ISSN 1041-9489

SAFETY BRIEF

May 1995

Triodyne Inc.

Volume 11, No. 2

Consulting Engineers & Scientists – Safety Philosophy & Technology
5950 West Touhy Avenue Niles, IL 60714-4610 (847) 677-4730
FAX: (847) 647-2047
e-mail: infoserv@triodyne.com

Safeguard Evaluation Protocol–

A Decision Tree for Standardizing, Optionalizing, Prohibiting, Ignoring, Enhancing, or Characterizing Safeguards

by Ralph L. Barnett* and Steven R. Schmid**

Abstract

A decision protocol is developed for assessing whether a candidate safeguard should be offered as standard or optional equipment or whether it should be enhanced, prohibited, ignored, or just characterized. Satisfaction of the protocol is a sufficient condition for satisfying the code of ethics for engineers, extant codes and standards, the Intrinsic Classification of Safeguards, and the Dangerous Safeguard Consensus. Decisions that do not satisfy the protocol violate one or more of these safety philosophies. This decision making process intellectually disposes of the judicial position that a manufacturer has a nondelegable duty to include safety devices with his machines. It further challenges the advocacy pronouncement that "safety should not be optional."

I. INTRODUCTION

Presently, no methodology exists for rationally dealing with the conditions and circumstances under which candidate safeguards can be accepted or rejected. Decisions are generally grounded intuitively with guidance from codes, standards, and industry practice. By and large, sensible judgements flow from this approach; however, it is not error free and it does display randomness and inconsistency. Moreover, it fares rather poorly when the decision making procedures are challenged in courts or other tribunals.

In our development of a protocol we have adopted a principle enunciated by Albert Einstein, "Everything should be made as simple as possible, but not simpler." To this end, a small number of concepts are described which represent required relationships among safety entities (necessary conditions). These are assembled into a decision tree that will simultaneously satisfy the engineering code of ethics, value systems such as codes and standards, the Intrinsic Classification System, and the consensus position on safeguards that introduce new dangers.

* Professor, Mechanical and Aerospace Engineering, Illinois Institute of Technology, Chicago, and Chairman of the Board, Triodyne Inc., Niles, IL.

** Assistant Professor, Aerospace and Mechanical Engineering, University of Notre Dame, Notre Dame, IN, and Senior Engineering Consultant, Triodyne Inc., Niles, IL.

No Charge

We thought it might be instructive to present the decision tree and run through a couple of examples before explaining its development. In Fig. 1, each element of the safeguard adoption decision tree has been numbered in its upper corner for tutorial purposes.

Example 1. Rear Seat Air Bag - Year 1994

For this first example, enter Fig. 1 at [1] and move down to value systems. Rear seat air bags are not presently used. Furthermore, there are no codes, standards, statutes, or regulations that require, recommend, or prohibit the use of air bags in the rear seat of an automobile; therefore, move to [4]. Assume for the purpose of this example that the candidate air bag has no downside; it either *helps or does nothing* from a safety point of view. Move to [9] and then to [12] since the automobile is a uni-functional machine. Because the air bag has no effect on the function of an automobile, we move to [16]. Air bags are quite expensive and will adversely effect cost, [19]. Proceeding to [24] which is the branch of *Unreasonable Economic Impact* associated with [9], we find three courses of action; the air bag for the rear seat may be offered as optional equipment [27], may not be offered [28], or advice on the characteristics and outsource availability may be given to vehicle users [29].

Example 2. Machine Mounted Two Hand Hostage Controls - General Purpose Press Brake

Referring to Example 2 in Fig. 1, move from [1] to [2] since this safety feature is approved by the American National Standards Institute, Safety of Press Brakes, ANSI B11.3-1982. Although the standard approves of two-hand hostage controls, it neither requires or recommends them; hence move to box [8]. A general purpose press brake is multi-functional and not dedicated. Furthermore, its use is not known to the machinery manufacturer; therefore, move to [14]. Two-hand controls have many limitations, e.g., operators cannot reach them when bending large sheets or when the trailing edges must be supported throughout the forming operation. Furthermore, a bent workpiece may invade the space where the two-hand controls are located. For these reasons we proceed to [18]. From [18] we may select [22] and offer the two-hand controls as an optional accessory or we may proceed to [21] and inquire into its market status. Two-hand hostage controls are widely available [26]. This fact is known to the community of press brake users who are all familiar with the characteristics of these devices [30]. Consequently, we may choose to drop any further consideration of these controls [32], or we may advise customers of their functional and safety properties, their cost and their availability from outside sources [33].

II. CONCEPTS AND DEFINITIONS

A. Suppliers

The term supplier will be used in this paper to represent manufacturers, fabricators, builders, distributors, retailers, and others in the chain of commerce who supply hardware in the form of systems, machines, or machine components. A procedure is developed to enable suppliers to proactively evaluate candidate safety features. The evaluation of safety systems normally falls within the purview of manufacturers and not distributors. There are, nevertheless, two reasons for including distribution entities in our scope.

First, they may be compelled by law to assume the responsibilities and liabilities of a manufacturer. This frequently happens when manufacturers are absent because they have gone out of business, are insolvent, or are shielded by international law.

Second, suppliers often have input information related to the exact use of machines by their customers. This knowledge may impose duties upon them.

The methodology developed in this paper is not applicable to regulatory agencies, code or standard writing bodies, individual equipment users, or their employers.

B. Safeguards/Safety Features

These terms will be taken to represent safety notions in the broadest sense. In addition to safety devices and contrivances, candidate safeguards may include safety concepts such as proof testing, preventive maintenance, and safety factors; they may be workplace procedures or training programs or they may be safety communication systems such as safety colors, warning signs, and safety manuals.

C. Dangerous Safeguard Consensus

Perhaps the most unequivocal and widespread position taken in the safety literature is the admonition against the use of safeguards which introduce hazards of their own. Typical excerpts from this literature, which date from 1916, provide some insight into this philosophy.[1] For example:

1994: "General Requirements for All Machines," 19 CFR 1910.212 (a) (2). Washington, DC, OSHA, effective August 27, 1971.

> "General requirements for machine guards: Guards shall be affixed to the machine where possible and secured elsewhere if for any reason attachment to the machine is not possible. The guard shall be such that it does not offer an accident hazard in itself."

1982: *American National Standard for Machine Tools - Power Press Brakes - Safety Requirements for Construction, Care and Use*, ANSI B11.3-1982.

> "6.1.4.1 Point of Operation Guards. Every point-of-operation guard shall meet the following design, construction, application, and adjustment requirements:
>
> (1) It shall prevent entry of hands or fingers into the point of operation by their reaching through, over, under, or around the guard.
>
> (2) It shall, of itself, create no pinch point between itself and moving machine parts."

1975: "*Handbook of Occupational Safety and Health,*" Chicago, National Safety Council, 1975.

> "It is a cardinal rule that safeguarding one hazard should not create an additional hazard." p. 138.

1943: C.M. Macmillan, "*Foremanship and Safety*," New York, John Wiley, 1943.

> "In considering a machine guard we must realize that it has to give 'tops' in protection and it must not interfere with operation. Also, care must be taken that in guarding against one hazard we do not create another." p. 46.

D. Value Systems

The admonition not to adopt safeguards that have a safety downside applies to individual designers and manufacturers. This prohibition is specifically stated in most of the standards, codes, or statutes yet these very standards, codes, and statutes, regularly demand, recommend, or permit safety features with dangerous side effects such as automotive seat belts or falling object

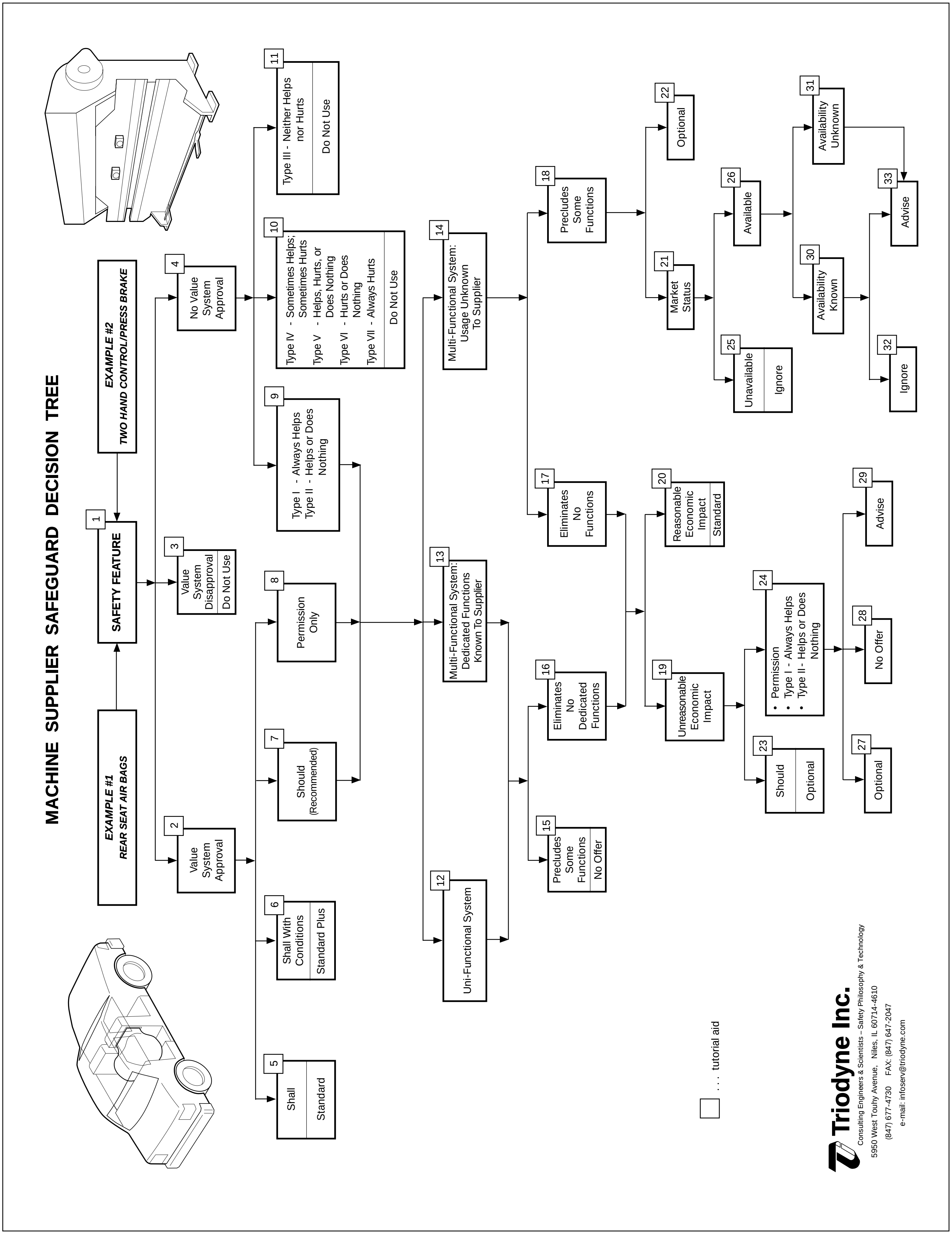

Figure 1. Machine Supplier Safeguard Decision Tree

protective structures on forklifts. There is no contradiction; engineers, designers, and manufacturers are not allowed to make judgements that hurt people even when the benefits are substantial, but value systems are.

A value system is defined as "the system of established values, norms or goals existing in a society."[2] Some of the more important ones that deal with safety issues are:

a. American National Standards Institute - A consensus value system comprised of all parties substantially concerned with the safety of a particular machine.
b. Occupational Safety and Health Administration - A government regulatory value system.
c. State Building Codes - Legislative value systems.
d. Case Law - The judicial value system.
e. Industry Practice.

Occasionally, there will be some dispute among value systems, at which time the relative merits of the positions must be judged. Usually, the more stringent requirements are accepted by a responsible party. It is not unusual for standards to include disclaimers such as "should any of the requirements of this standard conflict with federal, state, or municipal regulations, such conflict shall not invalidate other sections of this standard."

The very nature of value systems bears directly on the act of approval. When applied to the use of safeguards, value systems provide five levels of consent: demand, conditionally demand, recommend, permit, and reject. The following categories reflect these consent states using more familiar nomenclature. The boxes next to the key words indicate their appearance on the associated decision tree shown in Fig.1.

Shall: [5] Codes, standards, and statutes generally demand action with the word "shall" denoting a mandatory requirement. In our decision-making procedure, value system "demands" are held inviolate regardless of their effectiveness.

Shall With Conditions: [6] Sometimes demands carry additional warnings or requirements. For example, the demand for a rollover protective structure on a farm tractor carries with it the mandatory requirement for a seat belt. Together they represent a rollover protection system (ROPS).

Should: [7] Standards generally use the word "should" to denote a recommendation that is a sound safety practice which is not mandatory. For this reason, codes which often carry the force and effect of law, do not use "should." OSHA has expunged the word "should" from their regulations.

Permission Only: [8] Documented permission to use a specific safeguard may be found in some standards that neither demand (shall) nor recommend (should) them. Power press or press brake standards, for example, provide users with a menu of safeguard candidates which may be used in conjunction with a production system consisting of a press, dies, infeed system, off loading (parts and scrap) system, and safety system. Undocumented permission usually involves the accepted practice of a particular industry. The associated community of users tacitly concur that a particular safeguard has an acceptable safety value when there is widespread adoption and continuous use of the safety feature. Many of the safeguards used in printing presses and bakery equipment are undocumented and even state-of-the-art.

Disapproval: [3] Disapproval is the prohibition of a safeguard. It is not unusual for the Food and Drug Administration to preclude the use of certain medicines. The Environmental Protection Agency (EPA) has published codes that play an equivalent role by banning certain chemicals. For example, carbon tetrachloride can no longer be used in fire extinguishers and chlorofluorocarbons (Freon) cannot be used to eliminate the flammable characteristics of aerosol products. The Consumer Product Safety Commission prohibits fireproofing general-use garments with asbestos.

E. Engineering Code of Ethics

The first entry in the code of ethics of every engineering society requires that:

"Engineers shall hold paramount the safety, health and welfare of the public in the performance of their professional duties."

There are two points that should be emphasized. First, the duty of an engineer derives from an obligation to harness technology for the benefit of mankind. And second, welfare includes economic well-being. Welfare is defined as "a state characterized especially by good fortune, happiness, well-being or prosperity."[3]

Technical duties arise from the continually changing demands of society and take the form of independent functional requirements or specifications. They are not variables in the design process. Indeed, candidate safeguards that interfere with functional specifications must be rejected. The code of ethics imposes three additional conditions on the functional requirements - safety, health, and welfare. On the other hand, the code is silent on other properties such as those related to religion, history, and esthetics. One can recall that Ladybird Johnson championed a beautification program that effected the design of highway structures and power transmission poles. Such esthetic considerations are outside the purview of engineering, whereas, safety and cost control are major preoccupations of the profession.

F. Intrinsic Classification of Safeguards

Safeguards, under specific circumstances, may help you, hurt you, or do nothing. If one takes every possible combination of these positive, negative, and neutral characteristics, one obtains seven mutually exclusive and jointly exhaustive safeguard categories as shown in Table 1.[4] From a safety point of view, ignoring things such as function, practicability, and cost, this classification permits a clear delineation of professional responsibility. The most obvious problems are categories VI and VII where safeguards that compromise public safety are placed on a machine and are without any redeeming or offsetting characteristics. The code of ethics of every engineering society would consider the inclusion of such safeguards unethical and in conflict with the professional's obligation to protect the public.

Clearly, Type I and II safety features, which increase safety without collateral disadvantages, cannot be excluded from engineering systems on the basis of safety alone. Indeed, there are compelling humanitarian, ethical, and legal reasons to incorporate such safeguards when they are feasible, compatible, and economically practicable.

Type III safeguards, safety features that do nothing, must be rejected. One of the important objectives of engineering is to minimize cost. It follows that non-functional devices should be excluded from all engineering works. Furthermore, it is unethical to mislead the public and increase cost when no value is delivered.

Table I

INTRINSIC CLASSIFICATION OF SAFEGUARDING SYSTEMS

Type I -	**Safeguards that always improve safety.** Generally, power transmission guards are of this type.
Type II -	**Safeguards that sometimes improve safety and at other times leave the system unaffected**. An example is an awareness barrier which defines the safe (outside) from the unsafe (inside) region on a piece of equipment.
Type III -	**Safeguards that always leave the system unaffected.** Adding redundancy to a fail-safe system provides an example of this type.
Type IV -	**Safeguards that sometimes improve the safety and sometimes increase the danger, of the protected system.** The interlocked guard is usually of this type.
Type V -	**Safeguards that sometimes improve the safety, sometimes increase the danger, and sometimes leave the system unaffected.** The seat belt is a classic example in this category.
Type VI -	**Safeguards that sometimes increase the danger of the protected system and sometimes leave it unaffected.** An example would be an emergency stop button mounted on a slitting line recoiler unit which invites an operator into an area where he should never be located while the machine is running.
Type VII -	**Safeguards that always increase the danger of the system to be protected.** A "Man Cage" for a mobile crane is an example of a system which legitimizes an unsafe use historically admonished by every crane manufacturer. The philosophical positions arising from the intrinsic classification of safeguards are summarized in boxes [9], [10], and [11] of the decision protocol in Fig. 1.

Certainly, the most provocative safeguards fall into categories IV and V. Here, the safety features themselves create danger. As we have seen, a value system must balance the upside and downside effects of a particular safeguard. If they find the upside sufficiently compelling, permission is granted to use Type IV and V systems.

G. The System

In those cases where no value system has approved a candidate safeguard, its classification may require that we examine its relationship to the system under consideration. We observe in Fig. 1 that only three types of safeguards pass through the value system screening: those that are recommended [7] or permitted [8] or those that have no negative side effects [9]. There are two different approaches for handling such safeguards depending on whether the system's use is known or unknown. Uni-functional [12] and dedicated systems [13] are always known to their suppliers; general purpose multi-functional systems [14] are used in ways not revealed to the system's designers and distributors.

When suppliers know or, in the exercise of reasonable prudence, should know how a system will be used, it is straightforward to determine if the candidate safeguard precludes some functions of the system [15]. Such safety devices should not be offered since the welfare of the public is not served by prohibiting system functions the public desires.

In multi-functional systems where the use is unknown to suppliers, it is straightforward to determine whether a candidate safeguard will preclude some expected (as distinguished from foreseeable) functions of the system. Multi-functional machines are purchased specifically because they are general purpose in character and their value to users lies, in part, in their ability to use any of the expected functions. Safeguards that eliminate some expected functions [18] change the very nature of the system desired by the public or the community of users. These safety features must not be made standard equipment because of their adverse functional effects.

If a candidate safety feature can contribute to the system's safety during some of its operations, the public welfare is served when the supplier aids the user in the acquisition of the safeguard. This is certainly accomplished when the supplier offers the candidate safety feature as optional equipment [22]. Sometimes marketplace information is valuable [21]. Unknowledgeable users [31] may benefit from information defining when a safeguard may be used, how it may be used, and how it may be obtained by in-house construction or outsourcing [33]. When the community of users is already knowledgeable about the candidate safeguard [30], no enlightenment is required [32] although one may still volunteer such service [33]. If the candidate safeguard is unavailable in the marketplace [25], a decision to ignore terminates the process.

Dedicated and general purpose systems utilize the same screening process when no dedicated [16] or expected [17] functions are circumscribed by the proposed safeguard. Having passed the safety and functional requirements, the economic impact of the candidate safety feature must be evaluated. Recall that the spirit of the engineering code of ethics requires that welfare also be held paramount.

H. Economic Impact

Safeguards usually increase the system's cost. If the economic impact of a candidate safety feature is reasonable there is a clear mandate to adopt it as standard equipment [20]. Unfortunately, there is no exact protocol for determining reasonableness which may ultimately be a jury question if the efficacy of the safeguard is adjudicated.

Sometimes a candidate safety feature can be affected by a change or substitution that does not effect cost. Not infrequently, it may actually save money by increasing efficiency. For example, a manual centralized lubrication station eliminates maintenance exposure to moving parts while reducing lubrication time to a few seconds. Pressure relief valves not only eliminate explosion hazards to personnel, they protect pressure vessels and surrounding equipment from damage and destruction.

Some of the factors that should be considered in judging the economic impact of a proposed safeguard are:

1. Safeguard Cost

The absolute cost of a safety device or procedure can be stated together with its downstream implications for distributors, users, and the ultimate consumers of the system's production output. The cost is often presented as a percentage of the overall system cost. Judgements are easiest in extreme cases, e.g., the cost of available safety devices for a general purpose wood shaper is 300% greater than the cost of the machine.

2. Maintenance Cost

Safety devices wear out, break, go out of calibration, are by-passed, or are regularly examined as part of a preventive maintenance program. The associated cost of maintaining the candidate safeguard must be included in economic impact studies.

3. Certification Cost

Theme parks are required to regularly certify the safety devices on their amusement rides. Certain applications of light curtains on power presses may require regularly scheduled certification by qualified independent organizations. The cost of such certification must be included in economic impact studies.

4. Production Cost

Safeguards often increase the unit cost of the associated system's output by slowing machines or increasing the number of steps in the production process. Movable gate guards on power presses typically slow down production; higher prices follow. The through-put on meat grinders with safety throats or spider guards is often only 25% to 50% of the unguarded discharge rate.

5. Competition

A great many machines are treated like commodities and are procured by purchasing agents on the basis of "lowest price" alone. If a single manufacturer includes a unique safeguard, his cost increases may price him out of the market. The playing field is no longer level. Many municipalities have laws requiring them to accept the "lowest bid". Gigantic road building contracts are lost by a few thousand dollars on a half billion dollar bid. The point of these two examples is that *small differences between large numbers* can exert a disproportionate effect on a product's acceptance. A safeguard's cost may have a disastrous economic impact on a manufacturer.

6. Societal Cost

Inhibiting the production of vital products because of safeguard related inefficiency may carry with it an unacceptable societal cost, e.g., failing to produce a vaccine in a timely manner.

The inclusion and retrofitting of ground fault circuit interrupters (GFCI) on every electrical outlet in the U.S. would demonstrably save a significant number of lives every year. The cost of implementing such a program is so staggering that only bathrooms and kitchens *in new construction* are considered for GFCI by present value systems. Most rational evaluations of such safeguards rest ultimately on the monetary value of a human life. The courts have severely punished manufacturers who have had the temerity to publish their valuations of human life and limb. A more promising approach to the problem is to establish the cost of saving a life. If you figure it would cost 5 million dollars to prevent the electrocution of one person by adopting a full GFCI program you have achieved an unacceptable societal cost.

If the economic impact of a proposed safety feature is judged unreasonable [19], there are two situations to be considered. The first involves safeguards that are recommended by a value system in spite of their economic shortcomings. These should be made optional equipment [23]. The second involves safeguards that display redeeming safety advantages even though they are not recommended by a value system and have an unacceptable economic downside [24]. These candidates require no specific action on the part of their supplier [28] who, nevertheless, may voluntarily offer them as optional equipment [27] or advise their customers about their safety characteristics and market availability [29].

III. EXAMPLES

Candidate safeguards are evaluated in this section to familiarize the reader with the structure of the decision tree. The various examples make it clear that some of the steps in the decision process are very sophisticated. An understanding of safety side effects is essential to the classification of safety features, but, just as in the field of medicine, they may be difficult to forecast. Establishing the economic impact of a proffered safeguard may be a serious undertaking; establishing its reasonableness may defy analysis.

Example 3. Woodworking Table Saw

Among the various guards available for table saws, the slitter mounted guard is most often supplied as standard equipment; it permits *through-cuts* on any size workpiece. The guard is illustrated in Fig. 2 where it is observed that the slitter stands in the kerf that is cut in the workpiece. If *non-through cuts* are required, there is no through kerf and the slitter prevents passage of the workpiece beyond its leading edge. Examples of some *non-through cuts* are: da-do, cove, rabbets, grooves, panel raising, and resawing. The slitter mounted guard is fully or partially removed from the saw whenever non-through cuts are required.

To guarantee that the slitter mounted guard will be used during through-cutting, it has been proposed that the guard be interlocked so that the saw will not rotate when the guard is removed or is otherwise out of guarding position. Interlocking on saw guards is not called for or even described in woodworking codes and standards. Although it is not used in practice, it is not precluded by any value system. Consider the application of the decision tree to the saw guard interlock where we will presume that all the classical safety deficiencies of interlock technology have been cured (See Fig. 3).

We observe that the hypothetical candidate should either be ignored or offered as optional equipment. In reality a full safety analysis of such an interlock would reveal:

- It is foreseeable that the guard will be raised as an alternative method of shutting off the machine (Dependency Hypothesis).[5, 6]
- Because of the low reliability of interlocks, they must be tested at the beginning of every shift; this is usually done by raising the guard during operation.
- It is foreseeable that a raised guard will be substituted for proper lockout procedures during maintenance and blade changing.

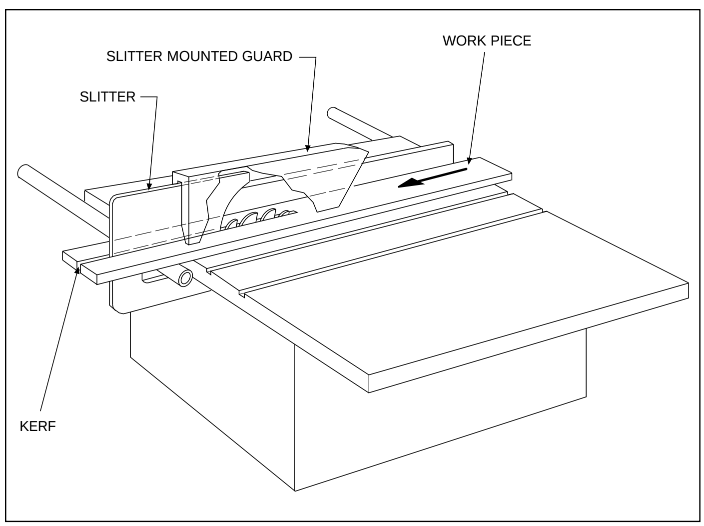

Figure 2. Slitter mounted guard without anti-kickback

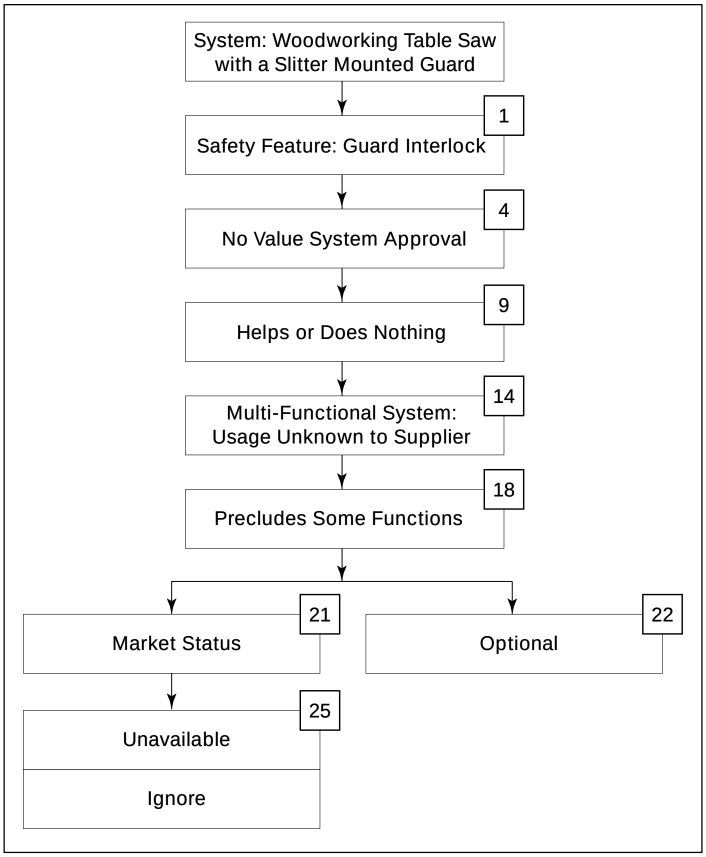

Figure 3. Decision process for woodworking table saw with a slitter mounted guard

- A pattern of interlock bypassing can be forecast with the attendant safety problems (Compatibility Hypothesis).[7]
- The interlock inhibits the adoption of other guard types that are superior to the slitter mounted guard in various applications.

This analysis would classify the safeguard as a Type V device (helps, hurts, or does nothing) not a Type II (helps or does nothing) and the decision tree will move from [1] to [4] to [10] where it terminates in the decision *Do Not Use*.

Example 4. Warning Signs

Some warning signs on ladders, agricultural equipment, lawn mowers, and electrical devices are required by codes and/or standards. For such straightforward applications of the decision tree, one moves from [1] to [2] to [5] where the warning sign is required to be standard equipment.

If the candidate safeguard is an "On Product Warning Sign" to be applied to an ordinary sharp knife, several value systems bear on this simple situation:

- American Standards Association, Specification for Industrial Accident Prevention Signs, ASA Z35.1-1941; (1.1) Scope: "These specifications apply to design, application and use of [warning signs] or symbols intended to indicate and, insofar as possible, to define specific hazards of a nature such that failure to designate them may lead to accidental injury to workers or the public, or both."
- Standard Practice: Ordinary knives carry no warnings.
- Judicial Value System: Most states require that latent, not patent, hazards be identified and characterized by warning signs.

These value systems do not decree that hazards be addressed that are open, known and understood by the community of users. The decision protocol for the knife would proceed from [1] to [4] to [11] where it mandates that the warning not be used. A warning dealing with the propensity of a knife to injure by cutting or stabbing is a Type III safeguard that neither aids nor detracts from the cause of safety. The warning does not transmit information that is unknown to the user; it has no safety downside such as clutter since no other warnings are found on knives.

Our final warning sign candidate is for on an extension ladder. Here, it is proposed that users be informed that large dogs can destabilize ladders by jumping against them. Certainly no value system would consider warning of such an obvious hazard. Even in those states that require warnings on open and obvious hazards, one would argue that the hazard is not reasonably foreseeable and that therefore no safety value is obtained. Because there are already three dozen warnings on an extension ladder, each new one adds to the clutter and diminishes thereby the conspicuity and impact of the other signs. Hence, the candidate warning is a Type VI safeguard that hurts or does nothing. The decision tree would then proceed from [1] to [4] to [10] where it advises against using the warning.

Example 5. Grinding Wheel

Proof testing is a safety concept that is used to eliminate weak elements from a statistical population. If grinding wheels, for example, are speed tested to failure, their fracture speeds will exhibit a significant scatter. For a seven inch diameter straight abrasive wheel rated at 6000 rpm the proof or test speed is 9000 rpm as specified in ANSI B7.1-1988. This standard requires 100% speed testing for all wheels six inches in diameter or larger. If their rated speeds are faster than 5000 rpm, the test speed is 50% greater. Under Exceptions (7.1.4) the standard states "Wheels that need not be speed tested are wheels less than 6" diameter."

Consider the application of the decision tree to the proof testing (safety feature) of a four inch diameter abrasive wheel (system). Here the standard gives permission to use proof testing without compelling (shall) or recommending (should) its use. Making the unrealistic assumption that the cost of proof testing is not significant, we obtain the following decision path shown in Fig. 4.

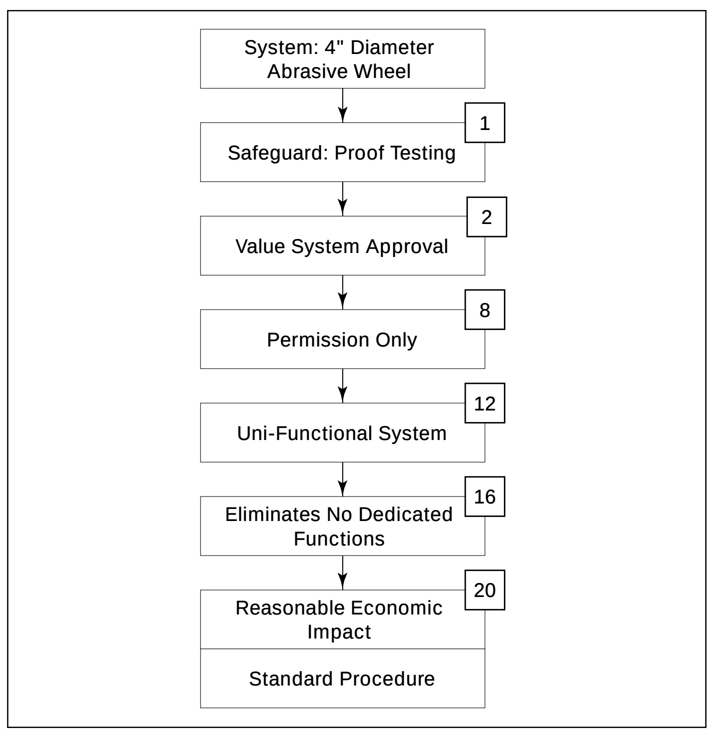

Figure 4. Decision process for a 4" dia. grinding (abrasive) wheel

In this case the proof testing procedure would be adopted as a standard safety feature on four inch diameter wheels. On the other hand, a realistic analysis would recognize that because small wheels are inexpensive, the cost of speed testing a wheel represents a significant cost increase that will certainly price the wheel out of the market. The resulting protocol logic is exactly the same as shown in Fig. 1 for Example 1, the rear seat air bag. Substituting the proof testing safety feature into Box [1] we obtain the same three safeguard adoption choices: Optional [27], No Offer [28], or Advise [29]. The authors would select No Offer [28] since 4" diameter wheels constructed to industry standards will, within a reasonable degree of scientific certainty, never fail the proof test; no safety value is delivered but the cost is increased.

Example 6. Mobile Crane

Three countermeasures have been proposed to eliminate the shock and electrocution hazards associated with power line contacts between the boom, load line, or crane protuberances. They are, respectively, cage-type boom guards, insulating links, and proximity warning devices (See Fig. 5). The phrase “construction management” will be used to describe other countermeasures such as de-energizing transmission lines, visibly grounding or insulating them, erecting physical barriers to preclude power line contact, and maintaining a minimum clearance between the lines and any part of the crane or load.

Referring to paragraph 5-3.4.5 (b) in the safety standard ASME/ANSI B30.5-1989 for Mobile and Locomotive Cranes, we find the following reference to the three “crane electrocution devices:”

> “(b) If cage-type boom guards, insulating links, or proximity warning devices are used on cranes, such devices shall not be a substitute for the requirements of (a) above, even if such devices are required by law or regulation. In view of the complex, invisible, and lethal nature of the electrical hazard involved, and to lessen the potential of false security, limitations of such devices, if used, shall be understood by operating personnel and tested in the manner and intervals prescribed by the manufacturer of the device.”

Note that the “requirements of (a)” are the construction management procedures previously described.

For purposes of the decision tree, the standard gives permission to use the “three crane electrocution devices” *if* construction management controls are in place, *if* operating personnel are aware of the limitations of the devices so that the potential of false security may be lessened, and *if* the devices are tested in the manner and at intervals prescribed by their manufacturers. The three devices are Type V safeguards that help, hurt, or do nothing for the cause of safety. When the three crane electrocution countermeasures are inserted into the decision tree without the three “ifs” [1], no value system permission is granted and we would move to [4] and then [10] where we would be prohibited from using them. On the other hand, when the three devices are evaluated on the basis that the three “ifs” are satisfied, the steps to be followed are shown in Fig. 6.

Here, we observe that a choice must be made relative to the reasonableness of the cost of the three devices. If judged reasonable, the three devices are standard equipment; if not, the authors would make the choice of not offering the devices [28], because of their downside safety characteristics.

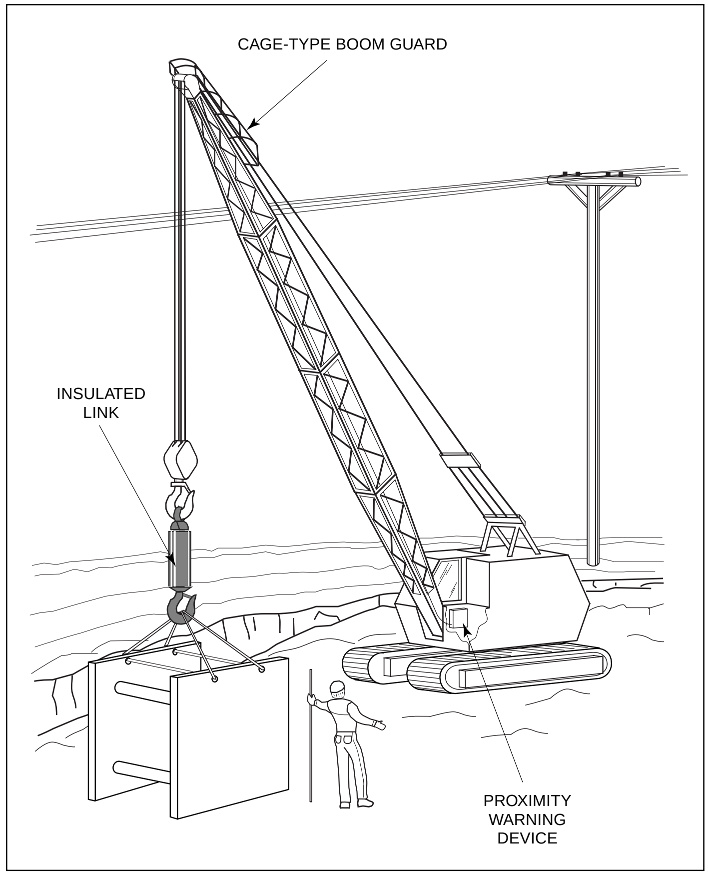

Figure 5. Electrocution and shock safeguards for moblie cranes

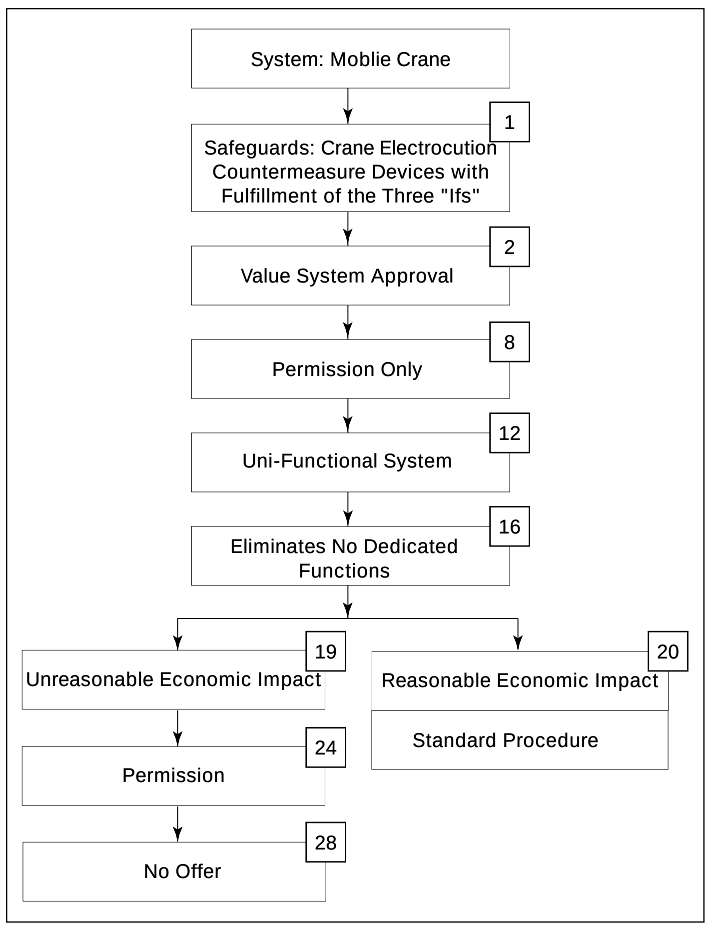

Figure 6. Decision process for mobile crane electrocution and shock safeguards

Example 7. Bowling Pinsetters

In the previous example, the quoted section of the standard contained the phrase "even if such devices are required by law or regulation." When the decision tree is applied to a specific locality where a law or regulation requires the candidate safeguard, the Shall Box [5] will prevail with its requirement that the safeguard be standard equipment. Local laws and regulations represent the local value system.

When various forums express different values, the protocol can be applied to each of them and the resulting collection of decisions can be used to make marketing judgements. As an example, one of the manufacturers of automatic bowling pinsetters developed a guarding system that was evaluated by Underwriters' Laboratories, Inc. In UL's judgement, the casualty hazards encountered during normal operations of the unit were "reduced to an acceptable minimum by the use of the guards." For many decades this standard guarding system has been used throughout the world with the exceptions of the states of California and Wisconsin which require as standard equipment an additional "special guard package." Although the special guards are described in all company manuals and are offered as optional equipment, no other forums have adopted them. The special guards are costly and impede certain maintenance procedures.

Using the following assumptions and observations, consider the application of the decision tree to the special guard package outside of California and Wisconsin:

a. No value system makes reference to the package.
b. The package is Type II; it helps or does nothing to the safety profile.
c. The costs attendant to the package have an unreasonable economic impact.

Under the stated scenario, the protocol follows precisely that illustrated in Example 1 where the "optional equipment" decision adopted by the manufacturer is one of the three choices advanced.

A different tactic would apply if the hazards addressed by the special guard package are not reasonably foreseeable. Here, the judicial value system *does not require safeguarding* because by its definition there is no safety problem. Thus, since the package does no harm, the guards would be classified as Type III; they neither help nor harm. The protocol would then move from [1] to [4] to [11] where we would be compelled not to offer the special guard package.

Example 8. Underride Guard

There is a class of cases where the candidate safeguard is an enhancement of an existing safety feature. For example, if it is desired to move from a safety factor of *three* to one of *five*, the candidate safeguard is the increase in the safety factor, *two*. Another example is provided by the underride guard that is used to prevent excessive underride of a passenger vehicle when it collides with the rear end of a heavy commercial vehicle (See Fig. 7). The resulting intrusion into the passenger compartment gives rise to a decapitation potential in addition to the normal injuries that result from collision forces imparted to the occupants.

The construction of underride guards is regulated by the Federal Highway Administration (FHWA) of the Department of Transportation. Specifically, Regulation 393.86 - Rear End Protection requires that:

"Every motor vehicle, except truck-tractors, pole trailers, and vehicles engaged in driveaway-towaway operations, the date of manufacture of which is subsequent to December 31, 1952, which is so constructed that the body or the chassis assembly if without a body has a clearance at the rear end of more than 30 inches from the ground when empty, shall be provided with bumpers or devices serving similar purposes which shall be so constructed and located that: (a) The clearance between the effective bottom of the bumpers or devices and the ground shall not exceed 30 inches with the vehicle empty; (b) the maximum distance between the closest points between bumpers, or devices, if more than one is used, shall not exceed 24 inches; (c) the maximum transverse distance from the widest part of the motor vehicle at the rear to the bumper or device shall not exceed 18 inches; (d) the bumpers or devices shall be located not more than 24 inches forward of the extreme rear of the vehicle; and (e) the bumpers or devices shall be substantially constructed and firmly attached. Motor vehicles constructed and maintained so that the body, chassis, or other parts of the vehicle afford the rear end protection contemplated shall be deemed to be in compliance with this section."

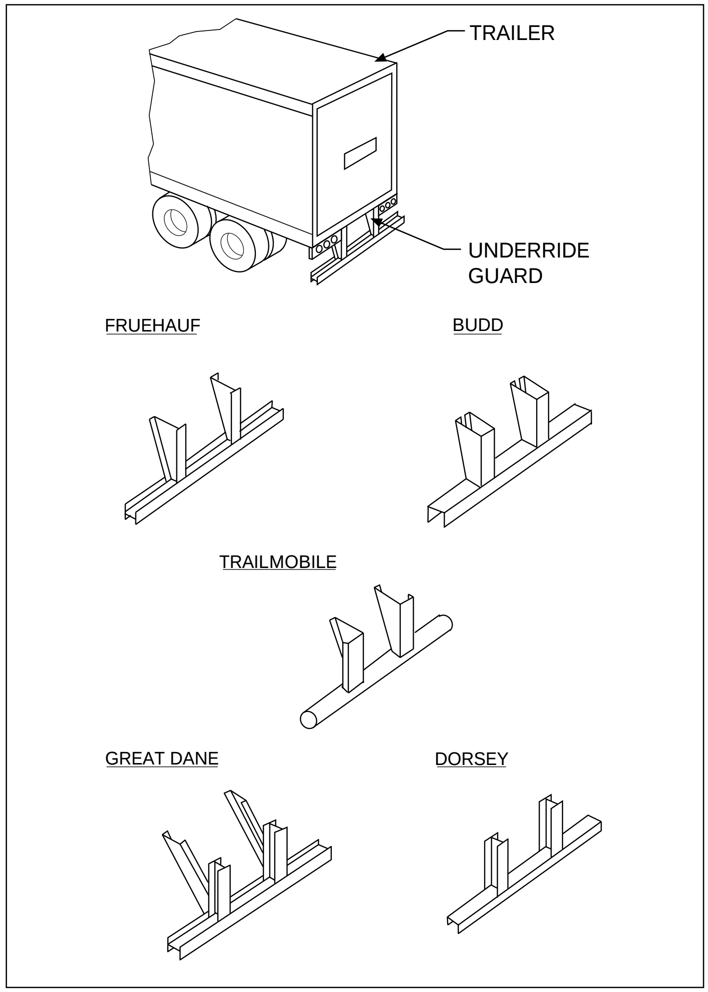

Figure 7. Current underride guards

Paraphrasing the structural integrity requirement, bumpers or devices shall be substantially constructed and firmly attached to afford the rear end protection contemplated. Note that the words *substantially, firmly,* and *contemplated* are never defined; surely this is rulemaking at its worst. Nevertheless, technologists have followed the spirit of the regulation and have produced the guards shown in Fig. 7. An amalgam of these guards was characterized by the FHWA as the "Current Guard"; its force-displacement property is defined in Fig. 8*i*. To proceed

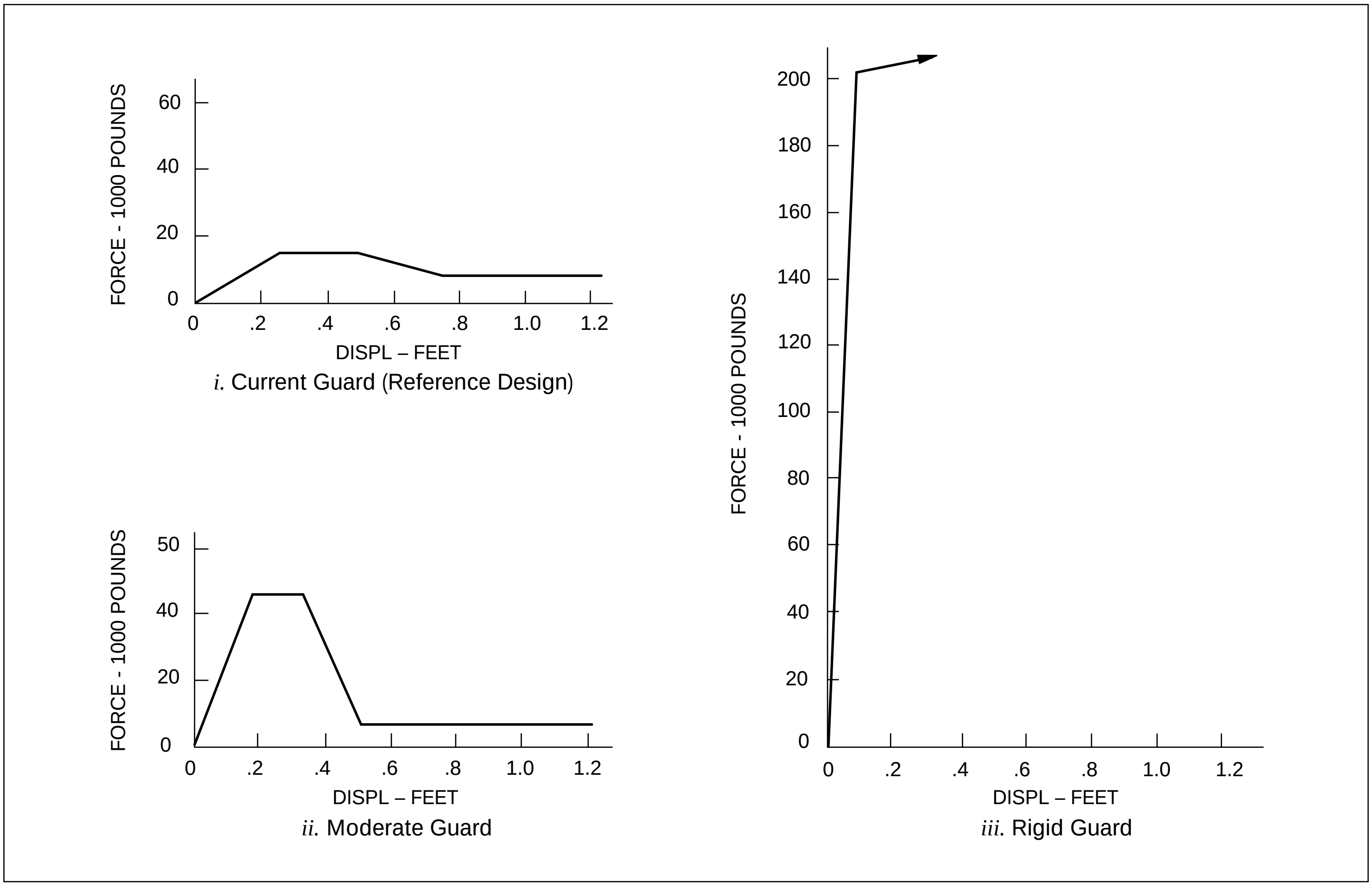

Figure 8. Force deformation properties for underride guards evaluated in the FHWA risk analysis

with our example, the system to be studied by the decision protocol is a truck outfitted with the "Current Guard." The candidate safeguards will be taken as the extra protection afforded by a "Moderate Load Guard" and a "Rigid Guard" which are characterized respectively by their load-displacement diagrams illustrated in Figs. 8*ii* and 8*iii*. Tomassoni and Bell report on a risk analysis performed by the FHWA on the three guards represented in Fig. 8.[8] Table 2 describes their benefit comparison. Both candidate guards improve safety by approximately 18% and both are considerably more costly than the "Current Guard."

The application of the decision tree begins by inserting the extra protection of the Moderate and Rigid Guards into Box [1]. No value system requires the *extra protection* which brings us to Box [4]. The *extra protection* is a Type I safeguard that always benefits; Box [9]. The truck/underride system is uni-functional [12] and eliminates no dedicated functions [16]; consequently, the decision tree takes the form shown in Fig. 9.

We observe that the final adoption strategy depends on whether the economic impact is reasonable or unreasonable. Recalling that the decision tree is not applicable to regulatory value systems, we can nevertheless inquire into the FHWA procedures for determining reasonable economic impact.

Lifetime cost estimates made by the FHWA included some of the following factors:

1. There are approximately four million vehicles that are underride candidates.
2. Initial cost of guards.
3. Added fuel cost related to the increased weight of the guards.
4. Guard maintenance.
5. Revenue loss due to payload displaced by the added guard weight.
6. Revenue loss due to decreased payload capacity caused by guards restricting the rear wheel sliders (1720 pounds of payload per foot of slider restriction).

In 1967 and again in 1977 the Department of Transportation initiated rulemaking efforts to improve protection for passenger car occupants. A number of underride guard concepts, including the Modified and Rigid Guards, were part of their studies. The 1967 efforts were terminated in 1971 when the Administrator of the National Highway Traffic Safety Administration concluded that the safety benefits achievable in terms of lives and injuries saved would not be commensurate with the cost of implementing the proposed rule. As of this writing, no modification of Regulation 393.86 has evolved from the 1977 study. It should be pointed out that the regulatory value system must wrestle with the difficult Cost/Benefit tradeoffs that ultimately involve placing values on human life and limb.

Returning to the determination of reasonable economic impact that must be made by the safeguard supplier in our underride guard example [20], all decisions are evaluated in the final analysis by the supplier's *perception* of the judicial value system. If the supplier believes that a jury will find the cost of preventing 150 fatal or serious injuries to be reasonable, Box [20] requires that the Moderate or Rigid Guard be included as standard equipment. A jury judgement of unreasonable economic impact [19] requires no departure from the Current Guard [28]. Voluntary measures such as optionalizing [27] or advising [29] are not precluded.

Guard Type	Predicted Fatal and Serious Injuries	Initial Guard Cost	Prevented Fatal and Serious Injuries	Increased Guard Cost
Current Guard	822	$50	–	–
Moderate Load Guard	682	$83	140	$33
Rigid Guard	669	$157	153	$107

Table 2. Benefit comparisons among candidate underride guards

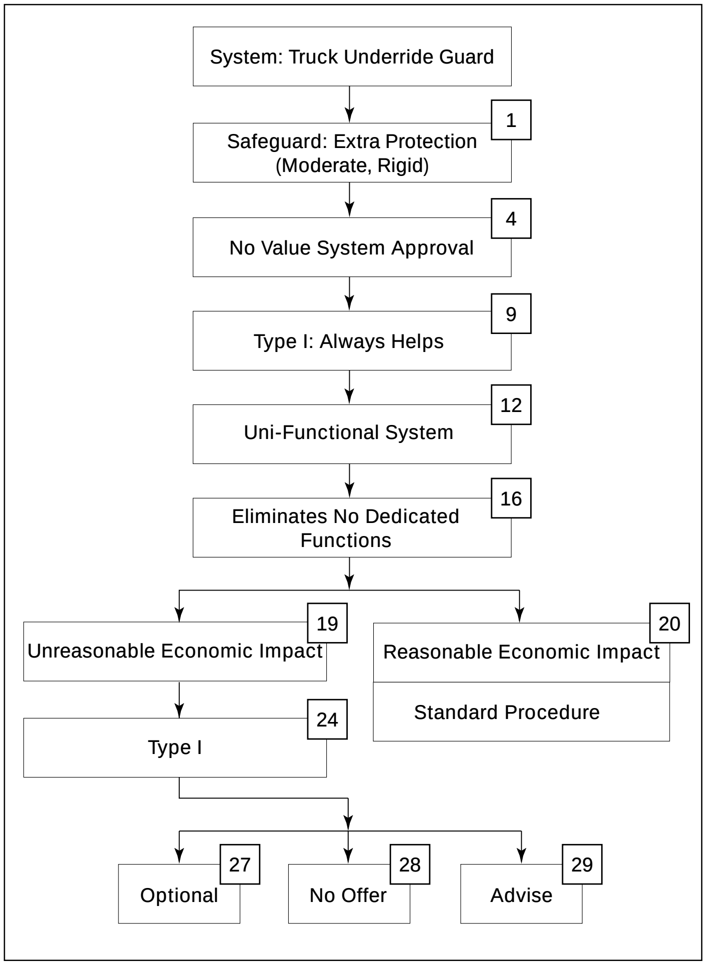

Figure 9. Decision process for truck underride guards

IV. CONCLUSION

The decision tree depicted in Fig. 1 is constructed using three safety philosophies that may be stated as follows:

1. Bend technology to the will of humankind while holding safety and cost paramount.
2. Private decisions to use safeguards that introduce new hazards should not be made.
3. The use of safeguards should comply with appropriate value systems.

To facilitate the application of these rules, two classification methods were employed that enable both *safeguards* and *systems* to be uniquely categorized. The Intrinsic Classification was used for *safeguards* and a dedicated/general purpose scheme was applied to *systems*.

The individual philosophical elements in the decision tree are all necessary conditions that must be followed. The array chosen to meet these necessary conditions is a sufficient condition, i.e., our decision tree, if followed, will meet all the required conditions. On the other hand, our decision tree is not unique, e.g., we may choose *economic impact* as our first screening procedure. Nevertheless, we have selected the screening order embodied in Fig. 1 because it goes from easy to hard; it leaves the most subjective category, reasonable economic impact, to last.

Support and partial corroboration of our decision making protocol can be found in another intellectual discipline; the judicial value system. A number of states have adopted the findings of Barker v. Lull Engineering Co. which first introduced the concept of risk/benefit as a liability criterion. Consider the following:

Barker v. Lull Engineering Co. 573 P.2d 454 (1978)

In this case the Supreme Court of California stated that, "a product may be found defective in design, so as to subject a manufacturer to strict liability for resulting injuries, under either of two alternative tests . . .

"1. a product may be found defective in design if the plaintiff establishes that the product failed to perform as safely as an ordinary consumer would expect when used in an intended or reasonably foreseeable manner.

"2. a product may alternatively be found defective in design, if the plaintiff demonstrates that the product's design proximately caused his injury and the defendant fails to establish, in light of relevant factors, that, on balance, the benefits of the challenged design outweigh the risk of danger inherent in such design.

"Among the 'relevant factors' the jury may consider when weighing the benefits of the design against the risks, in the second test, are:

(a) the gravity of the danger posed by the challenged design;
(b) the likelihood that such danger would occur;
(c) the mechanical feasibility of a safer alternative design;
(d) the financial cost of an improved design;
(e) the adverse consequences to the product and to the consumer that would result from an alternative design."

We first observe in paragraph (1) that a distinction is made between expected use and reasonably foreseeable use. The same distinction is made in our discussion of general purpose multi-functional systems. Our second observation concerns the three "relevant factors" related to alternative designs. The mechanical feasibility factor given in paragraph (2c) is equivalent to functional evaluations in the decision tree leading to boxes [15], [16], [17], and [18]. The determination of reasonable economic impact corresponds to paragraph (2d) dealing with financial cost. Finally, the adverse consequences to the consumer referenced in paragraph (2e) is directly related to the Intrinsic Classification entries in boxes [10] and [11] that deal with safeguards with negative characteristics.

Various types of decisions are incorporated into the safeguard adoption protocol; namely,

- Standard Equipment
- Standard With Additional Equipment
- Do Not Use
- Optional Equipment
- No Offer
- Advise
- Ignore

A number of practitioners in the field of product liability have taken the position that "safety should not be optional." Whatever its jury appeal, this simplistic approach violates one or more fundamental philosophies that society has adopted for its safety and well-being.

In 1972 the Supreme Court of New Jersey decided the case *Bexiga v. Havir Mfg. Corp.* Their ruling imposed a non-delegable duty on manufacturers to supply safety devices where it is feasible to do so. Subsequently, many state courts adopted similar findings. Although the Bexiga litigation involved a small Havir power press (open back inclinable), the decision has general applicability. The court's finding was an intellectual disaster on two levels; the specific punch press technology and the general non-delegable duty concept. With respect to the Havir press, a technical misrepresentation led the court astray; namely, that a two button safeguard would be appropriate for any of the machine's normal uses. On this basis they concluded it should be standard equipment. Indeed, our decision tree would also make a universal safeguard standard equipment if it was economically practicable. It should be noted, however, that no universal safeguards exist for general purpose power presses, that the most advanced two hand hostage controls preclude many machine functions (see Example 2) and that the Havir press with its full revolution clutch could only have been supplied with a two hand activation device that would never qualify as a safety device by ANSI or OSHA criteria.

The New Jersey court made two additional findings relative to presses:

(1) "The Court stated that the trial judge properly precluded the question of whether responsibility for the absence of safety devices was chargeable to Havir from going to the jury. It reasoned, 'Since the machine could be used to perform various tasks it conceivably could require a different group of safety devices in connection with each task.' Thus, it held, '[T]he imposition of such a duty upon Havir would have been impractical and that it did not act unreasonably in not equipping the press with safety devices on its own.'

(2) "We hold that where there is an unreasonable risk of harm to the user of a machine which has no protective safety device, as here, the jury may infer that the machine was defective in design unless it finds that the incorporation by the manufacturer of a safety device would render the machine unusable for its intended purposes."

We note that the court's use of the word "impractical" corresponds to our characterization of *unreasonable economic impact*; the phrase "unusable for its intended purpose" corresponds to our designation *precludes some functions*.

The next level of philosophical mischief associated with "the non-delegable duty" is far more serious. The 1972 court treated all safeguards homogeneously as if they were Type I (always improve safety); the Intrinsic Classification System was not published until 1981. Would the court impose a common law duty to compel manufacturers to furnish as standard equipment safeguards that only compromise safety (Type VII) or that have no safety value (Type III and VI) or that may do more harm than good (Type IV and V)? The following excerpt from the court's decision demonstrates their commitment to public safety notwithstanding their insufficient technical understanding:

> "Where a manufacturer places into the channels of trade a finished product which can be put to use and which should be provided with safety devices because without such it creates an unreasonable risk of harm, and where such safety devices can feasibly be installed by the manufacturer, the fact that he expects that someone else will install such devices should not immunize him. The public interest in assuring that safety devices are installed demands more from the manufacturer than to permit him to leave such a critical phase of his manufacturing process to the haphazard conduct of the ultimate purchaser. The only way to be certain that such devices will be installed on all machines — which clearly the public interest requires — is to place the duty on the manufacturer where it is feasible for him to do so."

On multi-functional machines whose applications are unknown to the supplier, the ultimate purchaser/user is the *only* one with the input information to maximize safety by the judicious selection of safeguards that exhibit no downside in a specific task. With reference to mechanical power presses, every known safeguard is a Type IV device that can compromise safety in the wrong application. The only responsible approach to the press safety problem is to appeal to users and not manufacturers to select and apply safeguards; this directly opposes the *Bexiga v. Havir* philosophy.

User safety involvement in the press industry has attained a high level of sophistication with the development of the "production system" methodology. The court's characterization of the ultimate purchaser's conduct as haphazard is inaccurate and reflects a very narrow view of manufacturing technology. Disciplined conduct of employers is compelled by regulatory law, statutory law and peer pressure; they are under pressure by worker's compensation carriers and unions and they are motivated by conscience, friendship and economics.

REFERENCES

1. Barnett, Ralph L. and Beth A. Hamilton. 1984. "Philosophical Aspects of Dangerous Safety Systems." *Triodyne Safety Brief* v. 1 #4 (December): 1-5.

2. *Webster's Third New International Dictionary*. 1966. Springfield, MA: G & C Merriam Company.

3. *Ibid*.

4. Barnett, Ralph L. and Peter Barroso, Jr. 1981. "On Classification of Safeguard Devices (Part I)." *Triodyne Safety Brief* v. 1 #1 (April): 1-2.

5. Barnett, Ralph L. and Peter Barroso, Jr. 1985. "The Dependency Hypothesis - Misuse." *#85-1624*. St. Joseph, MI: American Society of Agricultural Engineers.

6. *Ibid*. 1984. "The Dependency Hypothesis - Expected Use." *#86-5021*. St. Joseph, MI: American Society of Agricultural Engineers.

7. Barnett, Ralph L. and William G. Switalski. 1988. "Principles of Human Safety." *Forensic Engineering* v. 1 #3: 153-173.

8. Tomassoni, J.E. and G.K. Bell. 1980. "An Approach to Developing Underride Guard Requirements for Improved Occupant Protection." *SAE 801422*. Warrendale, PA: Society of Automotive Engineers.

SAFETY BRIEF

May 1995 – Volume 11, No. 2

Editor: Paula L. Barnett

Illustrated and Produced by

Triodyne Graphic Communications Group