Forensic Engineering

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2 authors:

Steven Batterman
University of Pennsylvania

Scott D. Batterman

Chapter 65
Forensic Engineering

Steven C. Batterman, PhD, and
Scott D. Batterman, PhD

Accident Reconstruction
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Forensic engineering, defined as the application of engineering principles and methodologies toward the purposes of the law, is a rapidly developing forensics specialty. The field of forensic engineering is extraordinarily broad, since by definition it encompasses all of the engineering disciplines applied in a legal context. Recognizing that it is not possible to cover such a broad field in a short chapter, the purpose of this brief review is to present some relevant forensic engineering applications in some areas of interest to the authors. To name a few, engineering disciplines such as electrical, chemical, civil, metallurgical, and environmental cannot be covered herein. Another purpose of this chapter is to encourage forensic scientists to seek the advice and consultation of forensic engineers in accident cases, or criminal matters, that have resulted in death or serious injury. This focus may come as a surprise to forensic scientists who are unaware that engineering methodology has indeed been successfully applied to understanding the response of human tissues to traumatic loading such as that resulting from impacts, falls, stabbings, bullet wounds, and explosions.

At present, the majority of forensic engineering investigations—but not all—are carried out in a civil litigation context rather than a criminal one. However, consider the example of a plane crash. The cause of the crash can be due to defective design, structural failure, or pilot error, which lie in the realm of civil litigation considerations, but could also be due to terrorist activity, such as a bomb or a hijacking, which are criminal considerations. Initially the cause of a plane crash is often unknown, and only by detailed investigation and engineering analysis can it be determined, if at all. For example, the explosion of Pan Am 103 over Lockerbie, Scotland, on December 21, 1988, was determined by engineers to be due to a small terrorist bomb that was strategically placed in a baggage container adjacent to the fuselage skin just forward of the left wing and was definitely not due to a design defect, malfunction, structural failure, or pilot error. The recovery and analysis of the debris in the Pan Am 103 disaster, the partial reconstruction of the aircraft, the analysis of the breakup of the aircraft, and the analysis of the biomechanics of the injuries sustained by the passengers stands as a premier model in forensic engineering for analyzing other disasters. In fact, similar techniques were indeed employed 8 years later in order to obtain an understanding of the TWA 800 disaster. When TWA 800 exploded over Long Island on July 17, 1996, the cause was initially thought by some to be due to an onboard bomb or a shoulder-fired missile from a boat on Long Island Sound. Only after a very meticulous reconstruction of a portion of the aircraft, whose fragments were recovered from underwater, along with sophisticated laboratory and engineering analyses, was it determined that the cause was likely due to a center fuel tank defect. Unfortunately, as this chapter was being written, the space shuttle *Columbia* disintegrated in flight over Texas on February 1, 2003, during reentry. Similar techniques will likely be employed on the recovered fragments of the shuttle along with trajectory analyses, laboratory analyses, thermal stress analyses, and the analysis of the data from *Columbia* in order to obtain an understanding of the cause(s) for the disintegration. Although at this writing the cause of the disaster has not been definitely determined, preliminary engineering analyses have ruled out terrorism or criminal activity as likely causes.

Engineering, including forensic engineering, often depends heavily on the use of mathematical analyses. However, this chapter will not focus on the use of mathematics and the presentation will be largely qualitative in nature. A short bibliography is provided for readers who are interested in mathematical detail as well as more in-depth information on forensic engineering.

ACCIDENT RECONSTRUCTION

The field of accident reconstruction is one of the more visible forensic engineering specialties. It is typically thought of as only applying to vehicular accident reconstruction, but it does encompass all types of accidents including vehicular, electrical, industrial, chemical, structural collapses, etc. However, for definiteness and the purposes of this chapter, further attention herein will be focused on vehicular accidents.

Vehicular accident reconstruction may be defined as the scientific process of analyzing an accident using the physical facts and data left at the accident scene in conjunction with the appropriate natural laws of physics, i.e., the laws of classical mechanics stated by Sir Isaac Newton in 1687. The obvious is worth stating: Newton was not thinking about vehicular accident reconstruction since cars and other modern vehicles were not going to be invented for more than 200 years. Although the laws of classical mechanics apply to the motion of all bodies in the universe, Newton was interested in planetary motion, concepts of gravity, and the development of the associated mathematical descriptions. With regard to accident reconstruction, the significance of this is that only qualified engineers and physical scientists should be retained to do accident reconstructions, since they are generally thoroughly educated in understanding and properly applying the laws of physics. Caution is in order, since the advent of user-friendly computer programs and the codification of the laws of physics into "cookbook" type manuals have seen the entry of many less qualified people into the accident reconstruction field, which often does not serve the interests of truth and justice.

General statements of Newton's laws, which are formulated for a particle, are stated below, with more detailed information given in some of the references (Greenwood, Beer & Johnston, Yeh & Abrams):

- *First law*. Every material body continues in its state of rest, or of constant velocity motion in a straight line, unless acted upon by external forces that cause it to change its state of rest or motion.
- *Second law*. The time rate of change of linear momentum (product of mass times velocity) of a particle is proportional to the external force acting on the particle and occurs in the direction of the force. An alternative form of this law, which is the more commonly stated form, is that the resultant force acting on a particle is equal to the mass times the acceleration.
- *Third law*. To every action there is an equal and opposite reaction. Or equivalently, the mutual forces of two bodies acting upon each other are equal in magnitude and opposite in direction.

Although Newton's laws appear to be simple statements, it must be emphasized that there are significant concepts and sophisticated philosophy embedded in the laws, which must be mentioned and which are essential to an understanding and proper application of Newton's laws. First, the laws are vector statements, which means that the magnitude and direction of forces, velocities, and accelerations must be considered and not merely their magnitudes. Second, "motion" and "rest" are relative terms that establish a frame of reference to which the motion of bodies is referred. For vehicular accident reconstruction calculations, the Earth is a suitable fixed reference. However, for space flights, rocket launchings, and general astronomical applications, the Earth would not be a suitable fixed reference and it would be more accurate to use a distant star. Third, Newton's laws mention forces without ever defining them. Force is a very abstract concept and nobody has ever seen a force, which is the action of one body on another. In automobile accidents, apart from forces due to gravity, forces on occupants only arise when an occupant is decelerated (accelerated) such as by contacting another surface or is restrained by a seat belt, air bag, another person, etc. Fourth, Newton's laws are stated only for a particle, which by definition is a mathematical point of constant mass. It requires a rigorous derivation to extend Newton's laws to deformable bodies of finite size such as a crashing automobile. Unfortunately, this is often not appreciated by unqualified accident reconstructionists, who may tend to erroneously oversimplify an analysis. Fifth, the concept of systems of units is defined by Newton's second law. In the SI system, mass is given in kilograms (kg), acceleration in meters per second squared (m/s^2), and force is the defined unit in Newtons (N), where one Newton equals one kg-m/s^2. In the US–British system of units, force is given in pounds (lb), acceleration in feet per second squared (ft/s^2), and mass is the defined unit in slugs, where one slug is equal to one lb-s^2 per ft.

The general philosophy employed in accident reconstruction is to work backward from the final positions of the vehicle(s), to the point(s) of impact or beginning of the occurrence, and if sufficient information exists, prior to the impact(s) or occurrence. Calculations, either by hand or by computer, are performed using the available data in conjunction with Newton's laws. Often Newton's laws are cast in other forms for convenience, such as the work–energy principle or impulse–momentum principle (see references previously cited). In collision problems at the moment of impact, the impulse–momentum principle is particularly useful since the resultant external force acting on the system of colliding bodies is zero. This then leads to the principle of conservation of linear momentum (product of mass times velocity), which states that the linear momentum of a system of colliding bodies is conserved at impact. This principle, combined with the information left at the accident scene and the vehicle data, is often sufficient to solve for the velocities of the vehicles at impact. Examples of the application of the principle of conservation of linear momentum, along with the associated vector concepts and mathematics, are given in Batterman & Batterman (2000), Beer & Johnston, and the SAE Accident Reconstruction Technology Collection. It should also be mentioned that numerous commercially available computer programs exist for accident reconstruction calculations and these programs will not be discussed herein. The programs are based on Newton's laws, as they must be, and many of them contain algorithms specialized for accident reconstruction, e.g., crush damage considerations. As indicated earlier, some of the programs are so user-friendly that it is possible for unqualified people, who do not have an adequate educational background and who do not understand their own limitations as well as those of the programs, to obtain solutions that may not be valid for a particular accident.

Another aspect of accident reconstruction, and undoubtedly the most difficult, is to determine how an occupant moves with respect to the crashing vehicle, i.e., the occupant kinematics. The determination of an occupant's kinematics is often critically related to the injuries that may have been sustained by the occupant. In order to determine the complete occupant kinematics, an enormous amount of physical information is required in addition to the complexities of solving a very difficult problem in dynamics. This physical information includes knowing the properties of the vehicle interior structures that may be contacted by the occupants, the actual contact points in the interior of the vehicle and on the occupant's body, since this will then change the direction of motion of the occupant, the dynamic response of the human body to impact, and the details of how the vehicle is moving as a function of time. It is not surprising that in order to completely solve an occupant kinematics problem throughout the entire crash duration, an enormous amount of information is required as well as assumptions that may influence or bias the outcome.

Sometimes only the initial occupant kinematics may be significant in an injury analysis, and this can often be determined without a complete occupant kinematics analysis. In general, an occupant initially tends to move toward the impact, which is opposite the change in velocity of the vehicle, referred to as delta-v, or opposite the resultant vehicle acceleration (see Batterman & Batterman, 2000). For example, in a frontal crash the occupants will tend to move forward with respect to the vehicle. If the occupants are unrestrained, front-seat occupants can impact the steering wheel, dashboard, or windshield while rear-seat occupants can impact the backs of the front seats. In a rear-end crash, occupants will tend to first move backward into their seats followed by a forward rebound phase. If unrestrained, occupants can then rebound forward into the vehicle structure in front of them while restrained occupants will not exhibit such large excursions. Another important aspect of rear-end collisions is that seat backs can fail, causing occupants to tumble into the rear of a vehicle and thus sustain serious injuries. In a lateral crash, nearside occupants to the crash will move toward the impact and may physically contact the impacting vehicle or a roadside object, such as a pole or a tree. Lap-shoulder belts worn by nearside occupants may not be effective in preventing injuries in this type of crash, but lateral air bags would offer some protection. However, a restrained farside occupant to a lateral crash may derive benefit from wearing a lap-shoulder belt, which would then limit occupant excursions toward the impact.

BIOMECHANICS OF INJURIES

Biomechanics, which simply means the application of Newtonian mechanics to biology, is a subfield of bioengineering, which can be defined as the application of engineering principles and methodology to biological systems. Bioengineering is a huge and rapidly developing field in the United States and worldwide, with burgeoning numbers of degree programs on the bachelors, masters, and doctorate levels. The field of biomechanics is likewise vast, with applications beyond the vehicular considerations discussed in this chapter. For example, to name a few, biomechanicians are involved in the design of artificial organs, prostheses, bioinstrumentation, medical devices, safety devices such as protective sports equipment, automobile design and restraint system design to minimize injuries in a crash, as well as with understanding the response of tissues, cells, and biological systems to mechanical loading.

Biomechanics of injuries has already been briefly mentioned when initial occupant kinematics was discussed. A complete discussion of injury biomechanics is beyond the scope of this chapter and instead only a few key ideas and concepts will be mentioned. The interested reader is referred to the bibliography, in particular the Stapp Car Crash Conference Proceedings and extensive literature available from the Society of Automotive Engineers.

A concept that frequently appears in automotive injury biomechanics is that of delta-v, which is often correlated with injuries sustained in a crash. Delta-v is defined as the change in velocity (not speed) of a vehicle from its immediate preimpact velocity to its immediate postimpact velocity. Delta-v is a vector quantity, which has both magnitude and direction, and it is generally incorrect to merely subtract speeds in order to determine delta-v (see Batterman & Batterman, 2000). The major reason delta-v is correlated with injury potential is that delta-v is closely related to the vehicle accelerations in a crash and, by Newton's second law, it is accelerations that determine the resultant forces acting on a system. However, it is emphasized that an occupant's body or body segments, in general, will not experience the same delta-v as the vehicle. This is because vehicle and body segment rotations can, and do, greatly influence the velocities and velocity changes an occupant may undergo in a crash.

Correlations of injury with delta-v appear in the biomechanics literature (Mills & Hobbs) and are continuously being collected and updated. It should be noted at the outset that the correlations are statistical in nature, i.e., they give the probability of a certain type of injury occurring as a function of delta-v. Furthermore, to ensure uniformity and standardization of reporting, injuries are typically described utilizing the Abbreviated Injury Scale (AIS) promulgated by the Association for the Advancement of Automotive Medicine (AAAM). The AIS is based on anatomical injury immediately following the accident and does not score impairments or disabilities that may result from the injuries over time. A severity code is used in the AIS which ranges from 0 to 6, as shown in Table 65-1.

In the 1990 AIS, each injury is assigned a seven-digit code with six digits to the left of the decimal and one to the right. The digit to the right is one of the severity codes given above while the six digits to the left specify injury

AIS	Severity
0	None
1	Minor
2	Moderate
3	Serious
4	Severe
5	Critical
6	Maximum (currently untreatable, fatal)

Table 65-1 AIS severity code

locations to the body region, type of anatomic structure, specific anatomic structure, and level of injury within a specific region and anatomic structure. The interested reader is referred to the detailed instructions for coding injuries given in AIS 90. Furthermore, other injury classification systems exist and are discussed by Pike.

It is again worth emphasizing that injury correlations are statistical and are not absolute. For example, if there is a 60% probability of a certain type and injury severity occurring, this means that in the same crash there is a 40% probability of not sustaining that injury. In addition, a person can be critically injured or killed (AIS 5 or 6) in a moderate delta-v accident, say 15 to 20 m.p.h., but can walk away uninjured or with minor injuries (AIS 0 or 1) in a high delta-v accident, say 35 to 40 m.p.h. Hence, care and discretion must be used when the injury correlation data is to be used in an attempt to predict injuries in a given crash.

It is also worthwhile mentioning a few other key ideas in the field of injury biomechanics. The concept of threshold injury criteria refers to those combinations of kinematic variables, i.e., related to geometry and motion, and kinetic variables, i.e., related to forces that cause the motion, which can cause a traumatic injury to various body tissues. These variables include, but are not necessarily limited to, forces, moments, or torques (rotational effect of forces), accelerations, stresses, strains, and their associated time histories. Time duration of loading (impulses and vibrations) can be very significant; for example, forces and accelerations applied for a short time period may not cause injury while the same forces applied for a longer time period may be injury-producing. In determining threshold injury criteria, an implicit assumption is made that such criteria do indeed uniquely exist and apply across the spectrum of the human population. This should be interpreted with caution, since not only is there expected biological variability between individuals, but factors such as age, disease, preexisting conditions, and other variables can and do influence the response of whole tissues and single cells to mechanical loading.

The concept of threshold injury criteria has entered into the law. The National Traffic and Motor Vehicle Safety Act of 1966 introduced the concept of vehicle crashworthiness, i.e., the ability of a motor vehicle to protect its occupants in a crash. This act led to the creation of the Federal Motor Vehicle Safety Standards (FMVSS), which require a minimum level of crashworthiness for all cars sold in the United States. The FMVSS contain essentially three threshold injury criteria (see Pike), which manufacturers must comply with and which are worth summarizing herein.

The first, known as the Head Injury Criterion (HIC), requires that a certain mathematical expression, i.e., an integral of the resultant acceleration-time history measured at the center of gravity of the head of a restrained ATD (anthropomorphic test device) in a crash test, cannot exceed a value of 1000 or else the vehicle fails the test. There are many deficiencies in the HIC, which include the fact that it does not distinguish between types of head injuries such as skull fractures, subdural hematoma, diffuse axonal injury, and so on (see Newman). In addition, the use of a surrogate such as an ATD may not accurately reflect conditions necessary to cause human injury. However, the HIC may be useful as a screening device, in that a vehicle that results in a lower HIC may be better for head injury occupant protection than a vehicle that results in a higher HIC. The caveat here is that it is indeed possible to walk away from an accident with an HIC greater than 1000, without head injury, while a person can be killed by a head injury in a vehicle where the HIC was significantly less than 1000.

The second criterion refers to a force measurement made in the femur of the restrained ATD. The vehicle fails the test if the force in the femur exceeds 10.0 kN (2250 lb). Again, the deficiency in this criterion is that femoral fracture loads are very variable and compressive fracture loads in human femora can be less than 2250 lb for a significant portion of the population.

The third threshold injury criterion refers to the resultant acceleration measured at the center of gravity of the thorax of the ATD. A vehicle passes this test if the acceleration does not exceed 60 *g*'s (sixty times the acceleration due to gravity) for intervals whose cumulative duration is not more than 3 milliseconds (0.003 seconds). This criterion is an example of where the time duration of loading is significant. Again, a major shortcoming is that it does not account for normal population variability and does not distinguish between types of thoracic trauma such as rib fracture, transected aorta, etc.

This section will be closed by noting that other injury criteria have been proposed and still others are undergoing intense research investigation. Biomechanics injury research, with its spinoffs to forensic engineering applications, requires the collaboration of engineers, medical researchers, and forensic scientists working toward the goal of understanding whole body and tissue responses to traumatic loading conditions.

PRODUCTS LIABILITY

Products liability is a burgeoning area of forensic engineering investigation. Products liability investigations revolve around the issue of whether a product is defective and if the defect is causally related to any injuries that may have occurred to the user(s) or people in the vicinity of the product. Essentially, the following three types of product defects are recognized in the law, but this may vary according to the jurisdiction of the lawsuit: (1) design defects, i.e., the product lacks those elements that are necessary for its safe and foreseeable uses; (2) manufacturing defects, i.e., the product was not manufactured according to the manufacturer's own specifications or standards; and (3) failure to properly warn or instruct the user in the proper and safe use of the product.

If a forensic engineer is retained on behalf of the person bringing the lawsuit (the plaintiff), the engineer will objectively analyze the product for defects, and if they are found, will determine if the defects are causally related to the plaintiff's injuries. The role of the forensic engineer retained by the defendant, which can often be the engineer(s) who designed the product, will be to objectively defend the product in view of the allegations made by the plaintiff. As part of the defense of the product, the defense forensic engineer(s) may argue that the defect does not exist, and/or the plaintiff grossly misused the product, and/or that the plaintiff's injuries are unrelated to the alleged defect. Products liability investigations can be very long and time-consuming and often require the expenditure of large sums of money for experts on behalf of both plaintiffs and defendants. They can also be very technically challenging, requiring a great deal of calculations, computer modeling, and laboratory testing.

In order to fix ideas, the following examples are presented to illustrate the three types of defects mentioned above. These examples are obviously not intended to be exhaustive and are illustrative only.

Design Defects

Consider the phenomenon of vehicle rollover, which may occur during intended and foreseeable use of certain types of vehicles. For example, such vehicles can be all-terrain vehicles (ATVs), designed for off-road use, or sport utility vehicles (SUVs) designed for highway use as well as off-road use. Engineering analyses show that the rollover propensity of these vehicles is in large measure due to the high height of the center of gravity of the vehicle in relation to the track width, which are vehicle parameters under the control of the designer. A plaintiff may be driving an SUV on the highway and suddenly be forced into making a sharp turn or evasive maneuver to avoid an accident, which then leads to the vehicle rolling over, resulting in serious injuries or death to the SUV occupants. The rollover propensity may then form the basis for a design defect lawsuit, and many of these types of cases have indeed been litigated. It is also worth emphasizing that a design defect is an absolute concept, not a statistical one, and it is irrelevant that the same vehicle can be used successfully many, if not millions of, times without rolling over. Note that when TWA 800 exploded, 747s had logged billions of passenger miles prior to the center fuel tank defect manifesting itself. When all physical conditions are satisfied, design defects can spell disaster for SUV occupants when the vehicle suddenly rolls over with little or no warning to the driver.

Manufacturing Defects

Simply because a person is injured using a product does not mean that a product defect of any kind exists. Sharp-edged instruments such as knives provide a good example since knives are designed to cut, and the fact that a person may be cut using a knife does not mean that the knife is defective. However, consider the situation where a person is using a knife to carve a turkey and during carving the blade fractures. This causes the person to lose balance, fall forward, and be stabbed by the fractured blade or, perhaps, another person in the vicinity was injured by a piece of the blade. Metallurgical analysis of the blade after the accident revealed that it was weakened by containing inclusions and by improper heat treatment during manufacture. This means that the blade was not manufactured according to the manufacturer's own specifications and was thus defectively manufactured. Manufacturing defect lawsuits are much easier to pursue than design defect lawsuits since the entire product line, which may involve millions of products, is not at issue, but only the single defectively manufactured piece. However, considering the SUV design defect example above, jurors may have a difficult time understanding the physics and mathematics of rollover propensity, or even believing that the design defect exists, especially if they themselves drive SUVs.

Failure to Warn

Proper warnings and instructions can be critical to the safe use of a product. For example, properly designed car air bags can be wonderful life-saving devices in a crash. However, a person sitting too close to an air bag can be seriously injured or killed by the air bag front, which can move at speeds up to 320 km/h (200 m.p.h.), i.e., the person may have survived the delta-v of the crash but it was the deploying air bag that caused the serious injury or death. Small adults and children sitting in the front seat of an automobile are particularly vulnerable to impacts by the moving air bag front. If an automobile did not carry prominent warnings about sitting too close to a deploying air bag—and many cars did not when air bags were first introduced—the vehicle would be defective by virtue of a failure to warn. Furthermore, warnings should never be used by a manufacturer to disclaim liability, and in many cases a warning may be interpreted as an admission of a defect that was not designed out of the system. Hence, it is relatively common for allegations of defective design to be coupled with a failure to warn in a lawsuit complaint. For example, in air bag technology, air bags can be designed to be depowered such that the deploying front does not move as fast but still offers occupant protection without as high a risk of injury.

General Product Design Considerations

The goal of design engineering is to design safe products and systems that are free of hazards caused by defects. Engineers must be able to identify hazards in advance, or prospectively, and then design out the hazards, if it is practical and feasible to do so, before the product or system leaves their control. Once an accident due to a design defect occurs, the injured person has essentially identified the design defect and it is too late for a prospective hazard identification analysis. Several hazard identification analysis procedures, and variations of procedures, exist, which should be part of the normal design process and which are routinely employed by engineers in the design stages of a product or system to eliminate defects and improve system reliability. Three of the commonly used identification procedures are:

- *Failure modes and effects analysis (FMEA).*

The FMEA is a bottom-to-top basic procedure where the system is examined component by component and a failure or malfunction of any component is traced throughout the entire system. Flow sheets and computer programs are available to assist the engineering design team in this procedure, which screens the entire system. If the component failure results in a hazard that can cause injury, it is identified and necessary design changes should be made to remove the hazard and/or protect the user.

- *Fault-tree analysis (FTA).*

The FTA is a top-to-bottom procedure where the undesirable outcome (top event or fault condition) is the starting point. This top event is then traced down through the system and the failures of individual components or events that can lead to the undesirable outcome are identified. Design changes are then made as required to eliminate or minimize the probability of the occurrence of the fault condition. The FTA is a complicated procedure, which is used to analyze complex systems, e.g., a space shuttle; it relies heavily on Boolean algebra techniques and symbols and is most often done on a digital computer.

- *Product safety audit (PSA).*

The PSA is basically a checklist containing hundreds, if not thousands, of questions concerning the design of the product. The questions are framed in a manner such that a negative answer triggers further investigation, which may lead to a design change. The major drawback, as with any checklist procedure, is that if the list of questions is incomplete, a defect can be easily overlooked.

Once the hazards in a product or system are identified by a proper hazard identification analysis, the engineer follows a codified procedure known as the "safety hierarchy" in order to prevent or minimize the probability of personal injury. This hierarchy is not a law of nature or a scientific law but rather a logical procedure that has been adopted by consensus and has the priorities shown in Table 65-2, in the order in which they should be used.

Typically, in products liability investigations applicable to consumer products, only the first three priorities are normally considered part of the safety hierarchy. Furthermore, the line between the first and second priorities can sometimes become blurred, depending on the product and its environment of use. This is because providing a proper guard can be thought of as an integral part of the overall design process, which includes considerations of man–machine interface safety in the concept stage and all design stages of product development. However, if the product is, say, a hand-held circular saw, the rotating blade is essential to the cutting function and obviously cannot be eliminated. Hence, the second priority would call for a blade guard to protect against inadvertent contact with the blade. Whenever a design change is contemplated, it is essential that the engineer examine the alternative design(s) for new hazards which may be introduced by the change(s). The alternative design(s) may not be as safe as the original design and the engineer must decide on which features to include in the final design.

Regarding warnings, it is important to emphasize that properly designed warnings, which can be words and/or pictographs, have to communicate three things to the user, i.e., what the hazard is, the steps the user can take to avoid the hazard, and what the likely consequences can be if the warnings are disregarded. Pictographs may be preferable to words since they can be more dramatic, in addition to eliminating a possible language barrier in locales where more than one language is commonly spoken. It should also be emphasized that too many warnings on a product may destroy their effectiveness. Furthermore, and very important, warnings should never be used by a manufacturer to disclaim liability and are never ever a substitute for a safe design that is practical and feasible to achieve.

First priority	Design out the hazard if it is practical and fea sible to do so.
Second priority	If the hazard cannot be designed out, guard against the hazard.
Third priority	Provide proper warnings concerning the haz ards and instructions for use of the product.
Fourth priority	If applicable, provide training in the safe use of the product or system.
Fifth priority	If applicable, prescribe personal protective equipment.

Table 65-2 Safety hierarchy

CONCLUSION

The purpose of this short chapter has been to expose the reader to the exciting and rapidly developing field of forensic engineering. In addition, forensic scientists are encouraged to utilize the services of forensic engineers in injury and death investigation cases. The topics discussed in the chapter are necessarily limited in scope and the interested reader is referred to the bibliography for references to further applications and in-depth treatments. The bibliography is provided for representative coverage of the field without endorsement of any publication. An attempt has been made to generally group the bibliography by subject matter, as discussed in the chapter, although there is considerable overlap.

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