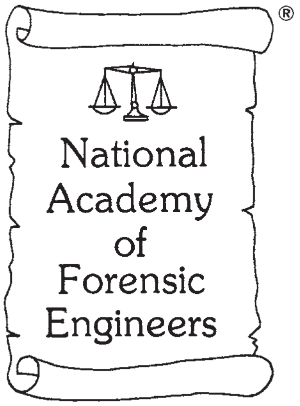
Journal of the
National Academy of Forensic Engineers®



Vol. XXXI No. 2 December 2014

National Academy of Forensic Engineers®

Journal Staff

Technical Review Committee Chair:
John Leffler, P.E.

Journal Editor:
Ellen Parson

Technical Review Process

The Technical Review Committee Chair chooses the reviewers for each Journal manuscript from amongst the members and affiliates of the NAFE according to their competence and the subject of the paper, and then arbitrates as necessary during the review process. This confidential process concludes with the acceptance of the finished paper for publication, or its rejection or withdrawal. The name(s) of authors are included with their published works. However, unpublished drafts together with the names and comments of reviewers are entirely confidential during the review process and are excised upon publication of the finished paper.

National Academy of Forensic Engineers®

Board of Directors

Submitting Proposed Papers to NAFE for Consideration

A concise abstract of approximately 100 words shall be sent to the Journal Editor for initial consideration. Upon approval of the abstract, the author will be scheduled to present their work at one of the semi-yearly NAFE Technical Conferences. A 90% complete draft copy of the manuscript shall be submitted to the Journal Editor for review and approval no later than 30 days before the conference.

For complete details about requirements for authors, visit:
www.nafe.org/assets/docs/journalcontents.pdf

For the NAFE Bylaws content "Responsibilities of, Obligations of and Guidelines for Authors, the Journal Editor, Technical Review Committee Chair, and Technical Reviewers," visit:
www.nafe.org/assets/docs/journalguidelines.pdf

Copies of the Journal

The Journal of the National Academy of Forensic Engineers® contains papers that have been accepted by NAFE. In most cases, papers have been presented at NAFE seminars. Members and affiliates receive a copy of the Journal as part of their annual dues. To obtain additional copies, the costs are as follows: $15.00 for members and correspondents of the NAFE; $30.00 for members of the NSPE not included in NAFE membership; $45.00 for all others. Requests should be sent to Arthur Schwartz, Executive Director, NAFE, 1420 King St., Alexandria, VA 22314-2794. Individual Journal papers may also be purchased and downloaded from the NAFE website at www.nafe.org.

Comments by Readers

Comments by readers are invited, and, if deemed appropriate, will be published.
Send to: Arthur Schwartz, Esq., Executive Director, 1420 King St., Alexandria, VA 22314-2794.
Comments can also be sent via email to journal@nafe.org.

Table of Contents

(All papers in this edition were presented at the NAFE seminar held 7/5/14 in Washington, D.C.)

Forensic Engineering Evaluation of an Automated Warehouse Accident

By Michael D. Leshner, P.E. (NAFE 559F)

Abstract

A worker was injured by fast-moving equipment inside an automated warehouse at a location where workers are supposed to be excluded during automated operations. The facility was designed with barriers, locking gates, lockout/tagout provisions, and a safety training program for operators. Despite the safety training, procedures, and equipment, a worker entered the danger zone and was struck by automated equipment. The worker knew he was in a restricted zone; however, he thought he had "locked out" the area where he was performing maintenance.

The safety equipment design and operator procedures will be discussed in this paper, along with deviations from operator procedures that caused the accident. The litigation issues involved design of the safety systems, training of operators, and additional safety components that the plaintiff's expert opined should have been in place. Conflicting opinions offered by experts engaged by the plaintiff and automation equipment designer/installer will be discussed.

Keywords

Forensic engineering, automation, warehouse, lockout, tagout, training

The Scene

The warehouse (**Figure 1**) is built around an automated storage and retrieval system (ASRS) designed and installed by the automation developer. The warehouse automatically stores and retrieves pallets loaded with cases of soft drinks, and can hold up to 250,000 pallets. The ASRS and building exterior are illustrated in **Figure 2**.

Figure 1
Warehouse exterior.

The apparatus within the ASRS consists of two storage and retrieval machines (SRMs). These operate and perform combined functions of a forklift and crane. The system also

---

Michael D. Leshner, 47 N. Lockwood Road, Elkton, MD 21921; (410) 964-0311; mike@leshner.com

includes a central rail system on which the SRMs move back and forth. The center aisle of the ASRS has two SRM cranes, each extending 13 levels high. The cranes automatically deliver and retrieve two loaded pallets at a time, using rolling platforms called “satellites” that travel down long aisles called lanes. The lanes each have a pair of horizontal rack rails to guide the satellites and support the loaded pallets. The lanes, satellites, pallets, and SRMs are all within a central protected zone where automated equipment may start or stop without warning.

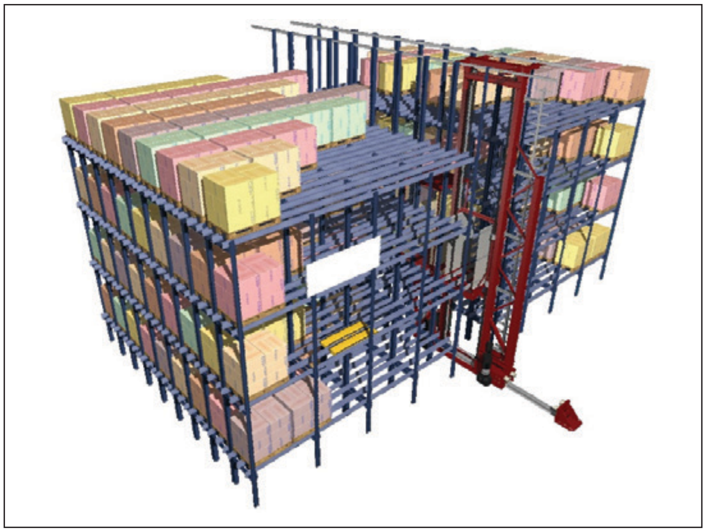


Figure 2
Automated storage and retrieval system (ASRS).

On the ground floor, some of the space is occupied by conveyors that carry loaded pallets in and out of the ASRS. The conveyors are protected within a peripheral protected zone where maintenance can be performed on the conveyor system. Workers must first gain entrance to the controlled peripheral protected zone before accessing the central protected zone. Access to the peripheral and central protected areas is controlled by limiting access only to qualified and trained workers using keys and passcodes.

The warehouse is equipped with multiple safety systems designed to prevent entry into the ASRS during operation. A system of interlocked entry doors and dedicated keys assures that the automation equipment within the ASRS must be shut down before the entry doors into the central protected zone can be opened. The key switch controlling ASRS operation must be switched off and the key withdrawn before the same key can be used to unlock the ASRS entry door (see **Figure 3**).

Before employees are permitted to work within the ASRS, the cranes are to be parked at the ends of the aisle, and large steel safety barriers are to be manually placed in front of the cranes, preventing them from traveling (see **Figure 4**). This step is a written administrative control without any physical interlock.

On the ground floor, conveyors carrying loaded pallets snake under and around the warehouse, carrying pallets of products into and out of the ASRS. There are also dedicated maintenance lanes within the peripheral protected zone

Figure 3
The ASRS must be switched off
before the entry door can be unlocked.

Figure 4
Storage and retrieval machine.

alongside and below the ASRS pallet rack lanes where workers can gain access to conveyors for maintenance while the ASRS is operating. Inside the central protected ASRS area, each crane delivers or retrieves a pair of pallets by means of a moving trolley platform (satellite) that travels down each lane as required to access the desired storage locations. The worker was struck by a moving satellite while standing on the ground floor in an active lane.

The Accident

At the time of the accident, the storage rack rails and steel support structure between the maintenance lane and active ASRS lanes formed a waist-high horizontal rail as a barrier to entry. The worker entered the automated area, bypassing the interlocked safety system doors and written procedures by climbing over or under the horizontal rack rail from the maintenance lane in order to gain entry to clean up a spill on the floor. The area where the worker was cleaning the floor at the time of the accident — and the satellite that struck the worker — are shown in **Figure 5**.

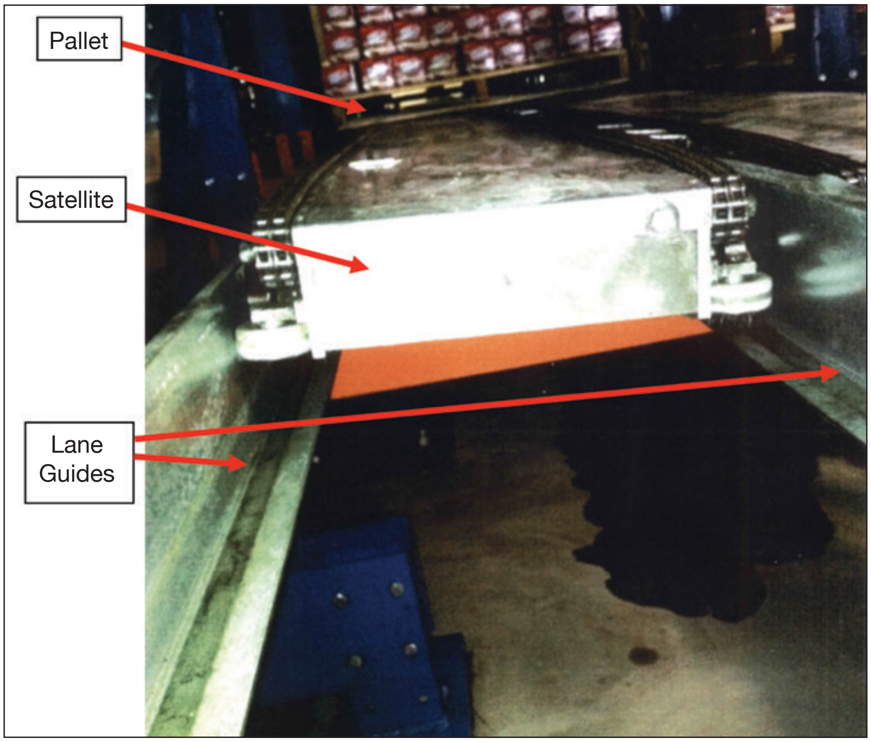


Figure 5
Accident location.

The worker bypassed controlled ASRS access doors by climbing over or under a horizontal rack rail from a maintenance lane to the adjacent ASRS lane while the equipment was operating (see **Figure 6**). He bypassed the electromechanical interlocks on the ASRS entry doors by entering through the rack system. He also propped open an emergency exit door from the maintenance area so that he could bring a shop vacuum from outside the building through that door to clean the floor under the rack system. Entering the ASRS by climbing through the rack system and propping the exterior door open were violations of the safety rules.

The worker did not believe he was putting himself at risk. He incorrectly thought that he had "locked out" two ASRS lanes adjacent to the maintenance aisle by entering commands into an ASRS control workstation to empty the lanes by preventing the system from filling these two lanes. This "work-around" was not an approved method of working inside the ASRS, nor was it effective.

Figure 6
The black mesh barriers were added after the accident.

Analysis

Entry to maintenance spaces in the warehouse is restricted to authorized, trained personnel by the use of keys and passcodes. Once inside the peripheral protected zone, barriers prevent workers from walking into the protected ASRS area from maintenance spaces. In this case, the barrier between the maintenance aisle and ASRS lane was nothing more than the horizontal rack rail. The rail was not marked with any warning. There are emergency exit doors from maintenance spaces that open from the inside only. The injured worker propped one of the exterior doors open, in order to re-enter the maintenance area with a shop vacuum, before being injured. These exterior doors are not alarmed or interlocked to shut down the ASRS.

Opposing Viewpoints

The plaintiff's expert opined that new barriers installed after the accident should have been installed in the original design. He also believed that a number of Occupational Health and Safety (OSHA) regulations and other industry standards were violated, including:

- OSHA Title 29 CFR 1910.212(a) Machine guarding.
- ANSI/RIA 15.06 -Safety Requirements for Industrial Robots and Robotic Systems
- ANSI/UL 1740 -Robots and Robotic Equipment
- ISO/ANSI/RIA 10218-1:2007 -Safety Requirements for Robots in an Industrial Environment
- ANSI B15.1 -Safety Standards for Mechanical Power Transmission Apparatus
- ANSI B11.19 -Performance Standard for Safeguarding
- ANSI B20.1 -Safety Standard for Conveyors and Related Equipment
- ANSI Z535.4 - Product Safety Signs and Labels

- OSHA 3067 - Concepts and Techniques of Machine Safeguarding
- OSHA 3170 - Safeguarding Equipment and Protecting Employees from Amputations

All of these regulations and industry standards provide guidance on protecting workers from injury by eliminating hazards, guarding the hazards that cannot be eliminated, and providing adequate training, warnings, and protective gear. The plaintiff's expert did not comment on any differences between the two defendants with respect to their roles and responsibilities. He had two critiques related to the equipment:

1. Without the mesh barriers shown in **Figure 6**, the only barrier between the maintenance aisle and adjacent ASRS lane was the waist-high horizontal rail used to support loaded pallets and guide the satellite. This horizontal rack rail was an inadequate barrier and was not marked with any warning.
2. In addition, it was suggested that the automation equipment should have been equipped with additional safety sensors to detect the presence of a worker during automated operation.

The automation developer hired two experts who opined that the safety systems and training materials prepared by the developer for use by the employer were robust and compliant with industry standards, including OSHA regulations. With regard to adequacy of the barriers between the maintenance area and points of operation, there was a difference of opinion. One defense opinion was that the waist-high horizontal lane rail met the minimum requirements for a barrier. In this case, a warning would not have deterred the worker, who believed (incorrectly) that he had made the two adjacent lanes "safe." Another defense opinion was that the equipment design was compliant with the noted industry standards but that the lane rail was not an adequate barrier.

The defense experts pointed out that OSHA only has jurisdiction over the employers' actions, not the equipment design. OSHA noted in its investigation report that the employer and employee should have followed the safety procedures prepared by the equipment developer. If the worker had followed those safety procedures, he would have had to shut down the equipment before entering the ASRS pallet rack lanes through the interlocked doors; therefore, the accident would not have occurred.

The parties also disagreed on the need for additional presence-sensing safety equipment to detect workers who may defeat the primary safety systems. If the primary controls are effective, there would have been no need for secondary controls. However, if the worker's intention was to defeat the safety control systems, he probably would have succeeded in doing so.

Opinions of the bottling company's expert were not disclosed to this author.

Why Did the Accident Occur?

The automation equipment was designed with current industry safety standards as a basis. OSHA regulations provide guidance on machine guarding and safety training requirements as they apply to the employer. The referenced ANSI standards provide additional guidance to equipment designers and users, and focus on the same basic principles applied to different kinds of equipment (elimination of hazards, guarding against hazards, warnings, operator training, and other measures to protect the public safety).

Training materials were prepared by the automation developer, and training classes were conducted for employees at the time the facility was commissioned. Following the initial training of bottling company employees by the automation developer, the training materials continued to be used over subsequent years to train new employees. Training was supervised by the bottling company after the initial employees were trained by the developer.

Employees attended weekly safety meetings where they learned about safety procedures and rules, including the proper procedures for entering the automation area. The injured worker had been promoted from the position of forklift operator, and had attended regular safety meetings. Despite this training, the employee decided to get creative, and attempt to “lock out” the lane where the floor needed cleaning. He attempted to make two lanes “safe” by entering commands into an ASRS workstation to empty the lanes and prevent the system from filling them. The “lock out” was not effective, and the employee was struck and injured.

How Could the Accident Have Been Prevented?

Regular work practices at the plant were to operate six days each week and perform maintenance on Sundays. The accident occurred on a Sunday when the plant was in operation due to an upcoming holiday. The injured employee’s solution was to invent a way to perform maintenance while the plant was in operation. If he had followed the standard work rules, maintenance would have been re-scheduled for the next plant shutdown.

Legal Issues

OSHA investigated this accident, and was critical of the bottling company’s practices and training. The injured worker filed a lawsuit against his employer (bottling company) and the equipment developer/installer. The employer was protected by workers’ compensation insurance laws.

All of the plaintiff’s theories lumped the developer/installer in with the employer, which, he claimed, had failed to provide and enforce proper training and therefore was in violation of numerous industry standards. The provision of a more substantial barrier between the maintenance aisle and active danger zone was a responsibility of both defendants. However, deficiencies in employee training and supervision could only be attributed to the employer. The question of responsibility on the part of the developer/installer involved two specific issues:

1. Was there a requirement for a form of presence-sensing technology to detect the presence of workers during automated operation capable of shutting down operations?
2. Before the incident, was the physical barrier between the maintenance aisle and active automation aisle adequate to guard against entry?

On the first question, no specific design of a presence-sensing system was suggested, and none was evaluated. The value of such a system is questionable because the design of the entire warehouse requires the absolute exclusion of people in the automation area. The potential for entry through the racks was apparently overlooked during the design.

Regarding adequacy of the physical barrier between maintenance aisle and automation zones, there was a difference of opinion. More robust steel grate barriers were installed after the incident, shown in **Figure 6**.

This author was of the opinion that the horizontal rack rails used to support pallets provided an adequate barrier. The rails were waist-high, requiring a person to intentionally climb over or under the rails to enter the automation area. Following the installation of the steel mesh barriers, it is still possible for a person to climb over or slip under the barriers. It was argued that such egress is needed to comply with fire safety considerations. However, a more appropriate solution would be floor-to-ceiling barriers with interlocked emergency exit doors between the central and peripheral-controlled areas.

Lessons Learned

Those who understand industrial safety principles can design very good systems with physical barriers, gates, guards, and controlled interlocks to protect workers from hazardous machinery. Industry standards require the application of recognized safety principles by competent engineers. However, physical barriers cannot prevent a creative worker from circumventing or otherwise defeating safety systems.

A strong safety culture is needed to complement the physical safety systems, but is not a substitute for proper design. When workers are in an environment where safety and safety training is highly regarded as a job benefit to protect them from harm, they are inclined to follow the rules. If, however, work flow is prioritized over safety — and safety precautions are regarded as a nuisance — workers are more likely to get creative and find work-arounds. In this case, the injured worker had good intentions and thought he had come up with a new way to perform maintenance without shutting down production.

The culture of safety in an organization is just as important as physical safety equipment and systems. Safety equipment design and safety training must be effective to prevent such accidents. However, attention to safety in the design process can eliminate or minimize the chances for human error in operation. The hierarchy of safe product design (**Appendix A and Appendix B**) prioritizes the importance of design controls over administrative controls.

Appendix A

Hierarchy of Safe Product Design

When a safety hazard is perceived by the designer, the options available are:

1. Modify the design to eliminate the hazard or reduce the danger to an acceptable level.
2. Design guards to isolate the hazard.
3. Provide effective warnings.
4. Educate and train workers to be aware of the hazard and follow safe procedures to avoid injury.
5. Anticipate common areas and methods of improper use and eliminate or minimize the consequences of the improper use.
6. Provide personal protection equipment to be used in conjunction with the product.

Appendix B

Reading on Hierarchy of Safe Product Design

- Petersen, Dan, “Techniques of Safety Management, A Systems Approach,” Goshen, NY: Aloray, 1989, P. 31.
- Krieger, Gary P. and Montgomery, John F., eds., “Accident Prevention Manual for Business and Industry – Engineering & Technology,” 11th Ed., Itasca, NY: National Safety Council, 1997. Pp. 4-14.
- Hammer, Willie, “Product Safety Management and Engineering,” 2nd Ed., ASSE Press: 1993.
- Laing, Patricia, ed., “Product Safety – Management Guidelines,” Chicago, IL: National Safety Council, 1989, Pp. 40-48.
- Kolb, J. and Ross, Steven, “Product Safety and Liability,” New York, NY: McGraw-Hill, 1980.
- McGuire, E. Patrick, “The Product Safety Function: Organization and Operation,” New York, NY: The Conference Board, Inc., 1979.

Forensic Engineering Usage of Surveillance Video in Accident Reconstruction

By Richard M. Ziernicki, Ph.D., P.E. (NAFE 308F),
William H. Pierce, P.E. (NAFE 846C), and
Angelos G. Leiloglou, M. Arch.

Abstract

With the increased use of surveillance cameras, more and more video footage depicting accidents is available these days for accident reconstruction. The authors present an accident reconstruction case study involving an impact between a tractor-tanker and a pedestrian using surveillance video footage from a nearby business. Overall, the video footage is of poor quality, which is typical of surveillance video. This is usually evidenced by low frame rate, low resolution, and significant lens distortion — not to mention the fact that the video is not centered on the actual accident. This paper addresses a solution to minimize the error often associated with such surveillance video.

First, the distortion in the video footage is corrected using software that warps the image with a reverse distortion. Once the distortion in the video footage is corrected, then accurate photo/videogrammetry is performed to attain desired measurements. These measurements are then processed to perform a more accurate and detailed time/space analysis. Finally, graphics and photo-realistic animation are used to present the accident in time-space domain.

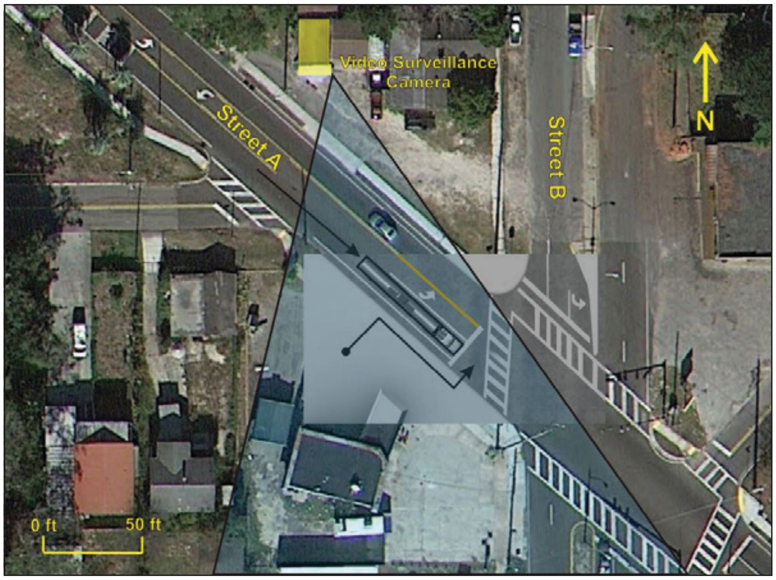


Figure 1
Aerial view of intersection (courtesy of Google Maps) showing eastbound tractor-tanker stopped at red light, pedestrian path, and video surveillance camera position.

Keywords

Accident reconstruction, forensic engineering, video, pedestrian, animation, photogrammetry, barrel lens distortion, surveillance video, focal length

Introduction

The lead author of this paper was retained by the law firm representing the injured party in an accident that occurred between a pedestrian and tractor-tanker. The accident occurred in Florida at an intersection between Street A and Street B (**Figure 1**). The tractor-tanker was driving eastbound on Street A and stopped at

---

Richard Ziernicki, P.E., 7185 South Tucson Way, Englewood, CO 80112-3987; (303) 925-1900; rziernicki@knottlab.com

a red light at the intersection of Street A and Street B. After the tractor-tanker stopped, the pedestrian began crossing the intersection in front of the tractor-tanker. While the pedestrian was crossing, the traffic signal for the tractor-tanker turned green, and the rig accelerated forward. The pedestrian was subsequently struck by the left side of the tractor-tanker's front bumper and knocked down, ultimately leading to the tractor's left-front tire running over the pedestrian's left leg. The tractor then came to a stop with the pedestrian lying directly in front of the tractor's second-axle left tire.

Across the street, a nearby business had a surveillance camera installed that happened to capture the accident (**Figure 2**). The video footage from this surveillance camera was used to perform a time-space analysis of both the pedestrian and the tractor-tanker.

Figure 2
Exterior surveillance camera of nearby business.

Surveillance Video Footage Correction and Enhancement

The overall quality of the raw surveillance video footage was very poor (**Figure 3**). As it was — with a frame size of only 352x240 pixels, a frame rate of 7.5 frames per second, and significant barrel lens distortion — the footage had to be corrected and enhanced before it could be used for any photogrammetric processing and engineering analysis.

Figure 3
Frame from raw surveillance footage.

The most adverse (unfavorable) problem with the surveillance video footage was the barrel lens distortion, which is attributed to the imperfections due to the physical characteristics of the camera lens and is commonly associated with wide-angle lenses like the one used by the surveillance camera. Barrel distortion, a type of radial distortion, is a quadratic function that increases as the square of the distance from the lens

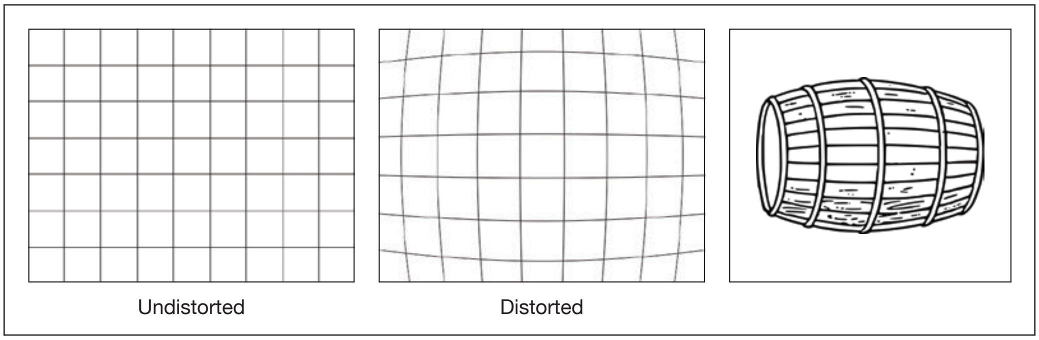


Figure 4
Barrel lens distortion.

center increases. The effect causes the image magnification to decrease as the distance from the center increases, causing straight lines to appear curved or bowed out toward the edges of the image like a barrel (**Figure 4**).

In order to use photogrammetry techniques to accurately attain measurements from the video frames, the lens distortion needed to be corrected. Many software applications (i.e., Photoshop, Premiere, PTLens, DxO Optics Pro, Syntheyes, Virtualdub) can correct for lens distortion automatically if the camera and lens used to capture the video is known. Because the camera used to record the accident in this case was not known, a manual method for lens distortion correction was applied.

The method used to correct the barrel lens distortion in the surveillance is based on the principle that straight lines in the real world would appear straight when viewed through a perfect lens. The road on which this accident occurred was straight and level. Therefore, the engineer was able to use the striping and curb lines seen in the surveillance video as a guide to determine how much the image needed to be "un-distorted" to correct for the barrel distortion using the custom parameters of the lens correction filter in Adobe Photoshop (**Figure 5**). This correction was then applied to all the frames in the video surveillance footage.

Figure 5
Surveillance video with lens distortion (left). Surveillance video corrected to eliminate barrel lens distortion (right).

Once the lens distortion was corrected, the footage was further enhanced by adjusting the levels of tonal range/color balance and sharpening the edges to improve the clarity of the subject vehicles and important landmarks in the video.

Solving the Camera

Finally, the position, orientation, and focal length of the camera were solved using the inverse camera method in Photomodeler, a software package based on the science of photogrammetry. The virtual 3D camera solved in the previous step, along with the control points of the accident scene, were then imported into a 3D animation package and matched to the corrected/enhanced surveillance video.

Tractor-Tanker Position and Velocity Versus Time Using Video Footage

Using measurements obtained during inspection of the tractor-tanker, a scaled 3D model of the tractor-tanker was created in Maya, a modeling and animation software product developed by Autodesk

(**Figure 6**). The modeled tractor-tanker was then placed in the virtual accident scene. For each surveillance video frame, the modeled tractor-tanker was aligned with the actual tractor-tanker seen in the video (**Figure 7**), and the position of the modeled tractor-tanker was recorded.

Figure 6
3D computer-generated model of tractor-tanker.

After establishing the tractor-tanker's position data for each of the frames, the position data was used to determine the instantaneous velocity between each of the position points (**Figure 8**). The instantaneous tractor-tanker's velocity determined from position data at 7.5 frames per second varied erratically. The variance in instantaneous velocity was attributed to the sensitivity in the determined tractor-tanker's positions between each frame spaced only 0.13 seconds apart. For example, 4 inches of position error between two adjacent frames would result in an instantaneous velocity error of 2.5 feet per second (fps). Therefore, the instantaneous tractor-tanker's velocity was determined to not be very helpful for forensic engineering purposes.

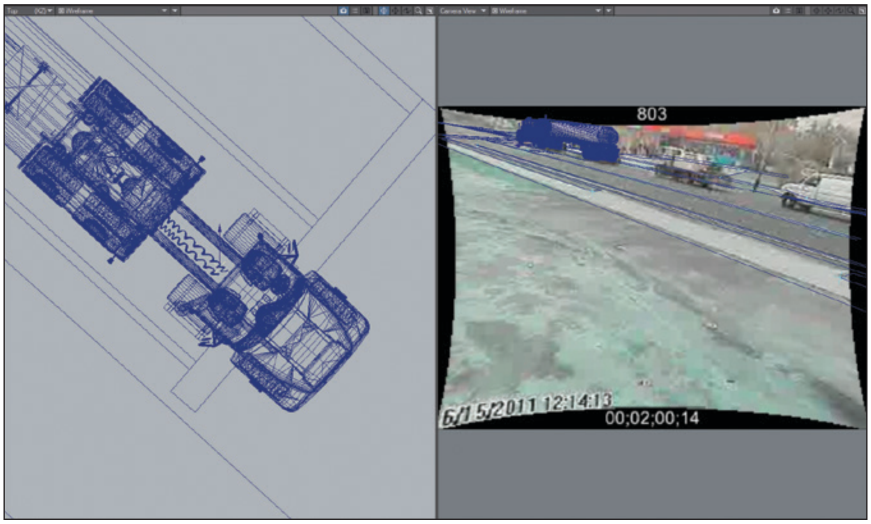


Figure 7
Virtual tractor-tanker aligned with tractor-tanker depicted in video.

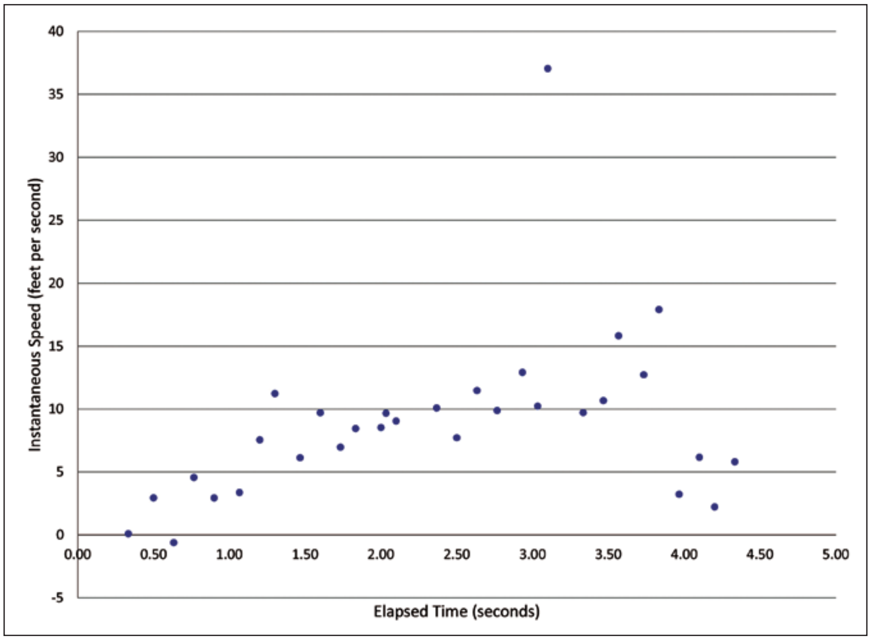


Figure 8
Instantaneous tractor-tanker velocity versus time from position data at 7.5 fps.

In order to smooth the velocity data, an iterative process was performed to separate groups of points from within the plotted tractor-tanker position versus time data that could be assigned good-fit 1st and 2nd order polynomials. The second derivative of each polynomial was calculated

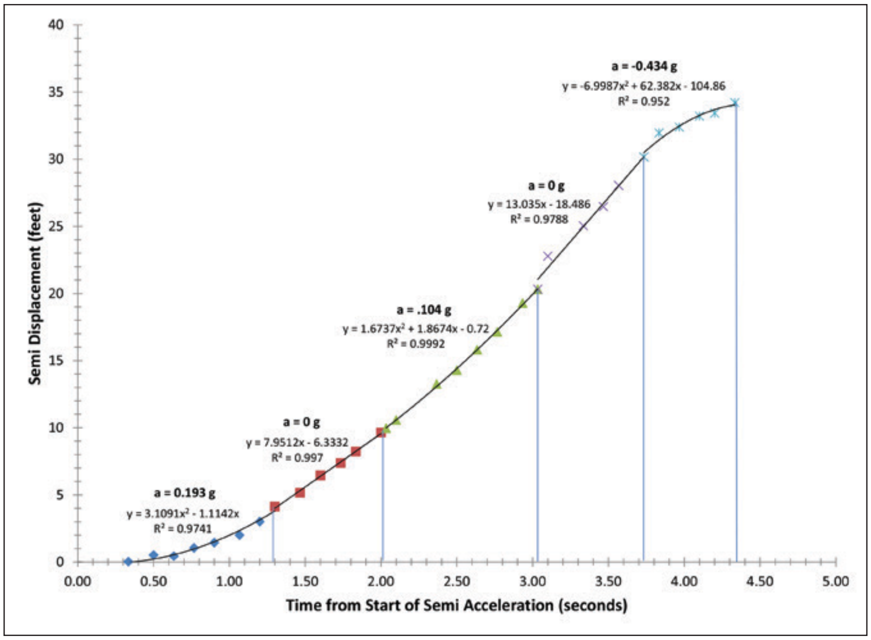


Figure 9
Plotted tractor-tanker position data with 1st and 2nd order polynomials and calculated acceleration.

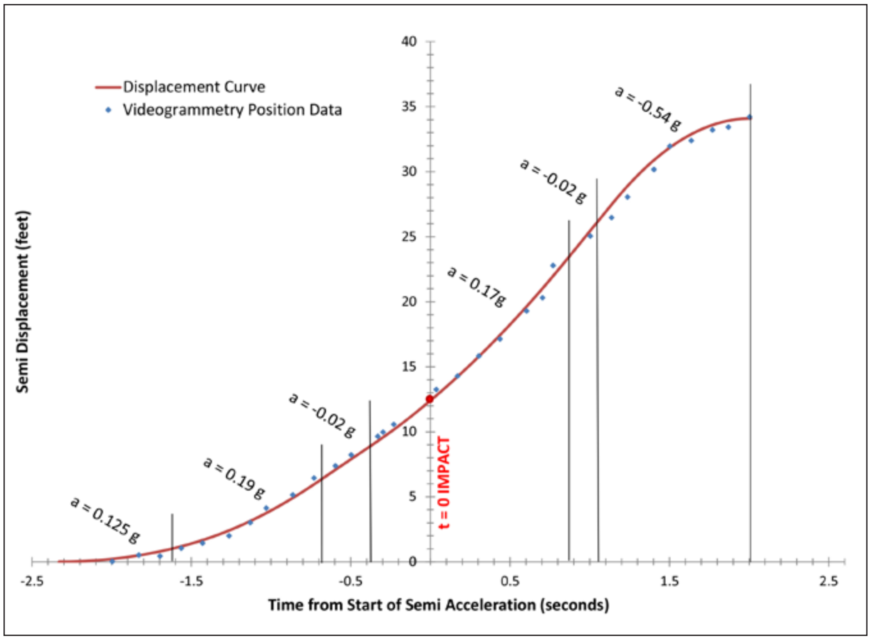


Figure 10
Plotted tractor-tanker position data with best-fit curve.

to determine the tractor-tanker's approximate acceleration versus time (**Figure 9**).

The approximate acceleration values were then integrated from the polynomials in 0.02 second time-steps to determine position as a function of time. An iterative process was performed by adjusting the acceleration values until the resulting position versus time curve best matched the position versus time data points obtained from the videogrammetry process (**Figure 10**). Once the acceleration values were determined, the acceleration values were integrated to determine velocity as a function of time (**Figure 11**).

Tractor-Tanker Engine Speed Versus Time

After determining the position, velocity, and acceleration of the tractor-tanker as a function of time, the tractor-tanker's engine speed was calculated as a function of time. First, published gear ratios and the tractor-tanker's tire size were used to determine the engine speed as a function of velocity. The tractor's tachometer redline occurs at an engine speed of 2,200 rpm. In first gear, 2,200 rpm occurs at a speed of 13.3 fps.

However, the tractor got up to a speed of approximately 15 fps. Therefore, there was a likely transition into second gear at some point prior to reaching that speed. Based on the tractor-tanker's velocity versus time chart, there was only one brief period of time before the tractor-tanker reached 15 fps in which a very gentle deceleration occurred. This period corresponded to the timing of a typical gear shift. Therefore, it was determined the gear shift occurred in the short period of deceleration. The calculated engine speed was plotted as a function of time (**Figure 12**).

Pedestrian Seen in Surveillance Video

After determining the tractor-tanker's position, velocity, and engine speed as a function of time, the pedestrian's movement leading to impact was reconstructed using the video surveillance footage.

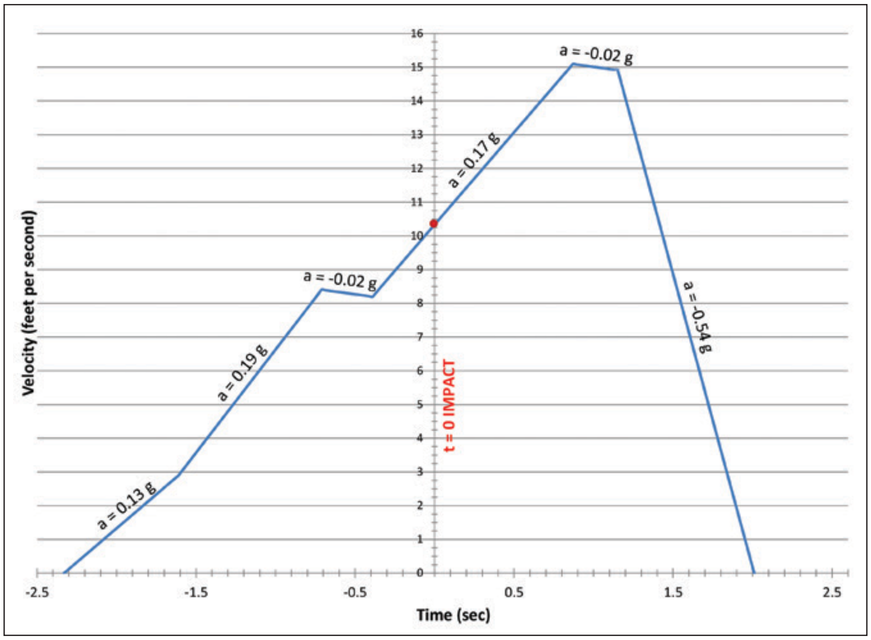


Figure 11
Plotted tractor-tanker velocity versus time.

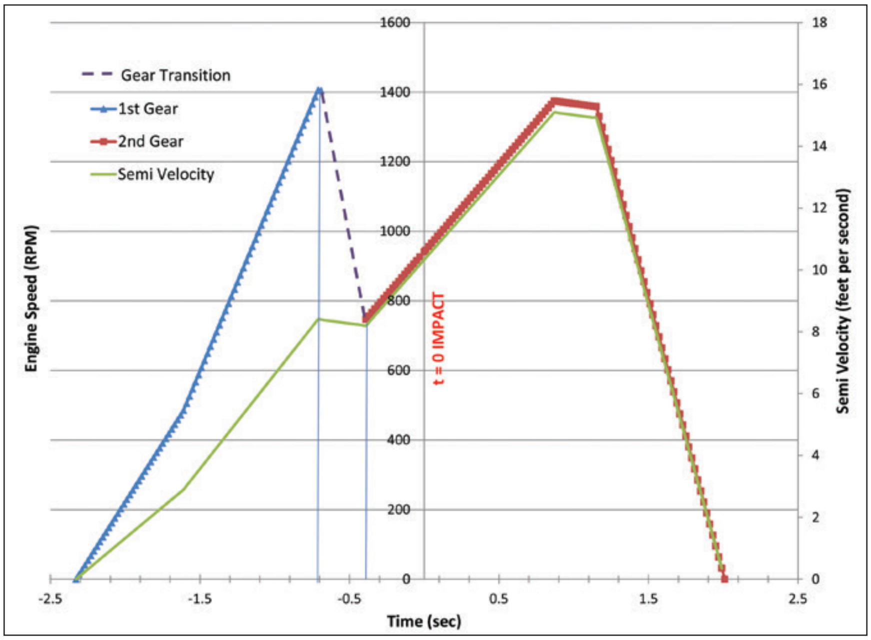


Figure 12
Tractor-tanker engine speed versus time.

The pedestrian is first seen in the surveillance video walking toward the sidewalk from a convenience store. The pedestrian stopped walking near point P0, as shown in **Figure 13**. As the pedestrian was stopped at point P0, the tractor-tanker came to a stop at the intersection, obstructing the view of the pedestrian from the surveillance camera. After the tractor-tanker had stopped, the pedestrian appeared in the surveillance video frames from under the tanker walking from point P1 to point P2. After point P2, the pedestrian was obstructed from view due to the semi-tractor's position between the pedestrian and camera. Shortly after the tractor-tanker started moving, the pedestrian came briefly into frame again at point P5 from under the front of the tractor. The pedestrian came into frame again at impact point P7.

Pedestrian Position and Velocity Versus Time

The methods that were used to determine the tractor-tanker's time-space could not be applied to determine the pedestrian's time-space because the pedestrian appeared very small and pixelated in the video, and the pedestrian was obstructed from view in many frames. The tractor-tanker time-space analysis, video camera's line of sight, and published pedestrian walking speed data were used to determine the pedestrian's time-space during the accident sequence.

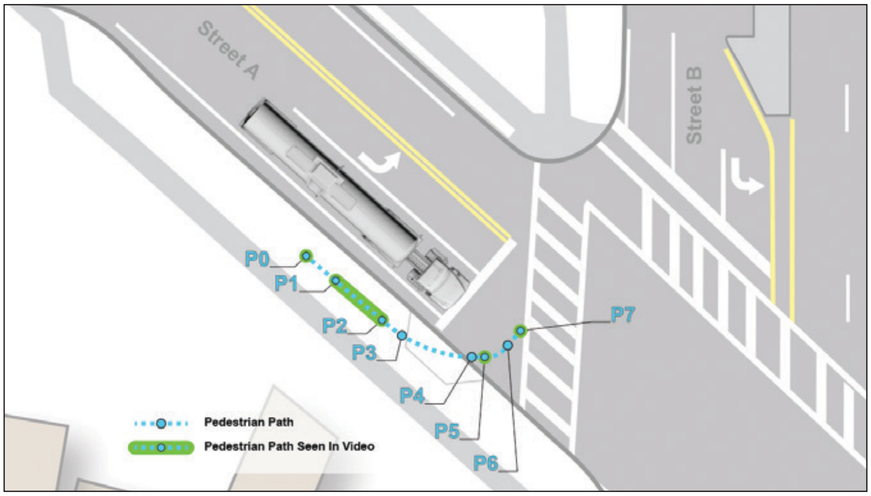


Figure 13
Path of pedestrian to impact.

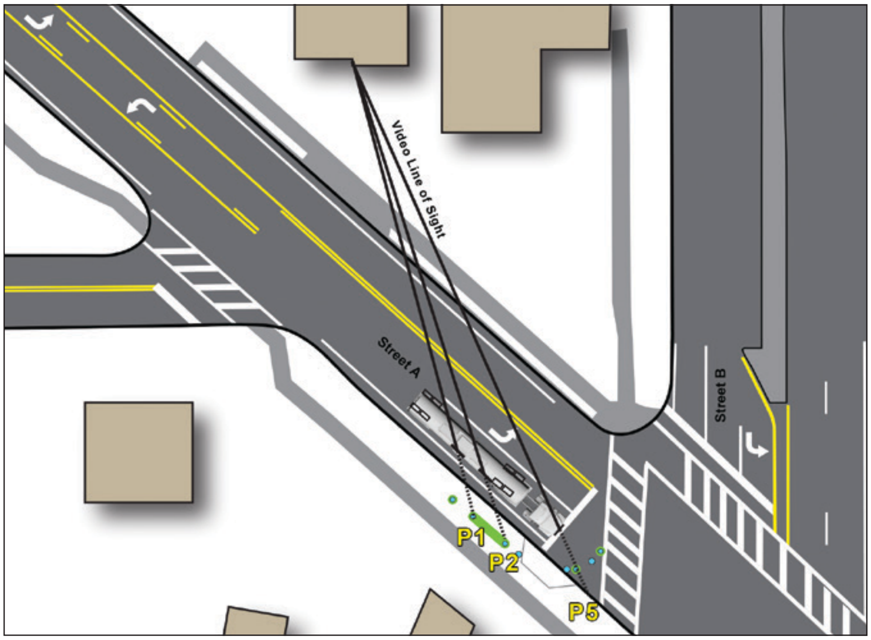


Figure 14
Line of sight method used to determine range of positions for points P1, P2, and P5.

The pedestrian's position at the point of impact (P7) was first analyzed. The pedestrian was visible on the surveillance video as she was struck by the left front bumper of the semi-tractor. The known position of the semi-tractor at the point of impact and the impact point on the tractor's left front bumper were used to precisely locate the pedestrian at the point of impact (P7).

After determining the pedestrian's position at the point of impact, attention was directed at the points in the video sequence where the pedestrian could be seen, such as under the semi-tanker walking between points P1 and P2. The pedestrian could also be briefly seen in the surveillance video from under the front of the semi-tractor at point P5. The video line of sight method was used to determine the range of positions at points P1, P2, and P5. The range of possible pedestrian positions is depicted as dotted lines in **Figure 14**.

Two constraints and a reasonable assumption were applied in order to determine pedestrian positions P1 and P2. One constraint was that positions P1 and P2 fell along the camera's line of sight shown in **Figure 14**. A second constraint was that positions P1 and P2 were between the tanker and a vehicle that had been parked partially on the sidewalk. The applied assumption was the pedestrian walked in a straight path that was parallel with the direction of the sidewalk. With the given constraints and assumption, P1 and P2 were chosen such that the distance between the points (when divided by the known time between points P1 and P2) best matched the 50th percentile walking velocity of a 40-year-old woman pedestrian (5.3 fps). The fastest velocity that could be obtained with the constraints and assumption was 3.79 fps. Therefore, the path corresponding to the fastest velocity of 3.79 fps was chosen.

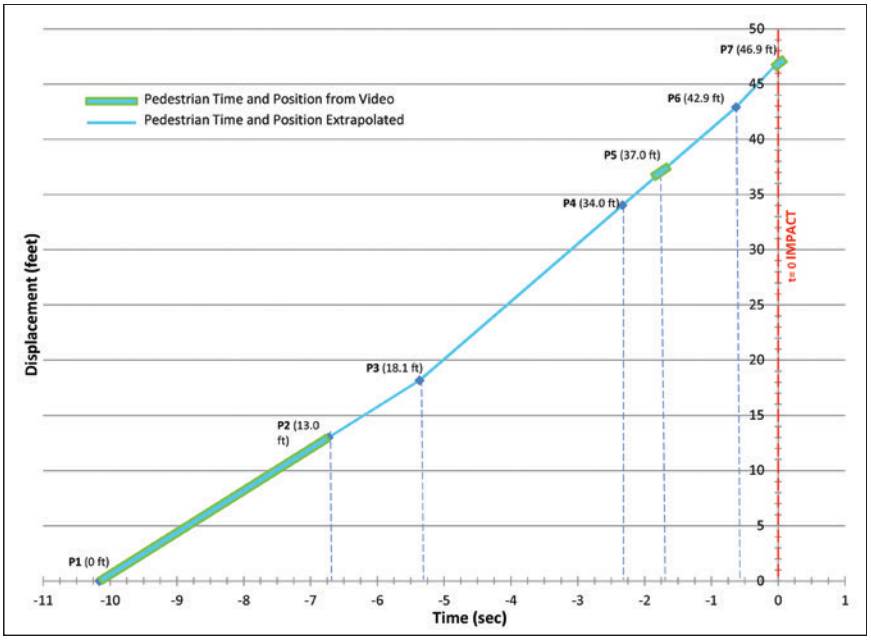


Figure 15
Pedestrian's position versus time.

After determining the pedestrian positions at points P1 and P2, the position of the pedestrian at point P6 was determined. Point P6 corresponds to the point in time the pedestrian testified that she heard the tractor's gears and began to walk fast. The authors of this paper assumed that she heard the gears at the time the tractor likely switched from first to second gear. The gear transition was previously determined to occur 0.63 seconds prior to impact. In order to determine the position at point P6, it was estimated the pedestrian walked along the quickest path to get out of the way of the semi-tractor, according to the 85th percentile walking velocity for a 40-year-old woman pedestrian (6.4 fps). The resulting distance between points P6 and P7 was 4 feet.

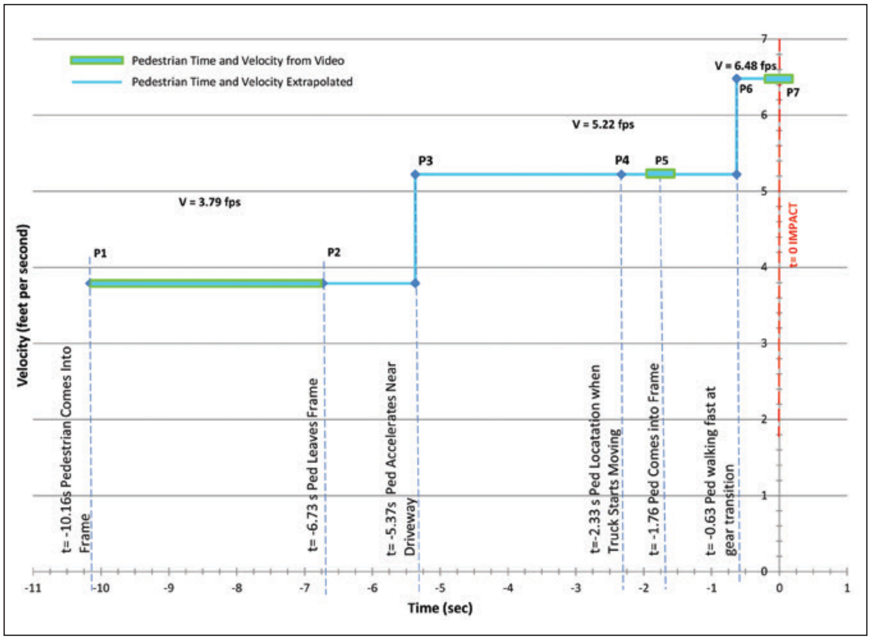


Figure 16
Pedestrian's velocity versus time.

Next, the position of the pedestrian at point P5, corresponding to the location the pedestrian came into video frame from under the semi-tractor, was determined. The timing at point P5 was known as well as the range of possible positions based on the surveillance camera's line of sight (**Figure 14**). A series of iterations was performed, changing the pedestrian position P5 until the distance between points P5 and P6

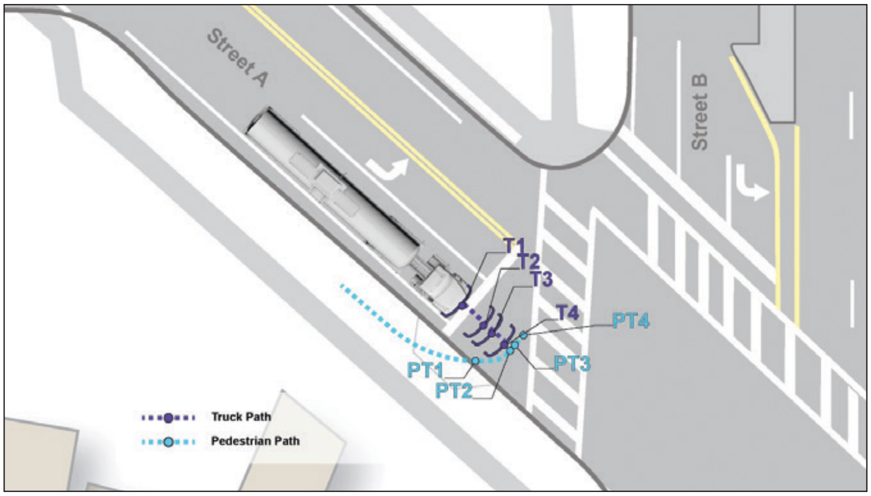


Figure 17
Tractor-tanker and pedestrian time-space diagram.

Figure 18
Still frame taken from photo-realistic animation.

(when combined with the timing between points P5 and P6) best matched the pedestrian's initial velocity of 3.79 fps. The minimum velocity that could be obtained between points P5 and P6 was 5.22 fps, which is near the 50th percentile walking velocity for a 40-year-old woman pedestrian.

Next, it was estimated that the pedestrian continued to travel in a straight path parallel to the sidewalk at a constant speed after point P2 until she started turning at point P3. The turning position (P3) was chosen at the edge of a driveway because the driveway slopes downward toward the road, providing a convenient location to walk down to street level.

After determining turning point P3, the path between points P3 and P5 was determined. In order to determine the path between points P3 and P5, the lowest possible velocity between points P3 and P5 was calculated based on a straight path between P3 and P5. The lowest velocity was determined to be 5.12 fps, which is near the pedestrian's velocity between points P5 and P6 of 5.22 fps. The forensic engineer assumed that the pedestrian traveled at a constant velocity after turning at the driveway. An arched path was chosen such that the distance and timing between points P3 and P6 corresponded to a constant 5.22 fps. After the position and velocities of the pedestrian were determined, time-space diagrams were prepared as shown in **Figure 15** and **Figure 16**.

Combining Tractor-Tanker and Pedestrian in a Time-Space Diagram

After determining the time-space of the tractor-tanker and the pedestrian, a combined pedestrian and tractor-tanker time-space diagram was prepared (**Figure 17**) as well as photo-realistic animations created in Autodesk Maya (**Figure 18**).

Conclusion

Video surveillance cameras occasionally capture and record accidents. Despite significant camera lens distortion, low frame rate, and low resolution frequently encountered with surveillance video, forensic engineers can apply several methods to perform high-quality accident reconstructions from the surveillance video footage.

The authors first corrected the lens distortion using software packages such as Adobe Premiere and Photoshop. PhotoModeler was then used to accurately locate the position, orientation, and focal length of the camera in virtual space. By placing the virtual vehicle model(s) in the virtual space, the position of the vehicle(s) in each video frame was determined. This process is a function of photogrammetry. By using methods addressed in this paper, smoothed position and velocity versus time curves were created from the raw position data captured at approximately 0.133 of a second time increment. Furthermore, engine rpms, gear shifting, as well as impact speed of vehicle(s), were obtained using the surveillance video and published engine specifications.

The authors also used a method to reconstruct the motion of smaller objects seen in surveillance video, such as pedestrians, which often appear very small and highly pixelated. However, the camera's line of sight method described in this paper can be used to constrain the range of possible pedestrian positions for each video frame. Published walking speed data can be used to estimate the pedestrian positioning in each video frame.

In summary, the video surveillance footage, even at very poor quality, can be used effectively by forensic engineers with the application of proper scientific methods. Those methods are a strong basis for foundation of the accident reconstruction and are considered by courts in the process of qualification of a forensic engineer as an expert in a court of law.

Bibliography

T. Thomahlen, H Broszio, and Ingold Wassermann. "Robust Line-Based Calibration of Lens Distortion from a Single View," in *Proceedings of Mirage 2003 (Computer Vision/Computer Graphics Collaboration for Model-based Imaging, Rendering, Image Analysis and Graphical Special Effects*, pp. 105-112. Rocquencourt, France, 2003.

W. Kim, C. Kim. "An Efficient Correction Method of Wide-Angle Lens Distortion for Surveillance Systems," in *Proceeding of Circuits and Systems*, pp. 3206-3209. Taipei, Taiwan, May 24-27, 2009.

F. Devernay and O. Faugeras. "Straight Lines Have to be Straight: Automatic Calibration and Removal of Distortion from Scenes of Structured Environments." *Machine Vision and Applications*, vol. 13, no. 1, Pp. 14-24, August 2001.

W. Hugemann. "Correcting Lens Distortions in Digital Photographs." Copyright 2010 by EVU.

J. Eubanks, P. Hill. *Pedestrian Accident Reconstruction and Litigation*. Tucson, Arizona: Lawyers & Judges Publishing Co., Inc. 1999.

2003 Diesel Truck Index. Santa Ana, California: Truck Index, Inc. 2003.

Richard M. Ziernicki, David A. Danaher, Jeff Ball, “Forensic Engineering Evaluation of Physical Evidence in Accident Reconstruction”, *Journal of the National Academy of Forensic Engineers*, December 2007.

Richard M. Ziernicki, David A. Danaher, “Forensic Engineering and the Use of Computer Animations and Graphics”, *Journal of the National Academy of Forensic Engineers,* December 2006.

Stephen Fenton, Wendy Johnson, James LaRocque, Nathan Rose and Richard Ziernicki. “Using Photogrammetry to Determine Equivalent Barrier Speed”, *Society of Automotive Engineers (SAE)* paper 1999-01-0439, 1999.

Forensic Engineering Investigation of a Three-Vehicle Accident

By Martin E. Gordon, P.E. (NAFE 699M)

Abstract

An accident involving three vehicles resulted in serious injuries to one of the drivers. It was alleged that the driver was injured because both of the other operators were inattentive and made driving errors. Through the use of electronic data retrieval and computer crash simulation, it was shown that only one of the non-injured drivers made a driving error.

A computer-aided dynamic crash simulation program (PC-Crash) was used to show the motion of the vehicles after impact. Because no formal police report was completed for the accident, electronic data retrieval and computer-aided engineering methods were needed to fill in the data voids. Witness statements, in conjunction with the reconstructed data, allowed a better understanding of the mechanisms involved in both the primary and secondary collisions.

Keywords

Forensic engineering, accident reconstruction, EDR, crash simulation, distracted driving, perception reaction time

Introduction

The accident involved three vehicles and two related crashes. Only one driver was seriously injured. The attorney for the injured driver initially brought suit against the other two parties involved. Subsequently, accident reconstructions were needed to determine causative factors and discover the mechanisms of the accident. Experts were hired by two of the three involved parties. Vehicle position, speed, and trajectory were needed for all three vehicles to properly reconstruct the physics of the accident. Fortunately, two of the three involved vehicles were preserved and had airbag sensing and diagnostic module (SDM) or electronic control unit (ECU) data available for download. Unfortunately, no substantive police report or scene photos were available, and one of the vehicles was disposed of prior to the initiation of legal proceedings.

Accident Location

The crash occurred on a four-lane state highway with a two-way center left turning lane. The highway was straight in the vicinity of the accident with clear sightlines along the highway in both directions of travel. Entrance sightlines from side roads, businesses, and residences varied from very good

---

Martin E. Gordon, P.E., 144 Aspen Look Drive, Henrietta, NY 14467; (716) 913-2912; megite@rit.edu

to obstructed. Roadway conditions were dry. The accident occurred during the daytime in a 45 mph to 55 mph transition regulatory speed zone southbound and a 55 mph to 45 mph transition regulatory speed zone northbound. Businesses and a few residences were located on both sides of the highway, which consisted of two 12-foot-wide travel lanes and a 4-foot-wide outside shoulder in each direction separated by a 12-foot center two-way left turning lane. **Figure 1** shows the highway looking in the northbound direction.

Figure 1
NY Route 78 looking northbound.

Description of Accident

The driver of a silver 2000 Saturn was pulling out of a modular home residence (The Woodlands – shown in **Figure 1**) and collided with a black 2011 Toyota Camry traveling northbound in the right travel lane on NY State Route 78. As a result of the collision, the Toyota Camry crossed the left northbound lane as well as the center two-way left turning lane and was involved in a subsequent impact with a black 2008 Chevrolet Impala traveling in the southbound left travel lane. During the first collision, the forensic engineer determined from photographic evidence and vehicle inspections that the Saturn's front bumper contacted the right front wheel of the Camry. During the subsequent impact, the Camry and Impala met essentially head-on, involving the full-frontal widths of the Camry and Impala.

There were three witnesses — all in moving vehicles, each of whom had slightly different information to supply to the investigation. Witness A said that the Impala driver appeared to be texting and was not paying attention to the road in front of her vehicle. Witness B said the second collision happened so quickly after the first that the driver of the Impala "didn't stand a chance." Witness C said that he saw the Camry going southbound after the first collision.

In addition, the involved drivers had different accounts of the accident. The driver of the Saturn said the Camry "came out of nowhere" and was traveling very fast. The Camry driver said she saw the Saturn pulling out to make a left-hand turn to go southbound and slowed down,

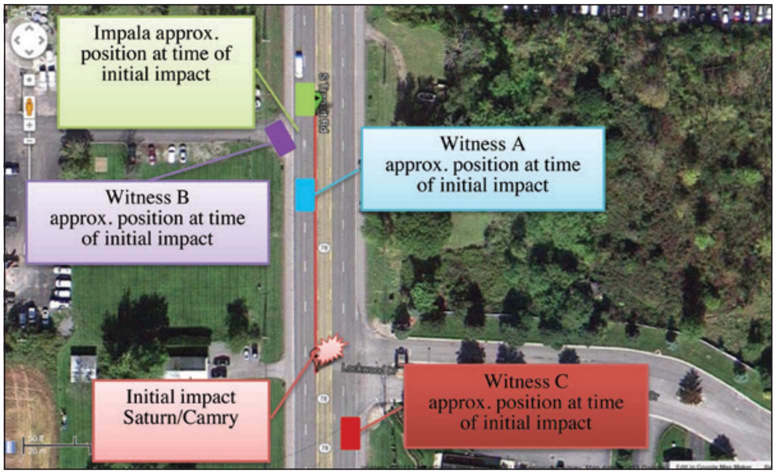


Figure 2
Vehicle and witness positions prior to the first collision[1].

veering to the left to avoid a collision. The driver of the Impala said she never saw the Camry before the second collision. The driver of the Camry said she saw the Impala driver looking right at her just before the second impact. **Figure 2** indicates vehicle and witness positions prior to the first collision.

Evidence Available for Review

The following items were available for engineering review:

- Basic police accident report, New York Form MV104
- Bosch crash data retrieval (CDR) downloads from the Impala and Camry
- Physical vehicle inspection of Camry and Impala
- Witness statements, depositions, and affidavits
- Driver statements and depositions (all three drivers)
- Several photos of the damaged Saturn
- Cell phone records from the Impala driver

The police accident report was very basic; it did not include any photos and contained only a simple sketch of the first collision.

The Impala and Camry were physically inspected, and the Bosch CDR system (versions 4.3 and 5.0, respectively) was used to download data recorded in the Impala's SDM and the Camry's airbag ECU. These devices contained information about each vehicle's speed, seat belt usage, and brake/throttle positions leading up to the time of the collisions. The Saturn vehicle was not available for inspection or download.

The Impala SDM download revealed the following information that was used in the reconstruction. Much of the data was used during the simulation process using PC-Crash[2]. Ranging is used to acknowledge the error band inherent in SDM data due to various factors, such as tire wear, tire slip, analog to digital conversion, etc[3].

- Longitudinal Delta V was approximately 36 mph.
- Lateral Delta V was approximately 8 mph.
- Principal direction of force (PDOF) was between 11 and 12 o'clock.
- Approximate vehicle speed 2.5 seconds prior to crash = 55 to 61 mph.
- Approximate vehicle speed 2.0 seconds prior to crash = 55 to 61 mph.
- Approximate vehicle speed 1.5 seconds prior to crash = 55 to 61 mph.
- Approximate vehicle speed 1.0 seconds prior to crash = 54 to 60 mph.

- Approximate vehicle speed 0.5 seconds prior to crash = 54 to 60 mph.
- Accelerator pedal position 2.5 seconds prior to crash was approximately 19% depressed.
- Accelerator pedal position 2.0 seconds prior to crash was approximately 12% depressed.
- Accelerator pedal position 1.5 seconds prior to crash was not depressed.
- Accelerator pedal position 1.0 seconds prior to crash was approximately 7% depressed.
- Accelerator pedal position 0.5 seconds prior to crash was not depressed.

The Camry ECU download revealed the following significant information that was used in the reconstruction. Much of the data was used during the simulation process using PC-Crash. Again, ranging is used to acknowledge the error band inherent in SDM data due to various factors, such as tire wear, tire slip, analog to digital conversion, etc[3].

- Elapsed time between initial and subsequent impacts was 2.1 (+/- 0.05) seconds.
- Longitudinal Delta V for initial impact was approximately 5 mph.
- Lateral Delta V for first impact was approximately 5 mph.
- PDOF for first impact was between 1 and 2 o’clock.
- Approximate vehicle speed 4.6 seconds prior to first impact = 52 to 58 mph, no brake.
- Approximate vehicle speed 3.6 seconds prior to first impact = 50 to 56 mph, no brake.
- Approximate vehicle speed 2.6 seconds prior to first impact = 50 to 56 mph, no brake.
- Approximate vehicle speed 1.6 seconds prior to first impact = 50 to 56 mph, no brake.
- Approximate vehicle speed 0.6 seconds prior to first impact = 49 to 55 mph, braking.
- Approximate vehicle speed around initial impact = 37 to 43 mph, braking.
- Longitudinal Delta V for subsequent impact was around 35 mph.
- Lateral Delta V for subsequent impact was around 3.5 mph.
- PDOF for subsequent impact was near 12 o’clock.
- Approximate vehicle speed 4.7 seconds prior to second impact = 50 to 56 mph, no brake.
- Approximate vehicle speed 3.7 seconds prior to second impact = 50 to 56 mph, no brake
- Approximate vehicle speed 2.7 seconds prior to second impact = 49 to 55 mph, braking.
- Approximate vehicle speed 1.7 seconds prior to second impact = 26 to 32 mph, braking (speed reduced significantly by initial impact).
- Approximate vehicle speed 0.7 seconds prior to second impact = 19 to 25 mph, braking.
- Approximate vehicle speed around subsequent impact = 12 to 18 mph, braking.

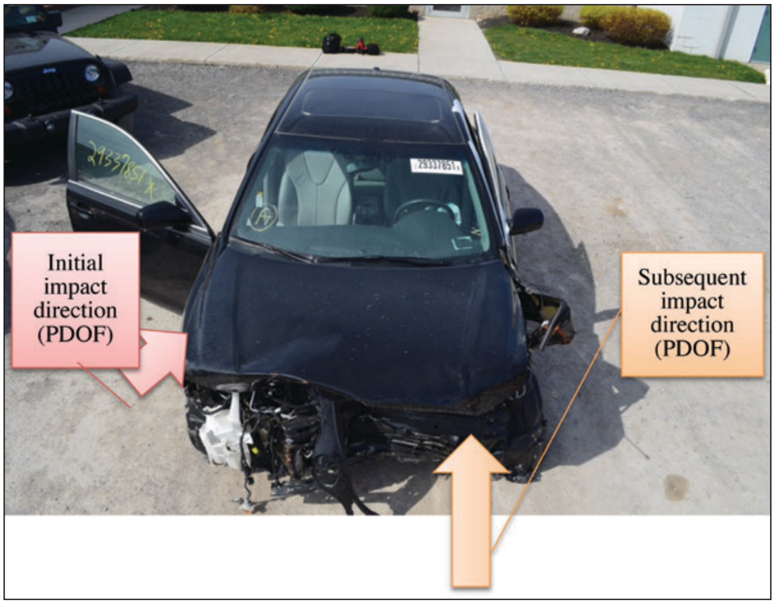


Figure 3
Damage to Camry.

Figure 4
Damage to Impala.

Figure 5
Damaged Saturn (note wheel mark on bumper).

A physical inspection of the Camry indicated significant crush damage to the front of the vehicle. Damage at the front right corner of the vehicle indicated that the initial impact with the Saturn was focused at this location. The Camry was first impacted by the Saturn at a 1 to 2 o'clock position. The physical crush found in the vehicle inspection for the initial impact is consistent with the airbag ECU data PDOF information. The relatively uniform crush along the remaining portion of the front of the vehicle also agreed well with airbag ECU data PDOF information. In other words, the subsequent impact with the Impala was at the 12 o'clock position relative to the Camry. **Figure 3** indicates the Camry damage and PDOF.

A physical inspection of the Impala indicated significant crush damage at the front left corner of the vehicle. This indicated, by this forensic engineer's judgment, an impact that was from the 11 to 12 o'clock position relative to the Impala. This correlated well with the airbag SDM data collected from the Impala. The SDM data provided lateral and longitudinal accelerations that were used to calculate the PDOF directions. Inside the vehicle, it appeared as though a liquid (perhaps coffee) was splashed about the front seating area and dashboard. **Figure 4** provides vehicle damage and PDOF for the Impala.

Photos of the Saturn indicate tire contact with the front bumper. **Figure 5** shows the damaged Saturn.

Using PC-Crash and airbag ECU, data locations and orientations for the initial and subsequent impacts were estimated. **Figures 6** and **7** provide these locations and orientations.

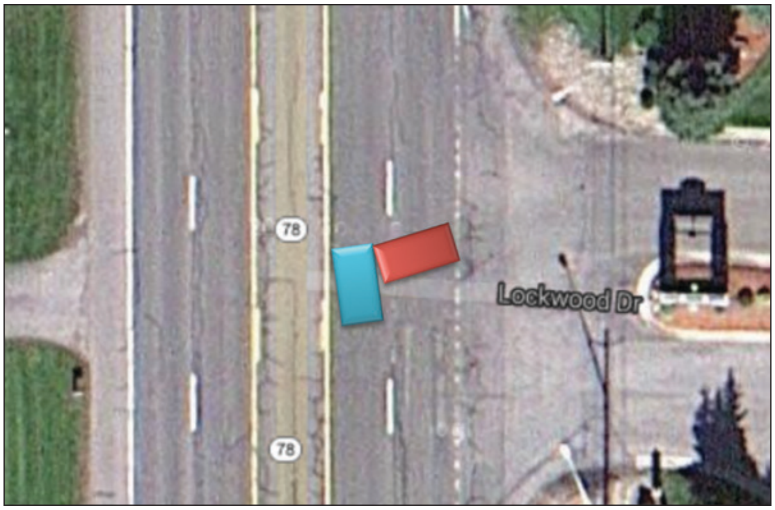


Figure 6
Determined probable location and orientation of the Saturn (red) and Camry (blue) during the initial impact.

Figure 7
Determined probable location and orientation of the Camry (blue) and Impala (green) vehicles at the subsequent impact (from PC-Crash simulation and airbag ECU data).

In reviewing the witness statements, depositions, and affidavits, the following key information was collected:

From Witness A (male):

- Witness A was driving a 2011 GMC Terrain SUV.
- He passed the Impala on the right and pulled in front of it after passing.
- While passing, he claimed he saw the driver's head down, allegedly texting.
- In his first affidavit, he claimed that the driver looked at him as he was passing – "I noticed her glance up to look straight ahead for a brief moment, then look down at her lap area again, and then look at me on her right as I passed her."
- In his prior statements to investigators, he claimed that "it appeared that it looked like she was maybe texting and looking down, but that's not a 100 percent…"
- In his second affidavit, the witness modified his statement, again saying, "My observations as I passed the operator of the black Impala were very brief and only limited to her at times looking down or at me."
- Witness A mentioned that he witnessed the first impact between Saturn and Camry "split seconds" after pulling in front of the Impala. He further mentioned that perhaps his SUV blocked the view of the first impact from the driver of the Impala.
- He said that nothing the driver of the Impala could have done would have avoided the accident.
- He also claimed that he was maybe 30 yards in front of the Impala at the time of the second impact.

From Witness B (male):

- He mentioned that he had just pulled out of a bowling lane parking lot when the second impact occurred.
- He mentioned that it would have been impossible for the driver of the Impala to avoid the accident.

From Witness C (male):

- The Camry was southbound. (The statements made by this witness regarding the Camry being southbound on NY Route 78 did not agree with the physics of the accident nor other witness statements.)
- Witness C said that the driver of the Impala "… was pretty much defenseless in the whole accident."

Cell phone records pulled by the cellular carrier for the driver of the Impala indicated that the driver was making a cellular call within approximately 0 to 5 minutes prior to the accident. The route stated by the driver did pass several lights, so it is possible that the phone was being used while the vehicle was not in motion. The driver stated that she was not using her phone at the time of the second impact; however, there was no way to verify this statement. There was a claim made by the opposition that the use of a cell phone impaired the driver's ability to react to the Camry. In the opinion of this author, it was unclear whether or not a cell phone was being used at the time of collision.

Driver Perception and Reaction Time

Perception and response (PRT) generally takes place in four steps: detection, identification, decision, and response. Under normal conditions, 85% of drivers complete the PRT cycle in less than 1.5 seconds[4]. However, Olson[5] has concluded that there are many things that can affect PRT, one of which is expectancy. In the case of a surprise situation, such as a car moving through a center two-way left turning lane and entering oncoming traffic, it may take significantly longer for a driver to perceive and react to the situation[4]. In addition, if a driver is checking mirrors or is distracted by a vehicle passing on the right, PRT may be lengthened by as much as 1 second per mirror glance[5]. In this accident, it would not be unexpected for the "normal" 1.5 second time to be exceeded. If the driver of the Impala had glanced at a single mirror — or been distracted by the vehicle passing on the right — her PRT could have been at least 2.5 seconds.

Forensic Engineering Reconstruction

The downloaded vehicle airbag data, the results of the physical vehicle inspections, witness statements, and human factors were used — along with generally accepted engineering principles and PC-Crash simulation software — to establish an accident reconstruction of the collision event. The following main points summarize the reconstruction:

- Both the Camry and the Impala were traveling at or about the posted roadway speed limit (determined from airbag data).
- The Saturn entered the Camry's travel lane from a driveway access, and the Camry driver had insufficient time to avoid a collision and impacted the Saturn (determined from witness and driver statements).
- The Impala was approximately 253 feet away from the location of the initial impact between the Camry and Saturn when the initial impact occurred (determined from PC-Crash and kinematic calculations).
- After colliding with the Saturn, the Camry proceeded to subsequently travel through the center two-way left turning lane into the southbound oncoming traffic. The Camry traveled approximately 78 feet (2.1 seconds) between the initial impact and the subsequent impact (determined from airbag data, PC-Crash, and kinematic calculations).
- The total distance traveled by the Impala between the time of the initial impact (between the Camry and Saturn) and when it collided with the Camry was approximately 175 feet (determined from PC-Crash and kinematic calculations).
- The Impala had just been passed by Witness A, who had immediately pulled to the left directly in front of the Impala. The potential exists that the Impala driver's view of the initial impact was obscured or partially obscured by Witness A's SUV. If the view of the initial impact was obstructed, the driver of the Impala would have had less time to react (determined from driver and witness statements).
- At the time of the initial impact, Witness B was waiting to pull out onto NY State Route 78. He was to the right of the Impala and may have created a distraction for the Impala driver, potentially contributing to a delayed reaction by the Impala driver not observing the initial impact between the Saturn and Camry (determined from driver and witness statements).
- PRT could have been at least 2.5 seconds for the Impala driver. Because only 2.1 seconds elapsed between the time of the initial and subsequent impacts, if PRT was 2.5 seconds (or more), there would not have been enough time for the Impala driver to do anything that would have caused her to miss or mitigate the severity of the collision. Data retrieved from the Impala indicated that the driver had taken her foot off of the accelerator approximately 0.5 seconds before impact but had not yet applied the brakes (determined from PRT evaluation and airbag data).

Several "what-if" scenarios were explored conceptually:

- What if the Saturn driver saw the Camry and did not enter the roadway?
    - – No accident would have occurred.

- What if the Camry driver was able to swerve around the Saturn?
    - If the Camry driver maintained control of the vehicle, no impact would have occurred.
    - If Camry control was lost, the accident could have involved more or less vehicles with more or less severity — but specific scenarios would be difficult to predict.

- What if the Impala driver observed the first impact just as it occurred? Total PRT (normally) would be around 1.5 seconds.
    - ◦ She would have had 2.1 – 1.5 = 0.6 seconds to exert a change.
        - She may have quickly steered to the right, potentially striking the vehicle of Witness B, who was waiting to enter the roadway from the right.
        - She may have quickly steered to the left, potentially causing the Camry vehicle to strike her vehicle in a more "broad-side" orientation or striking yet another vehicle not previously involved.
        - With full braking, she could potentially have reduced her speed by approximately 4 mph. With a 4 mph reduction in speed, the impact would have still occurred at nearly the same severity level.

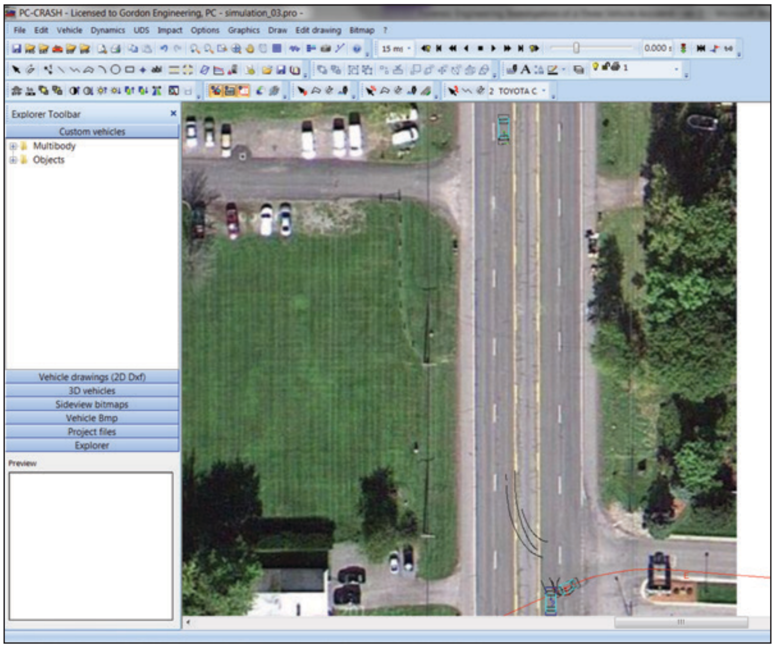


Figure 8
Screen shot of PC-Crash simulation[2].

Using data obtained by airbag SDM and ECU downloads, along with witness statements, a 3D computer simulation was created using PC-Crash. The simulation shows that the Camry would not have spun after the initial impact but would have been pushed off-course, resulting in a trajectory that would have taken the Camry through the center left-hand turning lane and into the oncoming Impala. It was determined there was enough spacing for the Camry to miss Witness A's SUV and strike the Impala. Through the simulation, it was also determined that the driver of the Camry was probably trying to move her vehicle back into the northbound lanes (a steering input was required in PC-Crash) when the subsequent impact occurred. **Figure 8** represents a screen shot of the crash simulation using PC-Crash.

Conclusions

- If the Saturn driver would have observed the Camry and not entered the roadway until the traffic lanes were clear, the accident sequence would not have happened.
- If the Camry driver could have avoided the Saturn, there would have been no first accident.
- The Impala driver could not avoid the subsequent impact with the Camry once the initial impact with the Saturn occurred.
- The Impala driver did not have any probable safer options available to avoid impact with the Camry.

References

1. Google Earth, Map Images captured October, 2012.
2. PC-Crash Software, version 9.1, DSD, Linz, Austria, 2013.
3. Haight R. CDR Data Analyst Course Materials. San Diego: Collision Safety Institute; 2011.
4. Fricke LB. *Traffic crash reconstruction.* Evanston (IL): Northwestern University Center for Public Safety; 2010.
5. Olson PL, Dewar R, Farber E. Forensic aspects of driver perception and response. Third Edition. Tucson (AZ): Lawyers and Judges Publishing Company; 2010.

Forensic Engineering Analysis of a Mobile Refuse Collection Vehicle Accident

By Drew Peake, P.E., DEE, DFE, CIH, CSP (NAFE 460F)

Abstract

As shown in this case, lack of attention to engineering, administrative, and management controls can lead to serious injury or death. Engineering controls include design or redesign of equipment, tools, or the workplace to reduce workers' exposure to hazards. Administrative controls are perhaps better characterized as workplace controls, which include changing work procedures, written safety policies and rules, supervision or schedules, and training, in order to reduce the duration, frequency, or severity of exposure. Management controls are a systematic effort by management to compare performance to predetermined standards, plans, or objectives, to determine if performance meets expectations and to take remedial action as indicated to reduce worker exposure to hazards. Because engineering, administrative, or management controls were not used in this case, a community service worker fell from a mobile refuse collection vehicle and suffered serious injury when his head struck the pavement.

Keywords

Forensic engineering, safety engineering, engineering control, administrative control, management control, gross negligence

Introduction

This case involves a county government that operates a public park. Trash trams, such as the one shown in **Figure 1**, were pulled through the park by a pickup truck, and trash cans would be emptied into the container at each picnic area and campsite. A park employee, who was responsible for safe equipment operation, drove the truck while community service workers rode on the tram.

Figure 1
Trash tram showing close-up of broken handle (in inset photo).

On Nov. 10, 2009, the plaintiff was riding on the back end of a tram — the cover of which had been left open. He

---

Drew Peake, P.E., 3111 Vandiver Drive, Marietta, GA 30066; (678) 521-4647; dpeake@peakeeng.com

was not made aware that there were gloves in the cap of the truck available for his use (gloves may have mitigated the impact enough to allow him to hold onto the rim). The hinge of the cover was in front. When the wind caught the lid, it closed. Because the handhold was broken (see inset of **Figure 1**), the plaintiff was holding onto the top of the container. When the lid slammed onto his hand, he fell off, suffering a left front temporal acute subdural hematoma with impending cerebral herniation.

As is often the case, several factors combined and contributed to the cause and seriousness of this event. Specifically, training was inadequate, the design was lacking key safety features, maintenance and repair were not performed, and the equipment was not operated in a safe manner.

Legal Standard

This is an engineering discussion, not a legal treatise. However, the standard of proof offers important context in this case. Georgia law says that when a local government purchases liability insurance, which, in this case, covered the motor vehicle and trailer in question:

> "….Neither the municipal corporation, county, or political subdivision of this state nor the insuring company shall plead governmental immunity as a defense; and the municipal corporation, county, or political subdivision of this state or the insuring company may make only those defenses which could be made if the insured were a private person (O.C.G.A. § 33-24-51)."

The defendant then pled immunity under the Community Service Act (O.C.G.A. § 42-8-71). Case law expanded such that, when applicable, a plaintiff must establish gross negligence, recklessness, or willful misconduct (Helton v. Glenn County et al. 2010).

Training

The county had an Employee Safety and Loss Control Manual (Adams 2008) that had been revised by Risk Management and the Safety Management Committee and approved by the County Board of Commissioners. Although employee training was addressed in the manual, it fell short of the requirements for operators of mobile waste and recyclable collection equipment (WASTEC 2008). These ANSI training requirements are basic initial training with periodic refresher regarding;

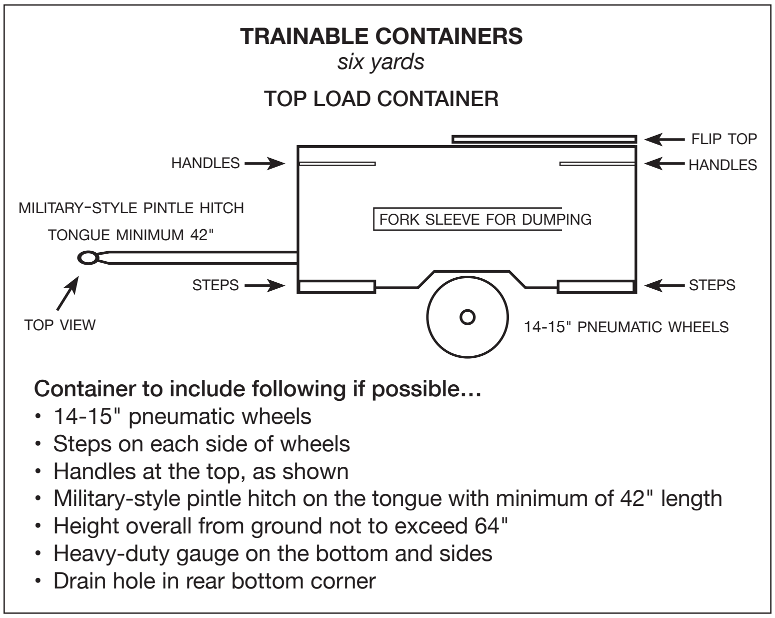
- The hazards assessment identifying type of hazard and who may encounter those risks;
- Required OSHA and DOT training;
- Operating instructions for each type of equipment;
- Equipment safeguards and features; and,
- Minimum requirements for each position.

Park Employee A testified that there was no policy or manual regarding training for those who ride the trash tram, nor was there a hazard assessment performed or available to the workers.

Community service workers rode the trash tram and emptied the trash cans. These workers satisfied their probation for relatively minor violations by working at the park. The plaintiff was performing community service because he had been driving with a suspended driver's license. From the park's perspective, these were transient workers. At each stop, the workers would empty trash cans into the tram, and then ride to the next stop standing on the step and holding onto the handhold. These workers were not trained; they were not forewarned of the hazards that may be encountered, they had no information on the equipment safeguards and features, and they were not given any information on the operating instructions for the equipment. They had a reasonable presumption that the equipment was safe and operated in a safe manner.

Design

In general, counties have small engineering staffs and limited budgets available to hire engineering support. Trash trams are not generally available in retail outlets. They are not easy to find through waste equipment suppliers. Over time, park employees had acquired several trash trams of unknown origin. It seemed reasonable (to park management) to sketch what was in use and engage a machine shop to manufacture more of the same. The trash tram requisition sketch is illustrated in **Figure 2**. There was no information regarding its origin.



Container to include following if possible…
- 14-15" pneumatic wheels
- Steps on each side of wheels
- Handles at the top, as shown
- Military-style pintle hitch on the tongue with minimum of 42" length
- Height overall from ground not to exceed 64"
- Heavy-duty gauge on the bottom and sides
- Drain hole in rear bottom corner

Figure 2
Trash tram requisition sketch.

A local machine shop received a contract to build trash trams based on the sketch. Some important details were left to the discretion of the machine shop. Had the county referred to *Mobile Wastes and Recycling Materials Collection Transportation and Compacting Equipment – Safety Requirements* (WASTEC 2008), it might have offered more detail. This ANSI standard called for a riding step at least 8 inches wide that provides a minimum surface of 220 square inches. As manufactured, the riding step was 10 inches wide and 14 inches long, providing a 140 in^2 step. The standard also called for handholds placed so that a rider can attain a four-point contact with the vehicle, using both hands and both feet approximately shoulder width. While it is not specified in the standard, these safety features need to be usable. The county safety and loss control manual required the County Safety Coordinator to:

"Recommend for incorporation in the program current practices, philosophies, and standards adopted by the safety profession, and its regulatory bodies, concerning injury prevention, occupational disease, vehicle accidents, liabilities or damage and loss to equipment and vehicles to the Safety Management Committee" (Adams 2008).

Maintenance

Broken handholds were a common and perennial issue. A park employee testified that the waste hauler damaged the handles with the forks of the container lifting devices — and that she had notified the waste hauler "years ago" about the problem. Another park employee testified that the handle on the side where the plaintiff was riding had broken off. Notifying the waste hauler once was insufficient management control.

Safety Program and Training

The minimum safety program includes (WASTEC 2008):

- A hazard assessment in which the employer conducts a review of the collection equipment used and the hazards associated with them, including the persons who may potentially encounter these hazards. *(This was not conducted.)*
- An evaluation of the means and methods of controlling the hazards identified in the hazard assessment, including information such as industry and regulatory requirements; operating, inspection, and maintenance of equipment. *(This was not performed.)*
- A written program, based on the hazard assessment and evaluation, including procedures for the operation, inspection, and maintenance of equipment, prohibited practices, recordkeeping, and training requirements. *(Equipment-specific assessment and evaluation were not performed.)*
- A training program that incorporates the above as initial and refresher training. *(There was not training available for community service workers.)*

Training was prescribed for county employees, and park employees participated in their own training. However, the training program did not include community service workers. Park Employee B testified that there was no policy or manual regarding training those who ride the trash tram. The ANSI Z245.1 standard specifies that contract labor must be trained as well.

Operation

A *NIOSH Alert* (NIOSH 1997) was published that offered safe riding instructions:

- Ride in the cab or a separate vehicle when not on the collection route;
- Use riding steps only when the vehicle is moving forward for short distances (0.2 mile or less) at slow speeds (10 miles/hour or less);

- After the vehicle has stopped, step — do not jump — on or off riding steps;
- Wear slip-resistant footwear, and avoid narrow cleats or spikes; and,
- Be extremely observant of the driver's blind spot behind the vehicle.

According to the vehicle driver, Park Employee C, the route was completed — and they were headed back to the staging area about 0.5 miles away at a speed of about 20 mph when the accident occurred.

Park Employee A had previously experienced wind blowing the lid of the trash tram closed while she was riding the tram. While the lid closing startled her, it did not cause her to let go. As a county employee, she had been trained and equipped with safety equipment (gloves). Gloves were available in the cab of the truck for the community service workers. However, testimony does not reflect that these workers were aware of this availability.

Conclusion

The plaintiff argued gross negligence applied. Georgia law defines gross negligence at O.C.G.A. § 42-8-71(d) as:

> "In general, slight diligence is that degree of care which every man of common sense, however inattentive he may be, exercises under the same or similar circumstances. As applied to the preservation of property, the term "slight diligence" means that care which every man of common sense, however inattentive he may be, takes of his own property. The absence of such care is termed gross negligence."

From an engineering perspective;

1. Good engineering practices were not used in equipment design, as indicated by deviations from the accepted standard (WASTEC 2008);
2. Management was aware of damaged safety features, and did not take effective and timely action to remedy broken hand grips;
3. Equipment was not operated safely. Specifically, riders did not stay in the truck cab when traveling to and from the park, and the recommended speed was exceeded, contrary to the NIOSH recommendations; and
4. Community service workers were not trained as required by Glenn County Procedures, and were not made aware of safety equipment (gloves) that was available.

Management controls could have prevented this injury at several points. The requisition process did not include engineering review or any search of standards for refuse collection vehicles. Proper and routine inspection and maintenance would have assured handholds were available. A safety and training program may have alerted management to the hazards and identified preventive action. In addition, operating as directed by NIOSH and the ANSI standard would have the plaintiff in the truck cab instead of hanging on the side of the tram while returning to the staging area.

In summary, the following engineering controls were not used to protect the worker:

- The riding step was under-designed such that riders could not stand with both feet shoulder width apart, in order to have the necessary stability. In addition, the handles were not designed for foreseeable use and abuse.

The following administrative controls were not used:

- Training was not extended to community service workers;
- Supervision was ineffective for both the park employee driving the truck and the plaintiff; and
- There was no written hazard assessment for the trash tram.

Management controls were not used effectively:

- Supervisors were aware of damaged handles and did not repair them or take action to prevent recurring damage.
- Supervisors were aware community service workers were not wearing the gloves, and did not take action to advise the workers.

While it is the jury's decision whether gross negligence applied, this engineering analysis offered useful clarification of the safety issues involved.

References

Adams, I. C. (2008). *Glenn County Board of Comissioners Employee Safety and Loss Control Manual.* Savannah: Glenn County Board of Comissioners.

Justin Helton v. Glenn County and Blythe Island Regional Park, CE10-02249-063 (Superior Court of Glynn County (GA) November 23, 2010).

National Institute of Occupational Safety and Health. (1997). *Preventing Worker Injuries and Deaths from Moving Refuse Collection Vehicles* (Vols. DHHD NIOSH Publication No. 97-110). Washington: NIOSH.

Waste Equipment Technology Association. (2008). *Mobile Wastes and Recyclable Materials Collection, Transportation, and Compaction Equipment – Safety Requirements* (Vols. ANSI Z245.1-2008). Washington: American National Standards Institute.

The Forensic Engineer in State and Federal Court

By Richard Ziernicki, Ph.D., P.E. (NAFE 308F)

Abstract

This paper outlines the legal system in the United States, the different types of courts, the differences between criminal and civil law, and the role of forensic engineering experts involved in civil lawsuits. After providing a summary of relevant procedures employed by civil and criminal courts, the paper describes the basic principles and requirements for the selection and work of a forensic engineering expert in both the state and federal court system. This paper outlines the role and function of forensic experts (specifically forensic engineers), in the United States court system. It is not a treatise on the legal system but on the role of experts. The paper presents the requirements typically used in today's legal system to qualify a forensic engineer as an expert witness and to accept his or her work and opinions. Furthermore, this paper discusses who can be an expert witness, the expert's report, applicable standards, conducted research, engineering opinions, and final testimony in court — and how those elements fit into the legal system. Lastly, the paper describes the concept of spoliation of evidence.

Keywords

Forensic engineer, expert witness, expert testimony, Daubert, Frye, spoliation of evidence

Introduction

"Forensic" in this context means the use of science and technology to investigate and establish facts in criminal or civil courts of law. A forensic engineer applies his or her engineering experience to forensic topics. These engineers typically work with civil cases involving accident reconstruction or products/structures that have failed to perform as expected; however, they can also be involved in criminal cases. In addition, they may be called upon to investigate patent disputes and other legal issues that require the input of an experienced engineer[1].

The forensic engineer, when qualified by the court, becomes an expert witness. Experts usually are involved in all processes of civil law. They are indispensable because their task is to explain to the court (the judge or jurors) what happened, how it happened, and how it could have been avoided, making comprehensive scientific methods understandable to the court.

Experts represent various fields and branches of science, including fire and explosions, chemistry, mechanical engineering, motor vehicle reconstruction, biomechanics, structural and civil engineering,

---

Richard Ziernicki, P.E., 7185 South Tucson Way, Englewood, CO 80112-3987; (303) 925-1900; rziernicki@knottlab.com

aircraft, vehicle and vessel design/performance, sociology, skiing, water recreation, and many more. In the case of motor vehicle accident reconstruction, for example, experts might explain and illustrate the reconstruction of the accident, the vehicle design, seat belt and air bag function/design, driver reaction time, driver visibility, sustained injuries, and federal rules/regulations related to a particular accident.

United States Court System

It is important to outline how the court system works in order to establish how the forensic engineering expert works within that process. The United States district courts are the trial courts of the federal court system. Within limits set by Congress and the Constitution, district courts have jurisdiction to hear nearly all categories of federal cases, including both civil and criminal matters. There are 94 federal judicial districts, including at least one district court in each state, the District of Columbia, and Puerto Rico. Three territories of the United States — the Virgin Islands, Guam, and the Northern Mariana Islands — have district courts that hear federal cases, including bankruptcy cases[2]. A typical courtroom is depicted in **Figure 1.**

Figure 1
A typical courtroom layout.

Although federal courts are located in every state, they are not the only forum available to potential litigants. In fact, the great majority of legal disputes in American courts are addressed in the separate state court systems, which have jurisdiction over virtually all divorce and child custody matters, probate and inheritance issues, real estate questions, and juvenile matters[3]. They also handle most criminal cases, contract disputes, traffic violations, and personal injury cases.

In criminal law and civil law, either a judge or jury is establishing guilt of the party. Every defendant has the right, guaranteed by the Constitution of the United States, to request his or her case be tried by the judgment of the jury and not the judge. A typical arrangement for the jury in the court is shown in **Figure 2**.

Figure 2
A typical arrangement for the jury in the court.

Criminal Cases

In 2013, there were a total of 91,266 criminal cases filed in the United States courts. In criminal cases, the "prosecution" is the party that brings the lawsuit; the "defendant" is the person accused of the crime.

In a criminal trial, the prosecution must prove the accused's guilt "beyond a reasonable doubt." Sometimes, this is a very difficult task to achieve. Therefore, in the absence of conclusive evidence, the accused is acquitted.

At the beginning of a federal criminal case, the principal participants are the U.S. attorney (prosecutor) and the grand jury. The U.S. attorney represents the United States in most court proceedings, including all criminal prosecutions. The grand jury reviews evidence presented by the U.S. attorney and decides whether there is sufficient evidence to require a defendant to stand trial[4].

In a criminal trial, the burden of proof is put on the prosecution. Defendants do not have to prove their innocence. Instead, the government must provide evidence to convince the jury of the defendant's guilt. As stated earlier, the standard of proof in a criminal trial is proof "beyond a reasonable doubt," which means the evidence must be strong enough that there is no reasonable doubt that the defendant committed the crime.

If a defendant is found not guilty, the defendant is released, and the government may not appeal — nor can the acquitted be charged again with the same crime in a federal court because the Constitution prohibits "double jeopardy" or being tried twice for the same offense.

If the defendant is found guilty, the judge determines the defendant's sentence according to special federal sentencing guidelines issued by the United States Sentencing Commission[5].

Civil Cases

In 2013, there were 284,604 civil cases filed in United States courts. In civil cases, the "plaintiff" is the party that brings the lawsuit; the "defendant" is the party being sued.

In a civil trial, apart from contract law, the plaintiff attorney hires a forensic engineer to prove the case "within reasonable scientific probabilities," which means "more likely than not" or with more than 50% probability.

A federal civil case involves a legal dispute between two or more parties. To begin a civil lawsuit in federal court, the plaintiff files a complaint with the court and "serves" a copy of the complaint on the defendant. The complaint describes the plaintiff's injury, explains how the defendant caused the injury, and asks the court to order relief. A plaintiff may seek money to compensate for the injury, or may ask the court to order the defendant to stop the conduct that is causing the harm. The court may also order other types of relief, such as a declaration of the legal rights of the plaintiff in a particular situation.

To prepare a case for trial (in criminal or civil cases), the litigants may conduct "discovery." In this stage of the process, litigants must provide information to each other about the case, such as the identity of witnesses and copies of any documents related to the case. The purpose of discovery is to prepare for trial by requiring the litigants to assemble their evidence and prepare to call witnesses. Each side also may file requests, or "motions," with the court seeking rulings on the discovery of evidence or on the procedures to be followed at trial.

One common method of discovery is the deposition. During this stage, a witness is required under oath to answer questions about the case asked by the lawyers in the presence of a court reporter, a person who is specially trained to record all testimony and produce a word-for-word account called a transcript.

To avoid the expense and delay of having a trial, judges encourage the litigants to try to reach an agreement resolving their dispute. In particular, the courts encourage the use of mediation, arbitration, and other forms of alternative dispute resolution, designed to produce an early resolution of a dispute without the need for trial or other court proceedings. As a result, litigants often decide to resolve a civil lawsuit with an agreement known as a "settlement."

If a case is not settled, the court will schedule a trial. In a wide variety of civil cases, either side is entitled to request a jury trial under the Constitution. If the parties waive their right to a jury, then the case will be heard by a judge without a jury.

At a trial, witnesses testify under the supervision of a judge. By applying rules of evidence, the judge determines which information may be presented in the courtroom. To ensure witnesses speak from their own knowledge and do not change their story based on what they hear another witness say, these parties are kept out of the courtroom until it is time for them to testify. A court reporter keeps a detailed record of the trial proceedings. A deputy clerk of the court also keeps a record of each person who testifies and marks any documents, photographs, or other items introduced into evidence.

As the questioning of a witness proceeds, the opposing attorney may object to a question if it invites the witness to say something that is not based on the witness' personal knowledge, is unfairly prejudicial, or is irrelevant to the case. The judge rules on the objection, generally by ruling that it is either sustained or overruled. If the objection is sustained, the witness is not required to answer the question, and the attorney must move on to the next question. The court reporter records the objections so that a court of appeals can review the arguments at a later time, if necessary.

At the conclusion of the presentation of the evidence, each side gives a closing argument. In a jury trial, the judge will explain the law that is relevant to the case and the decisions the jury needs to make. The jury generally is asked to determine whether the defendant is responsible for harming the plaintiff in some way and the amount of damages that the defendant will be required to pay. If the case is being tried before a judge without a jury, known as a "bench" trial, the judge will decide these issues. In a civil case, the plaintiff must convince the jury by a "preponderance of the evidence" (i.e., that it is more likely than not) that the defendant is responsible for the harm the plaintiff has suffered[6].

The vast majority of non-criminal cases in the United States are handled in state courts, rather than federal courts. For example, in 2013 in Colorado, roughly 97% of all civil cases were filed in state court.

Many state court civil cases produce quick default judgments or pretrial settlements. However, when considering only the cases that actually go to trial, state courts are the dominant forum for civil cases. For example, in Colorado, in 2002, there were 79 civil trials in federal court (41 jury and 38 non-jury), and 5,950 civil trials in state court (300 jury and 5,650 non-jury)[7].

Who Can Be an Expert Witness?

The U.S. court system recognizes two types of witnesses: a lay witness and an expert witness. The lay witness (also called a "fact witness") is the one who can testify regarding personal observations, but is not allowed to express his or her opinions. The expert witness is the one who can express opinions while testifying in court.

The expert is a person who, because of education and years of experience, can help the judge and jury to understand the technical aspects of the case. Furthermore, an expert witness is someone who is called upon to testify because of specialized knowledge or training that makes the expert knowledgeable about a particular subject matter. This person is generally used during a trial to prove or disprove a claim.

There are two important types of rules applicable to forensic work: "The Federal Rules of Civil Procedure," which govern civil proceedings in the United States district courts, and "The Federal Rules of Evidence," which govern the admission or exclusion of evidence in most proceedings in the United States courts. Rules 26 and 27 of "The Federal Rules of Civil Procedure" discuss disclosure, deposition, and requirements for an expert to produce the last four years of testimony in trial and deposition.

The most current version of Rule 702 of "The Federal Rules of Evidence," which was originally adopted in 1975, was adopted in 2013. It governs the admission or exclusion of evidence in most proceedings in the United States courts and outlines procedures related to expert witnesses.

Rule 702 of "The Federal Rules of Evidence," reads: "If scientific, technical, or other specialized knowledge will assist the trier of fact to understand the evidence or to determine a fact in issue, a witness qualified as an expert by knowledge, skill, experience, training, or education may testify thereto in the form of an opinion or otherwise"[8].

There are several expert witness qualifications that one must meet in order to be considered an expert witness in a trial or deposition. Although there is no set standard for being considered, determining who is eligible to act as an expert witness usually requires an examination of the person's educational background, years of experience, and knowledge in the realm or field of the particular case being tried. Any combination of these expert witness qualifications will be taken under consideration when choosing witnesses for a case[9]. For each case, the judge decides whether a person is qualified to participate as an expert. A potential expert, despite education, extensive knowledge, and years of experience, may not be accepted by a judge.

Federal judges are known for their critical attitude and high expectations when choosing a potential expert. In the United States, there is no license that would give an expert a guarantee to be approved as an expert by a judge. A productive engineering expert has to know more than his or her own area of experience (engineering aspect); he or she also has to understand the overall legal framework (forensic aspect).

Rule 702 provides guidelines that expert witnesses are expected to understand. First, an expert witness must base testimony on "sufficient facts or data." As an expert witness, the expert has to convince the court that those facts provide a solid basis for the opinions given. An expert witness may not solely rely on instincts or experience in the industry. The expert cannot rely on unsupported statements that rest solely on the authority of the expert witness. This concept is known as an "ipse dixit," which means "he himself said it" in Latin.

An expert witness, who could be hired by the defense or the prosecution, must determine the set of facts and data that will support any conclusions reached. To guide an expert witness, Rule 702 adds that an expert's testimony must be "the product of reliable principles and methods." The expert should already be familiar with the principles and methods used by others in the field. An expert witness has to be prepared to reference and explain any commonly accepted regulations, standards, or guidelines that govern the industry. Finally, Rule 702 dictates that an expert has to have "applied the principles and methods reliably to the facts of the case"[10].

The court may perceive an expert as objective when the expert has historically worked for both sides of cases: plaintiff and defense. Always working for defense attorneys or for plaintiff attorneys may suggest bias. If an expert chooses to always work for one side or the other, even for what seems to be good reasons, doing so may restrict the expert's choices of future work.

A good thing to remember as an expert witness is, as defense attorneys say, all defendants are entitled to a legal defense and are innocent until proven guilty. An expert does not resolve the right or wrong of a case. The expert brings his or her expertise and knowledge to the court, presents the analysis and findings, and then provides impartial testimony.

Standard of Admissibility of Experts and Their Opinions

In 1923, the federal court case *Frye vs. United States*[11] established the principle that the evidence presented by the experts must be based on the methods and scientific research accepted by experts in the given field. Since 1923, relevancy, in combination with the *Frye* test, was the dominant standard for determining admissibility of scientific evidence in federal courts. *Frye* is based on a 1923 federal court of appeals ruling involving the admissibility of polygraph evidence. Under *Frye*, the Court based the admissibility of testimony regarding novel scientific evidence on whether it has "gained general acceptance in the particular field in which it belongs." The trial court gatekeeper's role in this respect is typically described as conservative, thus helping to keep pseudoscience out of the courtroom by deferring to those in the field.

In 1993, the U.S. Supreme Court in *Daubert vs. Merrell Dow Pharmaceuticals*[12] established new rules for the admissibility of scientific opinion presented by experts in federal courts. The *Daubert* standard provides a rule of evidence regarding the admissibility of expert witness testimony during United States federal legal proceedings. Pursuant to this standard, a party may raise a *Daubert* motion, which is a special case of motion *in limine* raised before or during trial to exclude the presentation of unqualified evidence to the jury. The *Daubert* trilogy refers to the following three United States Supreme Court cases that articulated the *Daubert* standard:

- *Daubert vs. Merrell Dow Pharmaceuticals*, which held in 1993 that Rule 702 of "The Federal Rules of Evidence" did not incorporate the *Frye* "general acceptance" test as a basis for assessing the admissibility of scientific expert testimony, but that the rule incorporated a flexible reliability standard instead;

- *General Electric Co. vs. Joiner*, which held that a district court judge may exclude expert testimony when there are gaps between the evidence relied on by an expert and his or her conclusion — and that an abuse-of-discretion standard of review is the proper standard for appellate courts to use in reviewing a trial court's decision of whether it should admit expert testimony;

- *Kumho Tire Co. vs. Carmichael*, which held in March 1999 that the judge's gatekeeping function identified in *Daubert* applies to all expert testimony. In *Kumho*, the court continued to grant trial judges a great deal of discretion. The court generally permits trial judges to apply any useful factors that will assist the trial court in making a determination of reliability of proffered evidence as deemed appropriate in the particular case. The trial judge may use these factors whether they are identified in *Daubert* or elsewhere. The *Kuhmo* case also said that gatekeeper judges can use parts of *Daubert*, none of *Daubert*, or other appropriate tests to rule on admissibility of experts. Ultimately, *Kumho Tire* expands the gatekeeping role envisioned in *Daubert* to include all areas of expertise under Rule 702. It reiterates *Daubert's* desire for flexibility in trial court decisions on both admissibility and the means of determining admissibility — and broadens the applicability of the abuse-of-discretion standard enunciated in *General Electric Co. v. Joiner*.

Daubert Decision:

In *Daubert*, seven members of the court agreed on the following guidelines for admitting scientific expert testimony:

- Judge is gatekeeper: Under Rule 702, the task of "gatekeeping," or assuring that scientific expert testimony truly proceeds from "scientific knowledge," rests on the trial judge.
- Relevance and reliability: This requires the trial judge to ensure that the expert's testimony is "relevant to the task at hand" and that it rests "on a reliable foundation." (*Daubert vs. Merrell Dow Pharmaceuticals, Inc.*, 509 U.S. 579, 584-587). Concerns about expert testimony cannot be simply referred to the jury as a question of weight. Furthermore, the admissibility of expert testimony is governed by Rule 104(a), not Rule 104(b); thus, the judge must find it more likely than not that the expert's methods are reliable and reliably applied to the facts at hand.
- Scientific knowledge = scientific method/methodology: A conclusion will qualify as scientific knowledge if the proponent can demonstrate that it is the product of sound scientific methodology derived from the scientific method.
- Factors relevant: The court defined "scientific methodology" as the process of formulating hypotheses and then conducting experiments to prove or falsify the hypothesis, and provided a nondispositive, nonexclusive, flexible set of general observations (i.e., not a "test") that it considered relevant for establishing the validity of scientific testimony:
    1. Empirical testing: whether the theory or technique is falsifiable, refutable, and/or testable.
    2. Whether it has been subjected to peer review and publication.
    3. The known or potential error rate.
    4. The existence and maintenance of standards and controls concerning its operation.
    5. The degree to which the theory and technique is generally accepted by a relevant scientific community.

In 2000, Rule 702 of "The Federal Rules of Evidence" was amended in an attempt to codify and structure elements embodied in the "*Daubert* trilogy." The rule then reads as follows: A witness who is qualified as an expert by knowledge, skill, experience, training, or education may testify in the form of an opinion or otherwise if:

(a) The expert's scientific, technical, or other specialized knowledge will help the trier of fact to understand the evidence or to determine a fact in issue;

(b) The testimony is based on sufficient facts or data;

(c) The testimony is the product of reliable principles and methods; and

(d) The expert has reliably applied the principles and methods to the facts of the case.

(As amended April 17, 2000, eff. Dec. 1, 2000; Apr. 26, 2011, eff. Dec. 1, 2011.)

While some federal courts still rely on pre-2000 opinions in determining the scope of *Daubert* as a technical legal matter, any earlier judicial rulings that conflict with the language of *Daubert* are no longer a good precedent.

Although the *Daubert* standard is now the law in federal court and more than half of the states, the *Frye* standard remains the law in some jurisdictions, including California, Illinois, Maryland, New York, New Jersey, Pennsylvania, and Washington. On July 1, 2013, Florida passed a bill to adopt the *Daubert* standard as the law governing expert witness testimony. See Appendix A for a full listing.

Although trial judges have always had the authority to exclude inappropriate testimony prior to *Daubert*, trial courts often preferred to let juries hear evidence proffered by both sides. Once certain evidence has been excluded by a *Daubert* motion because it fails to meet the relevancy and reliability standard, it will likely be challenged when introduced again in another trial. Even though a *Daubert* motion is not binding to other courts of law, if something was found untrustworthy by one court, other judges may choose to follow that precedent. Of course, a decision by the Court of Appeals that a piece of evidence is inadmissible under *Daubert* would be binding on district courts within that court's jurisdiction[13].

Expert witnesses will hear the name *Daubert* frequently when speaking with attorneys. The expert and the attorneys with whom the expert works must anticipate legal challenges to the acceptability of investigations and analyses. *Daubert* standards and challenges guide what an expert witness must understand and how the expert should conduct the investigations, testing, and analyses[14].

The judge can exclude some of the expert testimony (either plaintiff or defense expert) and allow some other part of the expert testimony. An expert witness needs to remember that if the judge strikes him or her as an expert in a *Daubert* proceeding, the expert will not be allowed to testify, and if the expert testifies regarding the liabilities aspect of the case, the attorney will lose the case because the attorney will not be allowed to hire another expert.

Expert Witness Record Requirements

Anyone who testifies as an expert witness is required to provide certain information regarding his or her qualifications, including education, training, and experience. This is provided to opposing counsel as part of the required witness disclosures — typically in the form of a resume or curriculum vitae. There are fairly few procedural rules in place that require experts to provide information beyond what is normally included in a resume or curriculum vitae.

Rule 26 of "The Federal Rules of Civil Procedure," which governs civil proceedings in the United States district courts, requires an expert witness to provide a written report that includes all opinions, the basis for the opinions, and the information that was considered in arriving at those opinions. The report must include exhibits, such as photographs or diagrams, which will be used in trial to summarize or support the opinions. Along with the basic qualifications of the witness, education, training, and experience, a listing of all publications authored by the witness for the preceding 10 years must also be provided.

The rule does not differentiate between material that may or may not be germane to the case at hand; all published material for the preceding 10 years must be listed. Copies of the publications or articles do not need to be attached, but a bibliography must be provided. If an article is published more than once, only one needs to be listed as long as the other publications of the same article are substantially the same.

The written report must include the amount paid for the expert's services in the case in question. In addition, the expert will be asked to provide a complete listing of all other cases in which the expert has testified (in trial and deposition as an expert) for the preceding four years. The listing should include case caption, docket number, jurisdiction, and retaining party. There is no requirement to provide case outcome or court verdict. However, in the expert deposition, additional information can be requested by the deposing attorney regarding all other cases the expert has worked on in the past and whether or not the expert testified. Typically, the expert has to comply with these requests, if the requests are not unreasonably burdensome. In revealing such information for ongoing cases where the expert has not yet been disclosed, the expert should not provide any detailed information beyond the case caption and retaining party without the permission of retaining counsel for that case.

A number of states echo the federal rules in their respective civil and criminal procedures. Generally, state courts will follow the federal rules if the issue is not specifically addressed locally. Some states require previous case listings that cover periods greater than those in Rule 26.

The expert should maintain a current and continuously updated list of trial and deposition appearances and publications authored. Failing to provide the information required by the disclosure rules could result in the expert not being allowed to testify.

Expert Investigation and Opinion

Expert witnesses are typically hired by both plaintiff and defendant to conduct an independent investigation for the hiring party. In most cases, the expert will perform inspection of the evidence and the accident site. However, not all cases require inspection, or sometimes inspection is not possible. In some cases, the expert will perform testing or participate in group testing.

After completion of steps such as inspection, testing, study, and analysis of the results and available documents, the expert provides a verbal report or prepares a written opinion, if required by the client or the court. In many cases, the expert's work will end with a verbal report to the client, insurance company, attorney, or property owner. In some cases, the expert will be asked to write a report to document his or her opinion so the file can be closed, and a decision on how to handle the claim can be finalized. Some cases, however, will continue, and the expert may be deposed and asked to testify in court.

As mentioned, in federal cases, all methods of expert activities and all the evidence gathered by the expert during the investigation must be presented in a written report. The report must include all the expert's opinions and the basis for such opinions. Federal courts' approach to "The Federal Rules of Evidence" (Rule 702) is so rigorous that a judge will not allow the expert to testify to the opinions and its basis if they are not outlined in the expert report.

Some state courts require a written report; others do not. Many state courts, such as California, Georgia, Louisiana, and Missouri, do not require a written report. State court rules, procedures, and practices are quite different from state to state. When writing a report, an expert witness should have a clear understanding of the state requirements regarding form and content of the forensic report.

Evidence, documents, and expert opinions are public, which means that before the parties are in court, they exchange each expert's complete file no later than 30 days (discovery cutoff day) before the start of the trial. After the discovery cutoff day, the judge may not permit any new evidence, new witnesses, or new expert opinion to be admitted.

Forensic engineers should use the "engineering method" in evaluating cases. This means they should look at all the evidence available to them, perform the evaluation, and then draw conclusions without proffering theories at the beginning of the investigation. This is an important aspect of dealing with *Daubert* challenges, and this is why *Kumho* is important. During the investigation, the experts should not predetermine "fault" before examining all facts and doing a complete analysis. An experienced expert may weigh the relative "importance" of the evidence during the investigation, based on his or her specific experience in the field, and make some judgments on how to proceed with the case.

Spoliation of Evidence

If an inspection is conducted, the expert must proceed with due care to avoid spoliation of the evidence, which is the intentional or negligent withholding, hiding, altering, or destroying of evidence relevant to a legal proceeding.

Spoliation of evidence is a term often used during the process of discovery. It happens when a document, information, or evidence that is required for discovery is destroyed or altered significantly, intentionally, or negligently by a person (attorney, expert witness, forensic engineer, or any other party). Spoliation of evidence concerns are also applicable to physical evidence inspected or tested by a forensic engineer.

When a crucial document or physical evidence is lost by spoliation, the courts may try to infer the original information by applying spoliation inference rule, which is a negative evidentiary inference. When applying the rule, courts will review the altered document with inference against the spoliator in favor of the opposing party.

The theory behind spoliation inference is that when a party has destroyed evidence, it shows that the party had consciousness of guilt or other reasons to avoid evidence. Hence, the court will conclude that the evidence was not in the spoliator's favor[15]. The doctrine of spoliation has become a subject of increased attention in the field of discovery as well as in the field of evidence. The doctrine is applied to evidence that a party destroys and that was critical of another party's ability to make its case in court. Spoliation of evidence is prohibited by the American Bar Association's "Model Rules of Professional Conduct," Rule 37 of "The Federal Rules of Civil Procedure," and Title 18 of the United States Code. Sanctions for spoliation may be preventive, punitive, or remedial in nature[16].

Oftentimes, engineering experts are involved with evidence handling and storage. Whether they are a first responder to an accident scene or later in the legal process — when experts must be designated and an inspection is required — they must be intimately familiar with evidence handling standards and procedures. The engineering expert interacts with evidence by logging it and ensuring safe handling and storage; chain of custody usually starts with the engineer as the evidence-collecting entity[17].

The general recommendation for the forensic engineer is to identify and label all evidence, keep careful notes with dates, do not lose or spoliate materials, report all findings objectively, specify units and conditions of measurement, and develop reports with the expectation that the expert will be questioned under cross-examination about every detail.

The engineer may again be involved when evidence must be tested or altered (and documented as such) to be in compliance with standards[18]. When evidence is going to be tested or potentially modified or destroyed, the forensic engineer should outline a test and inspection protocol, and all parties to litigation need to agree on such protocol. Furthermore, if practical, all parties to the litigation have to be invited to participate in the inspection and testing. However, sometimes it is not possible to notify ALL parties that may eventually be involved in the litigation. And this is not something that is the responsibility of the engineer – it is at the discretion of the party retaining the engineer. The engineer can advise the hiring party to invite other parties and circulate the protocol, but going beyond that could introduce a conflict of interest.

Expert in Court

Before the trial begins, the hiring attorney typically meets with the forensic engineer to discuss answers to potential questioning. This helps the expert and attorney be ready on everything the expert might come upon during the trial.

Before a potential expert is accepted by the judge as an expert witness, the potential expert is subjected to questioning in court so the judge can make a ruling on the admissibility of the expert. This process is known as *voir dire*. The attorney retaining the expert is attempting to pave the groundwork so the expert will be accepted by the judge. The lawyer of the opposing party tries to degrade the expert's qualifications and hopes that the judge will strike the expert. This may be done in the presence of a jury. Only after admission by the judge is an expert witness allowed to testify.

Once the engineer is qualified as an expert in the case, the expert will be permitted to provide opinions regarding the subject at hand; however, if the court didn't recognize this engineer as an expert, the engineer will not be allowed to give any testimony. Both the prosecution and the defendant are allowed to attempt a tactic to recognize one's expertise in a particular field.

At the beginning of testimony, the expert delivers his or her expert opinion and answers the questions of the client's lawyer. During this presentation, called direct examination, which can take an hour up to a few days, the expert discusses the investigation, the evidence relied on, and what working methods were used to arrive at his or her conclusions. An example of an expert testifying in court is depicted in **Figure 3**.

Figure 3
Example of expert testifying in court.

After the direct examination, the expert would be subject to cross-examination by the opposing attorney. During this stage, the expert's entire work and opinion may be aggressively challenged. The expert should understand that his or her deposition may be used to confront and challenge the accuracy and truthfulness of the expert's opinion during the trial. Therefore, the expert needs to be very familiar with the deposition content. It is the cross-examination that can either "make" or "destroy" the expert. During the trial testimony (and deposition), the expert witness should not act as an advocate for one party or the other, but rather strictly be an advocate for his or her opinions and go into each case with an open mind. Furthermore, the expert testimony must be not only reliable and technically sound, but it also must be relevant to the case at hand.

The expert witness is a professional and has specialized knowledge in his or her field, which is why it is important to give the court a confident, straight answer that is easy to understand by the jurors. This will help the witness to prove that his or her testimony is credible. It will also help educate the court in determining and understanding difficult technical issues and the evidence. It is very important that the witness has confidence in his or her testimony and is clear in explaining technical aspects of the case so that the jury can comprehend and understand the testimony.

The jury carefully listens (it is hoped) to the testimony of an expert during the direct examination and cross-examination. If the expert is weak during this process — and explanations submitted by the expert are unclear, insufficient, or unreliable — then the jury will take it into account before reaching a final decision. It should be noted that the opposing party usually has his or her own expert, who typically has different opinions, and the expert is subject to the identical process of qualification, admission, examination, and cross-examination.

Conclusion

In conclusion, the forensic engineering expert should keep the following considerations in mind:

- All criminal defendants are entitled to a legal defense and are innocent until proven guilty. Plaintiffs in civil cases are entitled to their day in court but must prove their case — not unlike the prosecutors in criminal cases.
- A forensic engineer should be willing to offer objective analytical skills to attorneys on either side of any case.
- A forensic engineer does not resolve the right or wrong of a case. Instead, he or she brings expertise and knowledge to the court, presents the analysis and findings, and then provides impartial testimony.

References

1. What Is a Forensic Engineer? [Internet]. [Updated 2014 June 25]. WiseGEEK; [cited 2014 July 20]. Available from: http://www.wisegeek.com/what-is-a-forensic-engineer.htm
2. District Courts. [Internet]. United States Courts; [cited 2014 July 20]. Available from: http://www.uscourts.gov/FederalCourts/UnderstandingtheFederalCourts/DistrictCourts.aspx
3. Jurisdiction of the Federal Courts. [Internet]. United States Courts; [cited 2014 July 20]. Available from: http://www.uscourts.gov/FederalCourts/UnderstandingtheFederalCourts/Jurisdiction.aspx
4. Criminal Cases. [Internet]. United States Courts; [cited 2014 July 20]. Available from: http://www.uscourts.gov/FederalCourts/UnderstandingtheFederalCourts/HowCourtsWork/CriminalCases.aspx
5. Criminal Cases. [Internet]. United States Courts; [cited 2014 July 20]. Available from: http://www.uscourts.gov/FederalCourts/UnderstandingtheFederalCourts/HowCourtsWork/CriminalCases.aspx
6. Civil Cases. [Internet}. United States Courts; [cited 2014 July 20]. Available from: http://www.uscourts.gov/FederalCourts/UnderstandingtheFederalCourts/HowCourtsWork/CivilCases.aspx
7. State court (United States). [Internet]. [Updated 2014 July 18]. Wikipedia; [cited 2014 July 20]. Available from: http://en.wikipedia.org/wiki/State_court_%28United_States%29
8. Federal Rules of Evidence. [Internet]. [Updated 2014 July 15]. Cornell University Law School; [cited 2014 July 20]. Available from: http://www.law.cornell.edu/rules/fre
9. What Are Expert Witness Qualifications? [Internet]. [Updated 2014 May 18]. WiseGEEK; [cited 2014 July 20]. Available from: http://www.wisegeek.com/what-are-expert-witness-qualifications.htm
10. Judd Robbins. Expert Witness Training: Profit from Your Expertise. Presentation Dynamics. 2010. 22 p.
11. Frye vs. United States, 293 F. 1013 (DC Cir. 1923)
12. Daubert vs. Merrell Dow Pharmaceuticals, Inc., 509 U.S. 579, 593 (1993)
13. Daubert standard. [Internet] [Updated 2014 June 12]. Wikipedia; [cited 2014 July 20]. Available from: http://en.wikipedia.org/wiki/Daubert_standard
14. Judd Robbins. Expert Witness Training: Profit from Your Expertise. Presentation Dynamics. 2010. 22 p.

15. Spoliation of Evidence. [Internet]. USLegal, Inc.; [cited 2014 July 20]. Available from: http://civilprocedure.uslegal.com/discovery/spoliation-of-evidence/
16. Evidence Spoliation And Relevance. [Internet]. [Updated 2010 September 10]. Federal Evidence Review; [cited 2014 July 20]. Available from: http://federalevidence.com/blog/2010/september/evidence-spoliation-and-relevance
17. The Value of Evidence Handling & Storage. [Internet]. [Updated 2009 December 1]. CED Investigative Technologies, Inc.; [cited 2014 July 20]. Available from: http://www.cedtechnologies.com/index.php/areas-of-engineering-expertise-at-ced/slip-and-fall/278-the-value-of-evidence-handling-a-storage
18. The Value of Evidence Inspection, Handling & Storage. [Internet]. [Updated 2012 November 13]. CED Technologies Incorporated; [cited 2014 July 20]. Available from: http://www.cedtechnologies.com/blog/entry/the-value-of-evidence-inspection-handling-storage-1

Appendix A

Rules of Evidence and Tests Applied by States

Summary Table State	Rule of Evidence	Test Applied
Alabama	Ala. R. Evid. Rule 702	*Daubert* for DNA; *Frye* for all else
Alaska	Alaska R. Evid. 702	*Daubert*
Arizona	Ariz. R. Evid. R. 702	*Frye*
Arkansas	A.R.E. 702	*Daubert*
California	Cal. Evid. Code §720	*Kelly/Frye*
Colorado	C.R.E. 702	*Daubert*
Connecticut	Conn. Code Evid. §7-2	*Daubert*
D.C.	N/A	*Frye*
Delaware	Del. Uniform R. Evid. 702	*Daubert*
Florida	Fla. Stat. § 90.702	*Frye*
Georgia	O.C.G.A. § 24-9-67.1	*Daubert*
Hawaii	Haw. Rev. Stat. Ann. § 702	Some *Daubert* factors
Idaho	I.R.E. Rule 702	*Daubert*
Illinois	There is no substantial equivalent to Fed. R. Evid. 702	*Frye*
Indiana	Ind. R. Evid. 702	*Daubert*
Iowa	Iowa R. Evid. 702	*Daubert*
Kansas	K.S.A. § 60-456	*Frye*
Kentucky	Ky. R. Evid. 702	*Daubert*
Louisiana	La. C.E. Art. 702	*Daubert*
Maine	Me. R. Evid. 702	Some *Daubert* factors
Maryland	Md. R. Evid. 5-702	*Frye*

Continued

Appendix A — *Continued*

Massachusetts	N/A	*Daubert*
Michigan	Mich. R. Evid. 702	*Daubert*
Minnesota	Minn. R. Evid. 702	*Frye/Mack*
Mississippi	Miss. R. Evid. Rule 702	*Daubert*
Missouri	Mo. Rev. Stat. § 490.065(1)	*Unique Test for Civil; Frye criminal*
Montana	Mont. R. Evid. 702	*Daubert*
Nebraska	Neb. Rev. Stat. § 27-702	*Daubert*
Nevada	Nev. Rev. Stat. Ann. §50.275	*Daubert "may provide persuasive authority"*
New Hampshire	N.H. R. Evid. 702	*Daubert (although NH cts. have applied Frye to DNA evidence)*
New Jersey	N.J. R. Evid. 702	*Daubert for toxic tort cases, certain medical causation cases, Frye other civil cases; Frye for criminal*
New Mexico	N.M. R.E. 11-702	*Daubert*
New York	N.Y. C.P.L.R. §4515	*Frye*
North Carolina	N.C. Gen. Stat. § 8C-1	*Some Daubert factors*
North Dakota	N.D. R. Evid. 702	*Frye*
Ohio	Ohio R. Evid. 702	*Daubert*
Oklahoma	12 Okl. St. § 2702	*Daubert*
Oregon	Oregon R. Evid. 40.410	*Applies a multi-factor test that includes the Daubert factors*
Pennsylvania	Penn. R. Evid. 702	*Frye*
Rhode Island	RI R. Evid. 702	*Daubert*
South Carolina	Rule 702, SCRE	*Daubert factors*
South Dakota	S.D. R. Evid. 702 (SDCL § 19-15-2)	*Daubert*
Tennessee	Tenn. R. Evid. Rule 702	*Daubert factors*
Texas	Tex. Evid. R. 702	*Some Daubert factors*
Utah	Utah R. Evid. Rule 702	*Unique Test*
Vermont	Vermont R. of Evid. 702	*Daubert*
Virginia	Va. Code Ann. §8.02-401.1	*Unique Test*
Washington	Wash. R. Evid. 702	*Frye*
West Virginia	W. Va. R. Evid. 702	*Daubert*
Wisconsin	Wis. Stat. Ann. § 907.02	*Unique test*
Wyoming	Wyo. R. Evid. 702	*Daubert*

Based on 50 State Survey of Applicability of *Daubert by:*
Andrew B. Flake, Esq., Eric R. Harlan, Esq., and James A. King, Esq.