3 Hazard Control Hierarchy and Its Utility in Safety Decisions about Consumer Products

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3.1 INTRODUCTION

In general, the public at large expects the consumer products that they purchase to be relatively safe. In order to meet this expectation and to avoid injuries and product damage, manufacturers need to take steps in bringing products to the marketplace to ensure that the products meet people's beliefs about safety.

There is a concept in safety, as well as in human factors engineering and other disciplines, known as the hazard control hierarchy, or alternatively as simply the safety hierarchy (National Safety Council 1989; Sanders and McCormick 1993). This concept is a prioritization scheme for dealing with hazards. The basic sequence of priorities in the hierarchy consists of three approaches: first is to design the hazard out; the second is to guard against the hazard; and the third is to warn.

If a hazard exists with a product, the first step is to try to eliminate or reduce it through an alternative design. If a non-flammable propellant in a can of hairspray can be substituted for a flammable carrier and still adequately serve its function, then this alternative design would be preferred. Eliminating sharp edges on product parts or pinch points on industrial equipment are additional examples of eliminating hazards. However, safe alternative designs are not always available.

The second approach to dealing with product hazards is guarding. The purpose of guarding is to prevent contact between people and the hazard. Guarding procedures can be divided into two categories: physical guards and procedural guards. Personal protective equipment such as rubber gloves and goggles, barricades on the highway, and bed rails on the side of an infant's crib are examples of physical guards. Designing a task so as to prevent people from coming into contact with a hazard is a procedural guard. An example would be the controls on a punch press that require the operator to simultaneously press two switches, one with each hand, a sequence of activities that ensures fingers will not be under the piston when it strokes. Another example is a physician's prescription for a medication. Without it, the medication cannot be obtained.

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However, guarding, like alternative designs, is not always a feasible solution for dealing with hazards. One cannot design out all the hazards of a lawnmower even though the shell or cover of the mower physically guards against certain kinds of contact with the blade, and a so-called dead-man's switch at the handle provides a procedural guard that stops the engine when the handle is released from a grip. The protection that alternative designs and guarding can provide can be incomplete and serve only to reduce the hazard, not completely eliminate it or serve as a complete barrier to hazards, e.g., there may be some residual hazards given the design alternatives and guarding employed.

In cases where there are still hazards associated with the product after design and guarding have been implemented, warnings may be used as a third line of defense. Warnings can be thought of as safety communications. One of the purposes of a warning is to provide people with the information needed to make informed decisions about how to use a product safely, including the choice of whether to use it at all. Warnings are third in the priority sequence because they are generally less reliable than design or guarding solutions. Even the best warnings are not likely to be 100% effective. People at risk may not see or hear a warning, or they may not understand it. Further, even warnings that are understood may not be successful in motivating compliance because the message does not fit well with people's beliefs and attitudes. It is these and other reasons and difficulties that place warnings as the third strategy in hazard control, behind design and guarding.

There are other approaches to dealing with product hazards, such as training (influencing how the product is used), personnel selection (influencing who uses it), and administrative controls (employer/supervisor sets and enforces rules). In the context of dealing with product hazards, these approaches are viewed as similar to warnings in that they mostly involve efforts intended to inform and influence behavior.

3.2 ISSUES ASSOCIATED WITH THE HIERARCHY

Numerous questions or issues may arise when applying the safety hierarchy. A starting point, of course, is to have a good understanding of the product hazards. While it is not within the scope of this chapter to discuss the goals and methods of hazard analysis, there are two noteworthy points worth mentioning. The first point is that there are formal analytic procedures and/or tools for carrying out a product hazard analysis (Frantz, Rhoades, and Lehto 1999). Examples of such procedures are fault-tree analysis and failure modes and effects analysis. Such procedures are widely recognized and practiced. A second point to note is that hazard analysis is, or should be, viewed as part of the design stage of product development. Hazard analysis of the product ought to be carried out before it is made available to consumers. A product hazard that is not recognized until the product has been in the marketplace can be costly both financially and with regard to safety outcomes. Recalls and retrofits are not a good substitute for timely and competent hazard analyses. After the product is in the marketplace and being used by consumers, it is also necessary to conduct ongoing analysis of consumer injury data from sources such as government agencies and customer service departments. If data suggest a problem with the product, post-sale warnings and recalls can be used for hazard control. Also, those data can serve as input into future designs.

Whether from hazard analysis during product development or through feedback after the product has been marketed, the hazard control hierarchy comes into play. The hierarchy's role is to aid in decision making about how to address the hazards. Some of the issues involved in such decisions are discussed in the following sections.

3.3 ALTERNATIVE DESIGNS

A general rule of thumb for when to implement an alternative design is when it is technologically and economically feasible. However, the decision process is more complex than that. Clearly, alternatives must be technically possible, such as whether non-flammable carriers in hairsprays can be

produced or whether there is a way to reduce automotive tire deterioration due to aging processes. But decisions about alternative designs must include consideration of other aspects such as reliability and adequate function. If the alternative detracts from the effectiveness of the hairspray or causes the tire tread to wear faster, the alternative may not be an acceptable option, even though it addresses the hazard that led to its consideration.

It is also necessary to take into account economic feasibility in considering alternative designs. If the cost of eliminating a hazard with an alternative design is prohibitively expensive, it may not be an acceptable fix. Here again, however, the economically feasible decision may be considerably more complex than meets the eye. It might create another hazard elsewhere. Thus, a complex evaluation is needed, not just at the product level but also in a more global scope, as a part of a system of interacting components. Such considerations are not within the scope of this chapter, but one factor that is sometimes suggested or considered, rightly or wrongly, is the potential cost of defending lawsuits based on safety issues associated with the product.

When hazard elimination is feasible on both technical and economic dimensions through some alternative design, it should be examined with respect to the possibility of creating a new and worse hazard. An example would be a non-flammable carrier for hairspray that is extremely toxic if it gets into the eyes. Likewise, the harm could be to the environment, which could indirectly cause adverse health effects on users and others. The carrier in hairsprays used to be chlorofluorocarbons (CFCs), but its use was found to negatively affect the ozone layer and greenhouse gases, and they were banned from use in the United States and some other countries. Clearly, one should avoid using an alternative design that creates a worse hazard. Any new hazard that is created to eliminate another requires deliberate consideration about tradeoff acceptability. Thus, alternative designs that create as many or more hazards as they solve is not the intent of the safety hierarchy. The decision to ban CFCs was made to reduce a societal, environmental hazard, but it resulted in an increased personal-use hazard.

3.4 FACTORS THAT INFLUENCE SAFETY DECISIONS

In the previous section on alternative designs, a few factors were described that influence decisions on how to address product hazards. Technological and economic feasibility and the potential creation of other hazards were noted. There are other factors that can play a role in deciding how to address hazards. One factor is what the consumer wants or will accept; or, alternatively, what the manufacturer believes the consumer wants or will accept. An example of this issue in the context of a consumer product will help make the point. Most vehicles marketed in the United States have front seats that can be reclined to a nearly horizontal position. (Pickup trucks with bench seats are an exception.) It is generally agreed that it is hazardous for a passenger to have the seat significantly reclined to where the shoulder belt is not in contact with the torso while the vehicle is moving. The problem is that when the occupant is in the reclined position, the restraint system loses its effectiveness. Vehicle manufacturers do not even test restraint effectiveness with dummies in a reclined seat. There have been people in accidents who were reclined in passenger seats who were ejected or partially ejected and are now dead or with high level spinal fractures resulting in quadriplegia. Virtually all manufacturers now warn in the vehicle owner's manual not to recline the seat while the vehicle is in motion. While the quality of such warnings varies, the warning approach has been chosen to address the hazard—the third line of defense in the safety hierarchy. Studies show that most people are unaware of this hazard, although when called to their attention, people understand it (Leonard 2006; Leonard and Karnes 1998; Paige and Laughery 2003; Rhoades and Wisniewski 2004). Laughery and Wogalter (2008) have explored the use of warnings to address this hazard.

An alternative approach exists for addressing the seat recline hazard. It is technically and economically feasible to design the seat so that it cannot recline to an unsafe angle. According to the safety hierarchy, this would be a preferred solution compared to a warning approach. Part of the

reason is that people do not read, and do not have the opportunity to read, a vehicle owner's manual before using it, as in the case of rentals.

Vehicle manufacturers have taken into account at least two factors in deciding to address the seat recline hazard with warnings. First, they considered a marketing factor based on the belief that customers want the seat recline feature. A second cited factor is that in circumstances where the driver is experiencing fatigue, it will be possible to rest by stopping and reclining the seat, a safety consideration.

A guarding approach has also been proposed for addressing the seat recline hazard. Here, the vehicle cannot be driven from a stopped condition if the seat is reclined beyond some safe angle, and if the engine is running, the seat will not recline. Note that this guarding solution permits the fatigued driver to stop the vehicle, recline the seat, and rest. They can still get the benefit of being able to recline the seat. Like the above design alternative, it is likely to be more successful than warnings in dealing with the seat recline hazard. Note that there may be other design solutions, such as designing the restraint system so it works while in a reclined position.

3.5 WARNING VERSUS ALTERNATIVE DESIGN VERSUS GUARDING

The above seat recline example illustrates a product where the hazard is understood and there are options to deal with it. More specifically, there is a choice between a technologically and economically feasible alternative design or guarding or warnings. Note that to be successful the design and guarding options need to be fail-safe, unless of course there is some kind of structural failure or successful effort to override the kill switch. The effectiveness of a warning option depends on the communications successfully informing and motivating the occupant not to recline the seat in the moving vehicle. The differences in effectiveness, of course, illustrate the underlying value or purpose of the safety hierarchy.

Another example of a consumer product where the safety hierarchy could or should come into play is a turkey fryer. The base or stand for such a fryer, or cooker, is shown in Figure 3.1a. A large aluminum pot sits on top of the propane-fueled base shown in the figure. A typical application or use of the product would be to put cooking oil, such as peanut oil, in the pot and cook turkey parts or other meat.

A considerable hazard associated with this product is that it is unstable and can tip over if intentionally or unintentionally bumped or moved. The resulting hot oil spill can result in severe or catastrophic burns. Such incidents have occurred in situations such as outdoor picnics or similar events where children or animals may be active in the vicinity of the cooker.

The cooker comes with an owner's manual. The manual contains a warning that includes a statement that the hot oil can cause severe burns and advising to keep children and pets away. Note that the instruction to keep children and pets away is an example of a warning recommending a guarding solution. While the adequacy or inadequacy of the warning could be a concern, the manufacturer of the product should explore how to deal with the tip over hazard from the perspective of the hazard control hierarchy. As stated earlier, design alternatives are preferred over guarding or warning.

There are several design aspects of the turkey fryer that contribute to its instability. Included among these characteristics are: the width of its base, the height of its center of gravity, and the fact that it has only three legs. In terms of alternatives, these are design features that can be improved in ways that result in a significant increase in stability. For example, adding a fourth leg, lowering the center of gravity by shortening the legs, or adding a ring at the base of the legs, as shown in Figure 3.1b, are examples of design alternatives that are readily achievable.

There are numerous examples of the different ways that the hazard control hierarchy is used for any given product, person, and context of use. Take the example that Karnes, Lenorovitz, and Leonard (2010) discuss with respect to personal water craft (PWC). There is a hazard of orifices injuries caused by water jets used to propel PWC. For many years, manufacturers used warnings

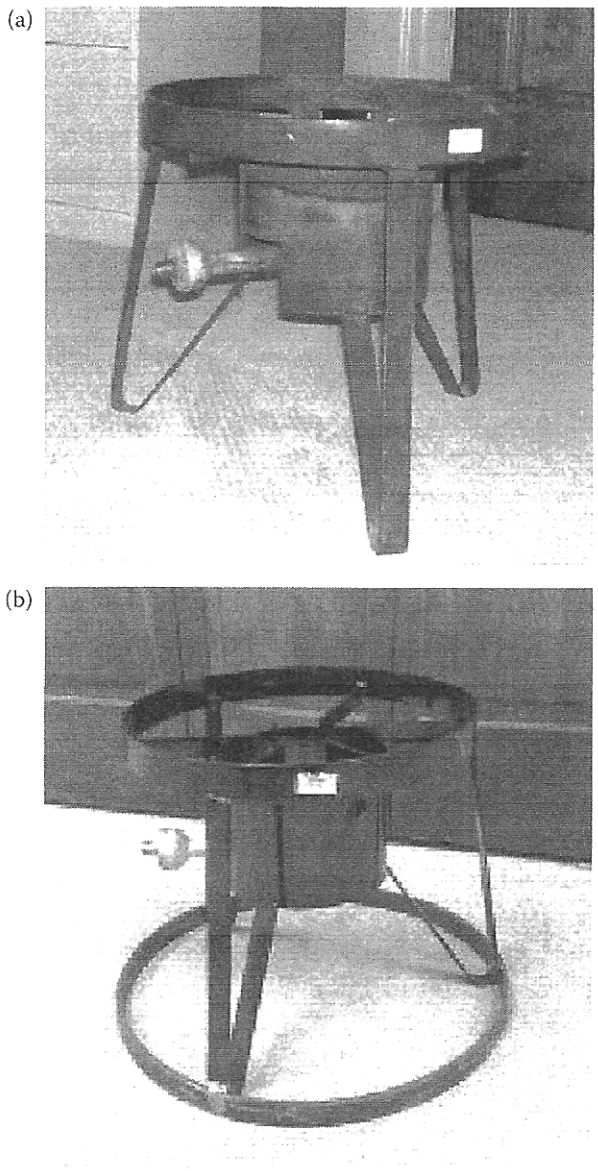

FIGURE 3.1 (a) Poultry roaster, (b) modified poultry roaster.

as the means of hazard control. Research indicates that people did not see the warning, and even if they had, they would not be able to carry out the warning due to the high cost of compliance of having to wear a wetsuit if riding as a passenger. A warning like this is not going to protect people if wetsuits are not readily available. A better solution is to design the PWC so that when a person falls off the unit, they do not end up in the path of the jets; perhaps by covering the top of the jet nozzles or shaping the back of the PWC so that people fall in directions away from the jets.

In the example above, the solution of redesigning the back of the PWC came after the warning method had been considered and used. The warning was not working. Also note that there is another related situation where a manufacturer decides, for whatever reason, not to warn. Both instances call for a recursive step, a return to consideration of design alternatives, perhaps some of which were not considered in the first round of hazard control analysis. Thus, these would be examples of cases in which the design–guard–warn hierarchy was considered but none of the methods looked promising for the various reasons already discussed in this chapter, followed by a step to relook at design alternatives and guarding methods to see if they can be accomplished, perhaps differently and in a different light given the preceding analyses.

3.6 FINAL COMMENTS

The examples of the vehicle seat recline hazard and the turkey fryer tip over hazard were presented as a context for exploring some of the issues encountered in deciding how to address product hazards. The hazard control hierarchy provides some principles and/or guidelines based on what is likely to be most effective; that is, the design, guard, and warn priority scheme. But, as indicated with the seat recline example, decisions about whether to seek solutions based on alternative design, guarding, or warning may be complex. In addition to technological and economic feasibility, there are other factors that can come into play, such as secondary safety effects and customer preferences.

Sometimes, the decision-making process may be relatively straightforward, as in the case with the turkey fryer. Clearly, it does not require a revision of Newton's laws of physics to come up with a more stable cooker by what would appear to be some simple design changes that would likely amount to only a modest increase in cost to produce the product. Certainly, in comparison to a warning that recommends a guarding solution (keep children and pets away), the design alternative that increases stability would appear to be more effective. The point, however, is not to suggest that children and pets need not be monitored around the fryer or that a warning spelling out the potential severe burn consequences of a tip over is not appropriate. These aspects are important and should be included. Rather, the point is that guarding and warnings should be viewed as a complement to better, safer design, not as a substitute for it.

A few additional comments are worthwhile at this point. Influencing human behavior is often difficult and seldom foolproof. Concerns about the reliability of warnings should not be regarded as a basis for not warning when it is appropriate to do so. Warnings are one of several tools available to product manufacturers and designers to facilitate product safety, and they have an appropriate role in the safety hierarchy.

A final comment on the complimentary aspects of the design, guard, and warn safety hierarchy is worth mentioning. The hierarchy should not be viewed as a prioritization scheme consisting of three options from which a selection can/must be made. Rather, it defines a preference scheme based on what is likely to be most effective from a safety perspective. It is not meant to imply some sort of exclusion principle; for example, if you guard (such as putting up a fence around a power station), that there is no need to warn (hang a warning sign on the fence that emphasizes danger and not to enter). Instead, the matter may be better thought of as: even with a better design, it may still be appropriate and necessary to guard or warn, or both.

Future warnings may do a better job in fulfilling their role to protect against hazards as technology allows warnings that are triggered by sensors and that display tailored warning messages. Nevertheless, alternative designs and guarding will likely remain the main means to keep hazards away from people and property.

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