Journal of the

National Academy OF Forensic Engineers®

http://www.nafe.org
ISSN: 2379-3252

Vol. XXIV No. 2 December 2007

Forensic Engineering Use of Surrogates in Injury and Fatality Cases

by John P. Leffler, PE (709M)

Abstract

In personal injury and fatality cases, particularly those involving biomechanics, it can occasionally be difficult to evaluate causation scenarios without the use of a "human tape measure", more commonly known as a surrogate. In these cases, for the incident to happen in the manner alleged, certain bodily positions, configurations and movements would be "necessary". A surrogate provides tangible, real-world dimensional and range-of-motion references that can assist both the causation analysis and the triers of fact. Three case studies will illustrate the benefits of using human surrogates: a vehicle crash injury, an alleged ramp slip-and-fall, and a tractor/mower fatality.

Keywords

Forensic engineer, surrogate, biomechanic, animation, simulation, tractor, mower, ramp

Forensic engineers are called upon to determine causation in insurance claims and litigation involving the injury or death of the claimants and plaintiffs. The majority of cases may be relatively straightforward. However, there may be cases where the absence of witnesses, scene information, and/or relevant peer-reviewed research complicates the ability to determine reasonable causation scenarios. In these cases, the use of human surrogates may provide valuable input to the overall investigation.

Forensic engineers, generally speaking, use a number of inputs in their investigation. Depending upon the case and at the discretion of the forensic engineer, these inputs may include:

- Claims and complaints
- Eyewitness statements & depositions
- Scene photos and security camera video
- Inspection and testing of involved objects & equipment
- Scene inspection
- Analysis and calculations

John Leffler PE, 1730-H Mount Vernon Road, Atlanta GA 30338

- Records and discovery documents
- Literature, peer-reviewed studies and other research
- Other expert opinions & testimony

Cases involving litigation may take years to develop to the point of initiating a forensic analysis; by that time, some relevant information may have been lost. Even recent insurance claims may be unwitnessed, with a scene that has been changed, evidence that has been discarded, and where no photographs were taken.

In such cases, there can be benefits to using computer graphics and animations. Such methods can allow viewing of a scene or an object from any angle, and subtle technical details can be clearly highlighted for consideration by the triers of fact. Modern computer graphics can be made to show anything you want – right or wrong. It requires special software, time, training, and skill to create such graphics, and because they are a "simplification" of the incident, many assumptions and approximations must be made during that creation. Similarly, at least one popular animation software package does not include the ability to assign specific proportions to the animated elements – they can only be stretched and scaled without any actual relative references. Such a significant limitation provides a clear opportunity for adverse experts or counsel to refute the validity of the animation.

One of the most challenging undertakings involved in these cases may be the evaluation of the human kinematics and kinetics associated with the incident, particularly those that would be "necessary" (or conversely, "impossible") for a particular mechanism of injury to have occurred. Again referencing computer graphics, there are high-end software applications that can model human movements and force reactions. However, as mentioned, they rely on many assumptions and initial configuration settings that may significantly affect the results. Computer simulations in general are unlikely to be able to provide conclusive information on human balance perception, levels of exertion, etcetera.

For cases that would involve certain motions by the claimant or plaintiff, and those motions are A) not supported by observations or evidence, B) not supported by literature or published research, and/or C) not supported by engineering judgment (or common sense), it may be helpful to conduct a human surrogate evaluation. In a surrogate evaluation, a "substitute" human is used whom is comparable to the allegedly injured person, and they are placed in an environment comparable to the incident scene. The use of exemplar objects and equipment may also be appropriate. In many cases, a surrogate evaluation may be more instructive and potentially less expensive than computer graphics and animations. Three case studies will be used to analyze and discuss the use of human surrogates.

Case 1: Limousine crash on highway

The client was an attorney representing the insurer of a truck freight firm. One of the firm's panel delivery truck drivers lost control and spun sideways on a multilane highway while braking for stopped traffic. A following limousine was unable to stop and impacted the side of the delivery truck with a delta-V of 5-10mph. A motorcycle then impacted the driver's side of the limousine. See Figures 1 and 2.

Figure 1
Damaged front of limousine

Figure 2
Damaged front and side of limousine

The right side rear-seat limousine passenger (Mr. Jones) suffered fractures of three left ankle bones, in a manner consistent with torsional loading of the lower extremity. He was interviewed and left the scene in an ambulance. After a few weeks of recovery, further treatment in an overseas medical facility led to an ankle infection and his death. The plaintiff, his wife, sued our client for causing the crash and the associated ankle injuries.

The limo passenger Mr. Jones, in his recorded statement, reported that he was wearing his seatbelt and was reading the newspaper at the time of the crash. Mr. Jones used the same limo company frequently, with the same driver – that driver reported that Mr. Jones usually wore his seatbelt but the driver didn't know if he had it on during that trip. The driver also reported that Mr. Jones would often rest his foot on the left-hand front passenger's seat track. The limousine was a domestic brand that comes from the factory with a 5-inch extended wheelbase for more rear legroom.

As it was inconclusive as to whether Mr. Jones had been wearing his seatbelt, a literature review was performed to determine causation patterns for ankle injuries to belted versus unbelted rear-seated passengers in frontal collisions. Government research[1] indicated that lower extremity injuries in general (for this seating position) were reported in only 2% of serious crashes, and ankle injuries were not specifically highlighted. Additionally, the data are for serious crashes of passenger cars overall, not just long-wheelbase limousines. The use of data for serious crashes was viewed as a "worst-case" scenario that would favor the plaintiff.

Figure 3
Measurement of exemplar limousine

The analysis then focused on the body kinematics that would be "necessary" for such an injury to occur. The most likely scenario involved the left foot becoming trapped or pinned by the footwell components, followed by crash-related upper body movement and the associated torsional loading of the ankle – leading to the reported fractures. Due to the complexities of the interaction between the 6 foot 1 inch tall, 190 pound body size of Mr. Jones and the seat contours, front seat track, and extra legroom of the limousine, it was decided to conduct a surrogate evaluation.

Figure 4
Surrogate seated in right rear of limousine

An exemplar limousine was found, as was a 35-year old male having the desired physical proportions. The surrogate evaluation allowed us to determine the significance of the front passenger's seat position, the seat track location and geometry, the comfortable foot positions and ranges of motion for the surrogate, and the ability of the surrogate's foot to be trapped or otherwise restrained by the footwell components. See Figures 3 – 5.

Figure 5
Surrogate's foot in seat track area

The key information we determined from the surrogate evaluation was that it was possible for the surrogate to have his foot trapped in the footwell, even while seated in a comfortable position, and that such a position was possible while properly restrained by the seatbelt. That information, combined with knowledge of the body movement that can be expected while restrained in a frontal collision, led to our conclusion that it was possible for Mr. Jones to suffer this injury while restrained. The case was settled before trial.

Case 2: Alleged slip and fall on delivery truck ramp

In this lawsuit, a delivery truck driver (Mr. Brown) was using a two-wheeled hand cart to roll a load of chemicals down the truck's metal ramp. While on the ramp, he allegedly slipped, both feet went in the air, and he landed on his back. Upon landing, Mr. Brown claimed that the top section of the hand cart struck him in the chest near his heart. An ambulance was called, and a diagnosed mitral valve prolapse led to heart surgery. He eventually claimed permanent disability. At the time of the incident, Mr. Brown was 5 feet tall, weighed 285 pounds, and had a history of an enlarged heart.

Figure 6
Delivery truck and ramp

Figure 7
Subject hand cart

Our client was the attorney for the delivery truck owner's insurance company. The focus of our investigation was whether the alleged fall and impact of the hand cart could have occurred as described, to cause the mitral valve prolapse. Our first step was to evaluate the extrinsic aspects of the incident environment. See Figures 6 and 7 for views of the truck, ramp, and hand cart. Note the top "hoop" of the hand cart – this is what allegedly struck the plaintiff's chest.

At the time of the incident, the hand cart was loaded with four 30-pound boxes of liquid soap jugs. In his deposition, Mr. Brown provided a detailed descriptive account of how he was handling the loaded cart while on the ramp: feet wide apart near the ramp's edges, cart handles pulled up next to his chest, and leaning over the cart. He demonstrated the position of his hands in pho-

tographs taken at his attorney's office. In those photos, the top hoop of the hand cart barely reached the plaintiff's chest – and those photos were taken with the plaintiff and hand cart on level ground, not the 19 degree sloped surface of the delivery truck ramp. This issue and others seemed questionable: the treating medical personnel observed no chest bruising, and the plaintiff's described cart-handling method was counter-intuitive. Being unable to find any relevant studies for injuries due to falls occurring on ramps while moving a heavily loaded hand cart, we decided to perform a surrogate evaluation.

An exemplar delivery truck/ramp and hand cart were obtained. The 20 pound hand cart was loaded with four appropriately-sized boxes of dirt, each weighing 30 pounds. Finding an appropriately-sized surrogate was a challenge, due to the 5 foot tall, 285 pound proportions of the plaintiff Mr. Brown. Anthropometrically, this represents a person two inches shorter than a 1.0 percentile male that is 40 pounds heavier than a 99.0 percentile male.[2] An actor was found who was 5 feet 3 inches tall and 185 pounds. See Figures 8 – 9.

Figure 8
Exemplar hand cart

Figure 9
Surrogate

The surrogate was asked to roll the loaded hand cart on level ground and up and down the ramp, in order to get used to its weight and balance. We then asked him to demonstrate various positions that he found most comfortable when moving the hand cart down the ramp. These positions presented body and limb orientations and configurations with arms straight, torso leaning back, and feet at approximately shoulder width. We then asked him to attempt to descend the ramp with the loaded hand cart in the manner described by the plaintiff, which proved to be somewhat opposite to the comfortable positions found by the surrogate: his hands up and close to the chest, arms bent, feet wide apart, and leaning forward over the cart. The surrogate found this to be a strenuous and

unstable task. See Figure 10 for a comparative view of these positions – and note the position of the top hoop of the hand cart in either view; it is at least 12 inches below the mid-sternum of the chest.

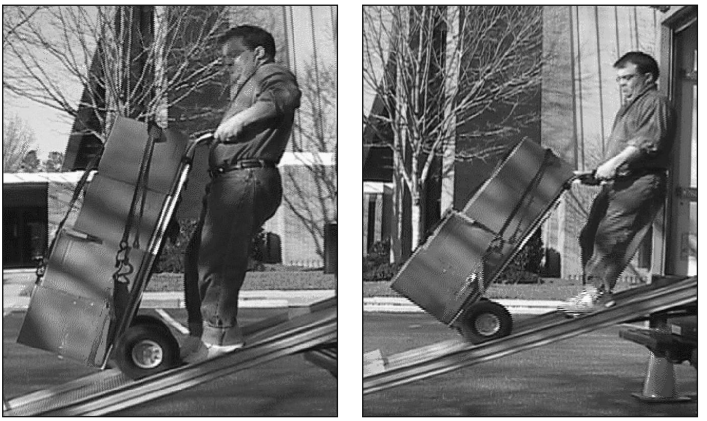

Figure 10
Comparison of plaintiff's claimed method of handling the cart (left) and surrogate's method that he found comfortable (right)

Another questionable action was that the plaintiff, Mr. Brown, maintained that he held the hand cart handles to his chest throughout and after the fall. Aside from the fact that his instinctive (unconscious) fall-protective reflexes would have caused him to let go of the cart in an effort to protect himself, this seemed unlikely from a biomechanics standpoint. We positioned the surrogate on the ramp with the loaded hand cart in the necessary position for the top hoop of the cart to contact his chest. The surrogate could not securely grip the cart handles due to extreme hyperflexion of the wrists and the associated pain and discomfort, and in fact it was necessary for the consultants to support the weight of the cart. See Figure 11.

Figure 11
Surrogate in position claimed by plaintiff

The conclusions from the surrogate evaluation were that the plaintiff, Mr. Brown, likely did not operate the hand cart on the ramp in the manner described, and that he could not have been struck in the chest by the top hoop (or any other part) of the hand

cart if he had indeed slipped and fallen as described. The plaintiff's claimed operating method was the most favorable for bringing the top hoop of the cart close to the chest, but it was not favorable for actually rolling the loaded cart down the ramp. The plaintiff's licensed mechanical engineer expert had opined that as Mr. Brown slipped, he pulled the cart to his chest in an effort to hold onto "something". We pointed out that a person slipping and falling does not have a base of support from which to pull 140 pounds of cart and chemicals to their chest, notwithstanding the fact that the tilted hand cart would immediately crash down to the ramp once Mr. Brown had lost his footing. The case against our client was dismissed and Mr. Brown was found guilty of insurance fraud.

Case 3: Tractor/mower operator fatality

A farm worker (Mr. Smith) was mowing a friend's orange grove using his friend's small farm tractor and 6-foot diameter mower. The man was last seen at 10am and didn't show up for lunch. He was found dead in the grove with catastrophic injuries, having been crushed by the tractor's rear wheel and then run over by the mower. The tractor/mower was found some distance away in the grove, where it struck an orange tree. It was found with the engine running and the mower blades and tractor wheels turning. See Figures 12 and 13.

Figure 12
Subject tractor and 6 foot diameter mower

Figure 13
Scene photograph taken by police

The tractor was a 1976 Romanian import that was built just before roll-over protection systems (ROPS) and seatbelts became required equipment.[3] The plaintiff was Mr. Smith's wife. She claimed that her husband had fallen off the tractor and died because of the lack of a seatbelt. Our client was the attorney for the tractor owner's insurance company, and we were hired to find reasonable causation scenarios and determine whether the absence of a seatbelt contributed to the accident.

The local police did a detailed inspection of the scene. They reported that the mowed area along the tractor's travel trajectory was largely level, with no ruts, boulders, or other obstacles. The mowed trajectory of the tractor/mower itself was largely straight along the entire incident location. The tractor was not found to have any significant mechanical problems.

Mr. Smith's body was too badly damaged to determine his body position, orientation and configuration at the time he went under the tractor wheel. His pelvis, ribcage and skull had all been crushed, and he suffered a near decapitation and gaping lacerations of the abdomen. The focus of the plaintiff and police investigations had been on how Mr. Smith might have fallen from the drivers seat. There was no evidence of any swerving or other significant travel direction change before, along, or after the decedent's final resting location. The condition of his body was such that a heart attack or similar event could not be ruled in or out during the autopsy. We decided to investigate whether or not he did indeed fall off the tractor at all.

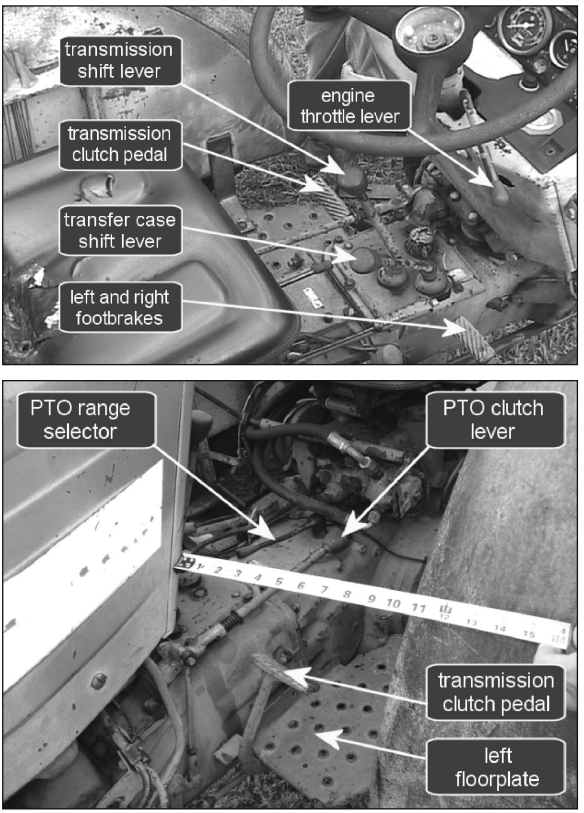

Figure 14
Tractor components and controls

This tractor could only be mounted or dismounted from the left side, due to the presence of a right-side bracket. When seated, the tractor operator sits astride the transmission with a variety of control levers surrounding him. This tractor had also been fitted with rear fenders; there was a narrow 11 inch gap between the left fender and both the steering wheel and dashboard edge. See Figure 14.

We wanted to determine what it would take biomechanically to mount and dismount the tractor, to operate the tractor, and to fall from the driver's seat. The plaintiff's experts did

their evaluation of the tractor with a tape measure. However, we believed that a human surrogate was necessary in order to fully evaluate the operator/machine interaction. The decedent, Mr. Smith, was 5 feet tall and weighed 185 pounds; again we had some difficulty finding someone of the same size. We hired an actor who was 5 feet 2 inches tall and weighed 160 pounds.

The surrogate was directed to mount and dismount the tractor in any manner he found appropriate. It became apparent that a complex series of movements was required, due to the positions of the fender, fender support, steering wheel, shift levers, pedals, and transmission housing. It was necessary to brace against the smooth fender edge with the right hand when mounting and dismounting. Once seated, the narrow 11 inch gap between the steering wheel and fender hampered the ability of the surrogate to "fall" from the seat. See Figures 15 and 16.

Figure 15
Surrogate bracing against the fender during mounting

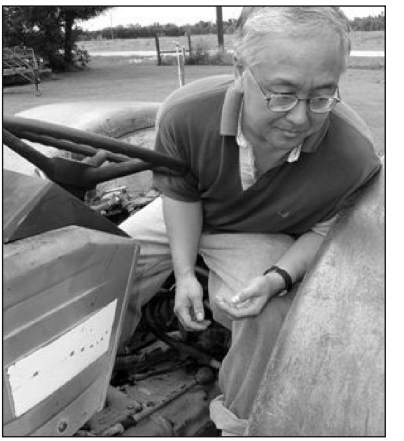

Figure 16
Surrogate demonstrating narrow gap between steering wheel and fender

The positions of the various controls relative to the surrogate were evaluated to see if one of the controls could have been inadvertently bumped in a way that could have caused ejection from the seat. The throttle lever was "guarded" by the steering wheel and was too high for inadvertent knee contact, and bumping the transmission shift lever or transfer case shift lever with the legs would knock the transmission into neutral. See Figures 17 and 18.

One key finding (though not unexpected) was that the transmission could be forced into first gear while the engine was running, without using the clutch, and that this could be done with the power-take-off or PTO (that drives the mower) engaged. This opened up the possibility that Mr. Smith may have knocked the


Figures 17 & 18
Control positions relative to surrogate

tractor into gear from neutral, but that was not likely to happen while he was seated based on our surrogate evaluation. The force vector necessary to move the shift lever from neutral into first gear points towards the operator's mounting position. With this finding, and considering that mounting the tractor requires a complex sequence of body pull-up actions, that include bracing against the smooth fender with the right hand, we hypothesized a reasonable causation scenario. If Mr. Smith was mounting or dismounting the tractor, at a time while it was running in neutral with the mower blades turning, and he slipped or stumbled during that mounting or dismounting, he may have grabbed at the tractor to steady himself. In doing so, he may have grabbed at the nearby shift lever, which would have provided the right force vector to force it into first gear and run him over. See Figure 19.

Figure 19
Surrogate (standing on ground) can pull tractor into first gear

This incident scenario was the most reasonable that we could find and justify using engineering, biomechanics, and human factors principals. We could find nothing to disprove it; the fact that his drinking water jug was strapped to

the front radiator grill provided one potential reason for him to dismount the tractor. We had earlier calculated that he had started that particular mowed trajectory about 23 seconds (at 5.6 mph) before the accident – we concluded that it was not likely enough time for him to have fallen asleep. At about the same time, incidental further study of one of the scene photos led to a poster-sized color photo enlargement and an observation that soundly buttressed the incident scenario of falling during mounting/dismounting. See Figure 20.

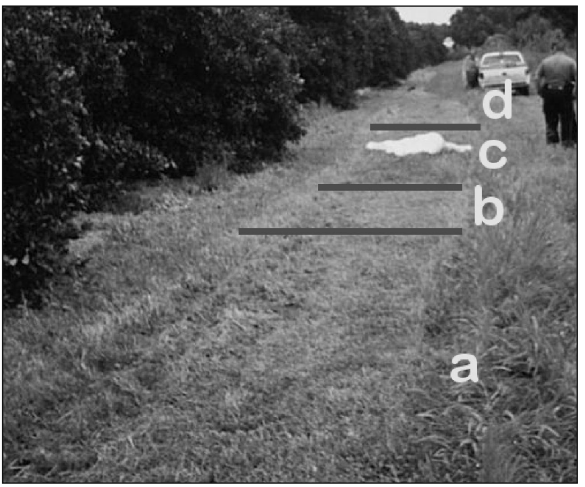

Figure 20

We observed that there were clearly four separate areas of mowed grass along the trajectory. As seen in Figure 20, in Zone A, the mowing had been occurring at about 3.2 blade cuts per foot of trajectory, leaving many blades uncut. As the rear wheel and mower went over the decedent, the mower rose up and left long grass in Zone C. In Zone D, the shading of the grass appears to show it is mowed "more" than Zone A. And in Zone B, the shading also shows it is mowed more than Zone A. The color photo enlargement shows clearly that the tractor/mower appeared to be stopped with the mower blades turning when the mower deck was over Zone B, completely cutting the grass in that area. This photographic evidence is consistent with Mr. Smith having been mowing at the normal 5.6 mph speed in Zone A, stopping (possibly to get a drink of water) in neutral with the mower cutting over Zone B, accidentally pulling the tractor into first gear (during mounting or dismounting) and getting run over in Zone C, and then the tractor/mower running slowly at 1.5 mph (in first gear) off into the trees in Zone D. This photographic evidence is <u>not</u> consistent with the plaintiff's theory of Mr. Smith having suddenly fallen from the mower's driver's seat (due to an unknown ejection force or collapse) while mowing normally at 5.6 mph.

The plaintiff's expert attempted to show that Mr. Smith had fallen asleep or otherwise collapsed while driving, and two weeks before trial they introduced an attractive (and expensive) animation showing just that. During our jury trial testimony, however, we were able to show how their fall animation had the steering

wheel-fender proportions (and other things) out of scale, and since the plaintiff hadn't revealed either the animation creator or the software used, the plaintiff could not refute our testimony. Additionally, it was clearly shown that the animated operator's arm actually passed through the fender, and that the animated operator's lower extremities all managed to pass through the shifters, transmission housing, and fender support unimpeded.

The jury reached a defense verdict in just over one hour.

Conclusions

These cases have involved certain "necessary" motions by the injured parties, and those motions were not reasonably supported by observations, evidence, published research, or common sense. Using the surrogates for "human tape measures" and "biomechanical tools" was invaluable to the analysis of these incidents. However, surrogate evaluations are not re-enactments or standalone analyses; they must be part of a broader overall investigation. Some issues to consider when using human surrogates include the following:

- Finding appropriate surrogates (and exemplars) can be challenging
- Use professional-quality photography and videography or it will detract from the presentation to the judge and jury
- Allow plenty of time to put together all the required elements
- Avoid posing or directing the surrogates on their body movements
- Make sure that any subtle yet important details are clearly highlighted in photos or video

Lastly, in the cases we have seen, the surrogate evaluations were both more effective and more economical than CAD or animation-based evaluations. Properly done, surrogate evaluations can provide robust and believable information to assist the triers of fact.

Special thanks to Michael Romansky, PhD, JD (NAFE 239C), who was the biomechanical engineer, injury causation expert, and partnering associate on these cases. Thanks also to reviewers Jeffrey Pike, ME, FSAE, and Philip Stover, PhD.

Appendix

1. National Highway Traffic Safety Administration. *Effectiveness of Lap/Shoulder Belts in the Back Outboard Seating Positions*. Springfield, VA: National Technical Information Service, June 1999. (DOT HS 808945).

2. Tilley, Alvin. *The Measure of Man and Woman*. Henry Dreyfuss and Associates, accessed through "AnthroCalc" Software. Copyright David Dresser / Lawyers & Judges Publishing Company, 2001.

3. Occupational Safety and Health Administration. *29CFR1928.51: Roll-over protective structures (ROPS) for tractors used in agricultural operations.* Washington: Government Printing Office, December 2005. (70 FR 77003).