade to a driver than simply the length of the grade. Section 2C.11 of the 2000 Edition [14], and Section 2C.16 of the 2009 [13] Edition of the MUTCD allows for the engineering judgment exercised by the engineer.

### TTC Left-Turning Vehicle at Signalized Intersection

The second case study involves an active construction site with temporary traffic control in place. The location consisted of a signal-controlled intersection with the configuration as seen in **Figure 2**. A westbound driver made a left turn into the path of another vehicle. The client requested a review of the TTC for the required sight distance.

The 2018 AASHTO *Green Book* [4] applied based on date and location, which was used to calculate the appropriate sight distance. The *Green Book* contains seven possible cases (A-G) with some containing sub-cases for a total of 10 options. Case F (left turn from major road) applied. The authors used Equation 9-1 ( $ISD=1.47 \times V_{major} \times tg$ ) with  $V_{major}$  being the Posted Regulatory Speed Limit (PRSL) of the approaching road and  $tg$  being the time gap provided in Table 9.16 to calculate the ISD. Note that the forensic analysis uses actual case information — meaning that the calculation used 5.5 seconds for passenger cars from Table 9.16, based on the vehicles involved, and not the 6.5 seconds for single unit trucks, which would

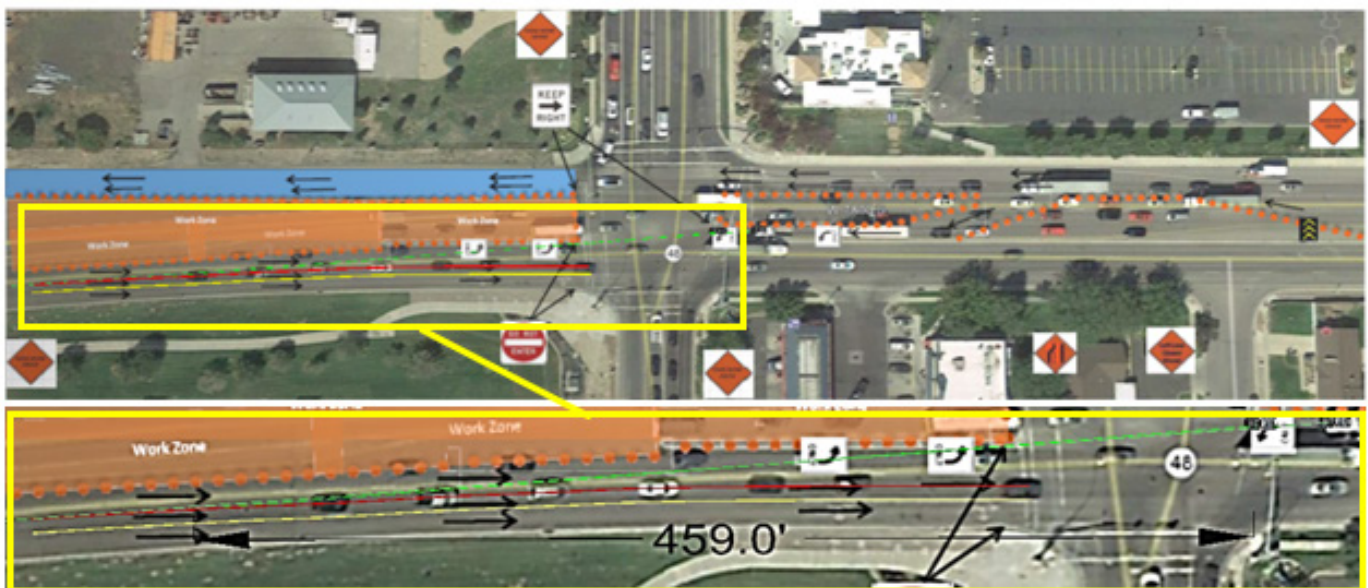
probably be the design vehicle based on road types. While the forensic analysis reviews design requirements, it also only applies collision-specific information.

The time gap given in Table 9-16 only accounts for passenger cars crossing one traffic lane with the requirement to add an additional 0.5 seconds per additional lane for passenger cars crossed.

The authors calculated the ISD by using the PRSL (40 mph) and the given first lane to cross (5.5 sec) plus two additional lanes (.5 sec each) = **3 total lanes** to cross during left turn:

$$ISD = 1.47 \times 40 \text{ mph} \times (5.5 + .5 + .5) = 382.2 \text{ feet}$$

The next step involved measuring the available sight distance. This case only involved horizontal issues for consideration because of existing infrastructure and topography. However, the *Green Book* contains specific guidance on eye and target elevations. Sight distance begins at the stop line and continues past any obstruction to the middle of the nearest approaching lane as described in Section 3.2.6.4 of the *Green Book* [4]. The question that remains is what is an obstruction? The *Green Book* Section 3.2.6.3 describes obstruction to sight lines as, "... a crest vertical curve or it may be some physical feature **outside of the traveled way** (emphasis added), such as a longitudinal barrier; a bridge approach, fill slope, a tree, foliage, or the back slope of a cut section." Note that the *Green Book* makes no consideration for random or temporal conditions



**Figure 2**

TTC plan with the ISD sight lines presented and then measured.

created by vehicles within the travel way, or for any other highly variable condition.

**Figure 2** presents the available sight distance. The available 459 feet well exceeds the required 382 feet.

The idea of offsetting the westbound turn lane to be directly in line with the eastbound lane to further increase available sight distance came into question. Note the three lanes approaching the intersection from the west, with one of those lanes becoming the eastbound left turn lane. The fact of a travel lane transitioning to a turn lane (as opposed to adding a turn lane) introduces an increased potential for head-on collisions. With sufficient sight distance available, the authors found the as-placed configuration to be the better option.

### TC Intersection Stop Sign Controlled

The third case study involves an incident in which a vehicle ran a stop sign and broadsided another vehicle. The 4-leg intersection contained a stop condition for the minor approaches. The litigant called into question the permanent signage and sight lines for the stop leg of the intersection. **Figure 3** presents an image of the viewshed experienced by the litigant, which is representative of the day of the incident. The stop sign at the right edge of the road remains visible past the trees in full foliage, but also note the supplemental stop sign on the left side of the road.

May the agency use a sign in this manner? Note that the state in which the collision took place chooses to use the federal MUTCD [13] with supplemental information.



**Figure 3**

Photograph taken during site visit with representative view available on day of collision, including traffic control.

The supplemental state MUTCD was used in the evaluation. Section 2A.16 Standardization of Location reads:

*Option:*

*Under some circumstances, such as on curves to the right, signs may be placed on median islands or on the left-hand side of the road. A supplementary sign located on the left-hand side of the roadway may be used on a multi-lane road where traffic in a lane to the right might obstruct the view to the right.*

With semantics in mind, an option represents a permissive condition and carries no requirement or recommendation but can be applied with appropriate engineering judgment. In general, additional information would only not be allowed when it introduces conflicting, confusing or too much information for a driver to process. None of these conditions exist; therefore, the MUTCD allows the additional stop sign on the left side of the road.

In deposition, the litigant stated he saw the stop sign on the left side of the road and believed it was for the crossing road. However, the agency also provided a properly placed and sized stop ahead sign on the approach to the intersection. The MUTCD [13] states the following regarding warning signs:

#### Section 2C.01 Function of Warning Signs

Support:

Warning signs call attention to unexpected conditions on or adjacent to a highway, street, or private roads open to public travel and to situations that might not be readily apparent to road users. Warning signs alert road users to conditions that might call for a reduction of speed or an action in the interest of safety and efficient traffic operations.

#### Section 2C.02 Application of Warning Signs Standard:

**The use of warning signs shall be based on an engineering study or on engineering judgment.**

*Guidance:*

*The use of warning signs should be kept to a minimum as the unnecessary use of warning signs tends to breed disrespect for all signs. ...*

In deposition, the litigant also acknowledged seeing and recognizing the advance warning sign. In his acknowledgment of the sign, he also admitted to not



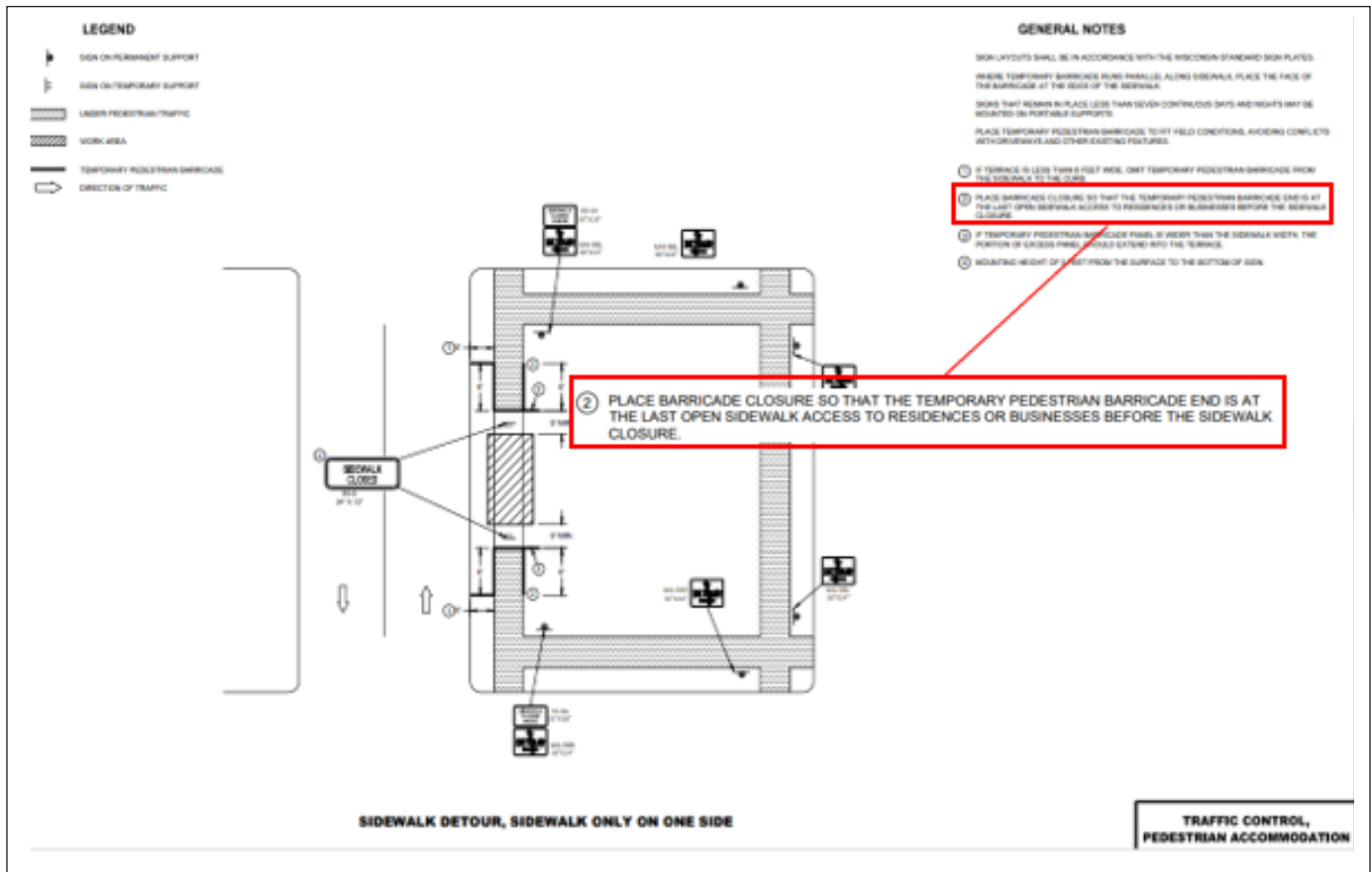


Figure 5

“State” Standard Drawing showing the appropriate sidewalk closure for the situation.

past the last access required (i.e., cannot lead to a dead-end. The TTC design does not meet the requirements of the standard drawing or the State MUTCD).

The inset photo in **Figure 4** shows the closure as it existed in the field at the entrance to the nearest road crossing. Therefore, the actual closure met the requirements of the standard drawing and the state MUTCD.

Another issue discussed was the lack of TTC near the railroad track, the actual location of the hazard. The incident occurred within an area closed to public entry or use, where no further TTC devices are required, recommended, or suggested by any applicable standards. Section 1A.13 of the state MUTCD defined traffic as:

Traffic — pedestrians, bicyclists, ridden or herded animals, vehicles, streetcars, and other conveyances either singularly or together while using for purposes of travel any highway or private road open to public travel.

Note the “open to public travel” in the definition of traffic. With no traffic comes no traffic control, even though the closure occurs 2,000 feet from the actual construction area. Additional traffic control violates the MUTCD because it provides conflicting guidance by suggesting that a closed path (or road) is actually open.

### Conclusion

Collision analysis, as it relates to design, construction, or temporary control measures, must be based on historical facts surrounding those activities. The forensic engineer’s role when evaluating a collision is similar to that of a historian piecing together artifacts to determine the events and causes leading to a collision event. Using evidence from the scene, design records, and historical design manuals, the forensic engineer constructs a timeline of events and decisions that culminates in the identification of the cause of an accident. Determining and correctly applying the semantics of the guidance documents relevant to the situation is the single most important aspect of this type of forensic analysis. Words have meaning, and only the defined meaning matters.

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