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Usability Evaluation for Product Safety

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Abstract

In addition to designing for simplicity and ease of use, designing for safety should be explicitly considered when developing usable products. In this paper, we provide an overview of a rational usability evaluation process for product safety. We use risk analysis and overall product usability to prioritize safety goals for usability testing. We then develop design recommendations for improved product safety that are refined through iterative usability testing.

Introduction

The modern design process is often multidisciplinary with work on various aspects of the design proceeding concurrently. Design teams no longer work in isolation from manufacturing. Introduction of relevant factors early in the design process improves product quality and reduces development time. With the recent development of usability engineering, designers have begun to consider human factors early in the design process (Dumas and Redish, 1999; Nielson, 1993). However, focus has typically been placed on “the effectiveness, efficiency and satisfaction with which specified users can achieve goals under controlled environments” (ISO DIS 9241-11 Visual Display Terminals). User safety is seldom explicit in designers’ definitions of usability (Staton and Baber, 1996).

Nevertheless, safety is an important component of good design; an unreasonably unsafe product will not be effective, efficient, or satisfying to users. Every year there are millions of unintentional injuries associated with consumer products in the United States. The majority of these injuries are related to how products are used, rather than mechanical defects (Ayres, Gross & McCarthy, 1993). Manufacturers can address the safety of product usage through provision of appropriate instructions and safety information, as well as through design of the product itself (Ayres, Byer & Wood, 1994).

Incorporating safety concerns into the design process can be a difficult task. Designers seldom have direct knowledge of how users interact with products in various environments and may not be fully aware of potential hazards related to the use of the products and their users (Norris & Wilson, 1997; Wilson and Norris, 1993). Designers need to look beyond the question of how to deal with individual hazards in order to consider product safety in the context of overall usability. Although designers do not control the environment of usage or the ways people use a product, it is important for them to consider likely usage settings and scenarios (Chang et al., 1999). Design changes that address one hazard may introduce or exacerbate other problems, yielding no net safety benefits (e.g., Piziali, Ayres, et al., 1993).

Human factors input can help designers prevent potential hazards and ensure that subsequent products are reasonably safe for their intended users. In this paper, we propose a practical integrated approach to usability evaluation for product safety in design (see Figure 1). The methodology described here shares features with the generic approach proposed by Norris (2000) and is very similar to what has previously been described as a warning label development process (Ayres & Wood, 1995). Indeed, warning label development can be regarded as a specific example of a more general safety design process. If the "product" is viewed as everything that is made available to the user, including instructions and information as well as product hardware and/or software, then integrated product usability evaluation incorporates consideration of instructions as part of product safety and usability.

Usability Evaluation for Product Safety

The following procedure is meant to provide general guidelines rather than to prescribe an exact algorithm. It describes the full set of steps we typically recommend; in individual applications, some steps may not be necessary. We distinguish between usability *testing* (observation of product usage) and usability *evaluation* (the broader process, of which usability testing is one part).

Review Standards and Regulations

Current standards and regulations that apply to the product are gathered and reviewed. Statutory safety regulations must be followed. Advisory or voluntary product safety standards can suggest directions for safety improvement. Currently, however, no product safety standards can guarantee accident prevention.

Specific product design regulations, such as for child restraints or medicine packaging, clearly identify potential hazards and performance requirements that must be met. More general standards, however, may advance ambiguous solutions to safety concerns. Some voluntary standards, for example, state or imply that all potential hazards merit design change, providing no guidance on how to decide when a product is acceptable for production and usage.

Perform Risk Factor Analysis

User and task analyses should be performed to evaluate separate contributions of various potential factors to overall risk (Ayres, Beyer & Wood, 1994). This can involve a variety of approaches, from proposing hypothetical accident scenarios to reviewing literature on characteristics and hazards associated with the product or with similar products.

Analyze Accident Data

Past experience with a product is the best guide to how it will be used (and misused) in the future. In the case of a new product, the history of precursors or reasonably similar products can be examined.

Several usability engineers have been using accident data to gain insight into product safety (Ritzel & Donelson, 2001). Analysis of accident data, available publicly or provided by manufacturers, can provide several types of information (Ayres, Gross, Wood, McCarthy & Weiss, 1992):

Accident modes - the ways in which people are likely to be injured through use of the product and the likelihood and injury severity for each accident mode.

Accident factors - aspects of the user, product, and environment that predispose or contribute to the likelihood of accidents.

Comparative risk - the relative risk of injury per unit of usage or exposure associated with the product.

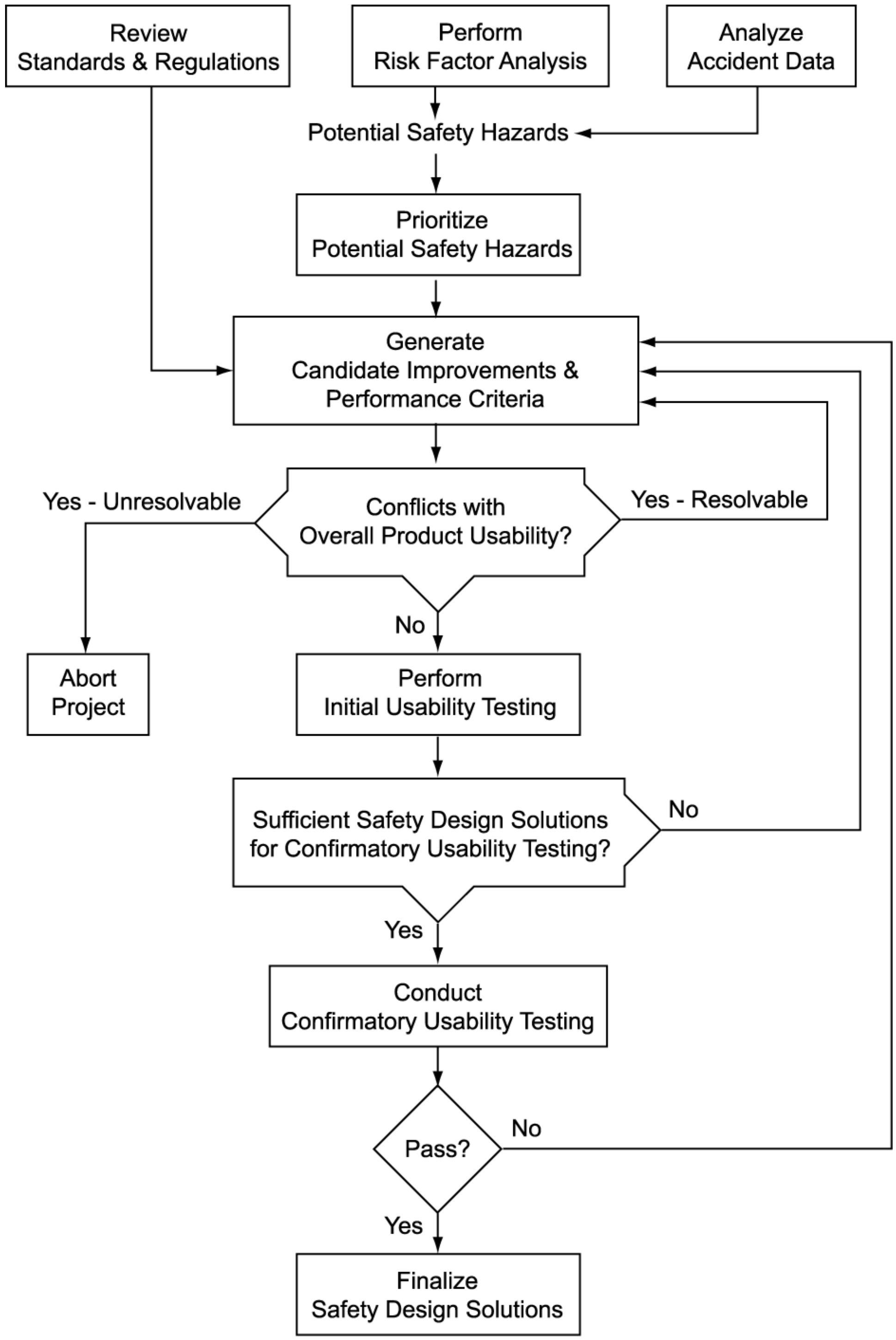

Figure 1. Usability evaluation for product safety.

Prioritize Potential Safety Hazards

It is usually impractical to incorporate design changes for every potential hazard that is identified through the review of accident data and anticipated through risk factor analysis. The list of potential hazards should be prioritized so that the most important hazards can be emphasized and addressed.

McCarthy, Ayres, Wood and Robinson (1995) have proposed that the most important criteria for prioritizing hazards are related to risk and effectiveness. The most important hazards for which to consider a safety design solution are those that are most likely to produce injuries, especially serious injuries. For each hazard, the likelihood of preventing accidents through design can be considered in the context of overall usability. The goal is to select a small set of hazards that contribute heavily to the total product-associated risk and for which design solutions have the greatest possibility of playing a useful role.

Generate Candidate Safety Improvements and Performance Criteria

With the exception of safety designs prescribed and constrained by regulations, design concepts can be developed using various techniques including voluntary standards, technical literature, focus groups, engineering analyses, and brainstorming.

Once the candidate design solutions are chosen, performance criteria can be defined so that the effectiveness of the design solutions can be quantified. This is equivalent to setting performance measurements for usability testing goals. For example, the improvement in product safety can be quantified as the reduction in the number of unsafe user interactions with the "improved" product and with the original product. In some cases, when it is difficult to prevent all hazards through design, a performance criterion can be set to include an acceptable level of risk (Norris, 2000).

Consider Conflicts with Overall Product Usability

A successful safety design solution should improve safety without substantially impairing system functionality. This step in the process reemphasizes the importance of introducing safety concerns along with other aspects of usability concerns early in the design process. Design improvements intended to reduce risk need to be considered in the balance with product utility. For example, shields designed to reduce the likelihood of needle sticks with certain catheters have been met with complaints by medical doctors because these shields make some applications (e.g. connecting a syringe for the purpose of aspiration) very difficult. The safety benefits of the shield need to be weighed carefully against the usability losses within the context of usage by skilled medical care providers.

Perform Initial Usability Testing

A goal of usability testing is to determine the extent to which proposed design changes have improved product safety while not impairing other aspects of product usability. Sufficient data can typically be obtained from small groups of users (Nielsen, 1993). Usability testing for product safety in design is an iterative process. Based on initial testing, the set of candidate design solutions can be successively refined.

Conduct Confirmatory Usability Testing

Initial usability testing should lead to one or more proposed safety design solutions, but may not be regarded as sufficiently thorough proof that the proposed safety design solutions meet the pre-determined performance criteria. For this purpose, it is appropriate to test a larger group of users who may see only a single proposed design solution. The users should match important demographic characteristics of the intended product users.

Finalize Safety Design Solutions

If the proposed design solution passes the confirmatory usability testing, then the testing can stop and a set of recommendations made to the product manufacturer. Otherwise, safety design solutions are modified or new candidate solutions are proposed and the initial usability testing cycle starts again.

Example: Passenger Car Trunks

Consider the usability of automobile trunks. Certainly trunks provide much-appreciated benefits to automobile owners. On the other hand, trunks are not absolutely safe, with injuries associated with both intended and unintended use.

In order to improve the usability of automobile trunks, with specific emphasis on improving safety, one could begin with a review of requirements in the Federal Motor Vehicle Safety Standards; there are design and performance specifications for trunks.

A risk factor analysis can generate a wide variety of possible hazards for trunks, from the obvious (e.g., closing trunk lid on one’s hand) to the occasional (e.g., losing the keys to the trunk and consequently being unable to change a flat tire in order to reach a hospital quickly in an emergency). There is extensive accident data available for review, however, so it is possible to rely more heavily on what has been shown to happen instead of on what imaginably might happen. In our review of data (from the National Electronic Injury Surveillance System, U.S. Consumer Product Safety Commission) for emergency-room-treated injuries associated with non-operating passenger vehicles, we found that thousands of injuries are reported each year in association with trunks; most of these involve injuries to arms, hands, or fingers.

Serious or fatal unintentional injuries involving automotive trunks are very rare. Recently, however, a number of fatalities have been reported involving children being trapped in trunks and exposed to high temperature. In light of these injuries, we were asked to perform human factors testing to guide design decisions to make such incidents less likely. This work is described in greater detail elsewhere (Wood et al., 1999).

A key aspect of the project was to test and improve an internal trunk release mechanism that children could use to open a locked trunk from inside. A series of designs were tested with small numbers of children (age 3-6 years) in an iterative process, with a total of 81 children voluntarily entering trunks in the course of the usability testing. Participants were not given any instructions except to try to get out. A successful design would be one that can be seen inside a dark trunk, recognized as a possible mechanism for opening the trunk, and operable by young children. A variety of lighting schemes, mechanism shapes, and operating modes were investigated. The final design recommended (based on the test results) involved a yellow, lever-style, handle illuminated by LEDs.

Conclusions

Incorporating safety in product design requires the designer to predict potential hazards, failure modes, and subsequent effects. The process described here can guide a designer through the steps of using a variety of resources – including standards and regulations, accident data, technical expertise, and test results – to enhance total product usability.

References

Ayres, T. J., & Wood, C. T. (1995). The warning label development process. *Proceedings of the Silicon Valley Ergonomics Conference & Exposition*, San Jose, May, 1995, 187-190.

Ayres, T. J., Beyer, R. R., & Wood, C. T. (1994). Applying basic principles of human factors and ergonomics. *Water Environment Federation 67th Annual Conference & Exposition*, Chicago, IL, October, 1994, 533-540.

Ayres, T., Gross, M. & McCarthy, R. (1993). A retrospective on attempts to reduce vehicular risk through operator training. In F. A. Elia, Jr. & D. W. Pyatt (Eds.), SERA-Vol. 1, S*afety Engineering and Risk Analysis*. ASME Book No. H00894-1993. Presented at the winter annual meeting of the American Society of Mechanical Engineers.

Ayres, T., Gross, M., Wood, C., McCarthy, R. & Weiss, J. (1992). Applications of risk analysis to off-road vehicles. Presented at the 1992 Society of Automotive Engineers International Off-Highway & Powerplant Congress, Milwaukee, Paper No. 921712.

Chang, P. B., Williams B. J., Santner T. J., Notz, W .I., Bartel, D. L. (1999). Robust Optimization of Total Joint Replacements Incorporating Environmental Variables. *Journal of Biomechanical Engineering*, *121*, 304-310.

Dumas, J. S., & Redish, J. C. (1999). *A Practical Guide to Usability Testing*. Portland, Oregon: Intellect Books.

Nielsen, J. (1993). *Usability Engineering*. San Francisco, CA: Morgan Kaufmann Publishers, Inc.

Norris, B. (2000). A framework for evaluating safety in design. *Proceedings of the IEA 2000/HFES 2000 Congress*, *6*, 937-940.

Norris, B. J., & Wilson, J. R. (1997). Designing Safety into Products – Making ergonomics evaluation a part of the design process. Institute for Occupational Ergonomics, University of Nottingham, October, 1997, ISBN 09522571 22.

McCarthy, R., Ayres, T., Wood, C. & Robinson, J. (1995). Risk and effectiveness criteria for using on-product warnings. *Ergonomics*, *38*(11), 2164-2175.

Piziali, R., Ayres, T., Paver, J., Fowler, G., & McCarthy, R. (1993). Investigation of the net safety impact of an occupant protection system for all-terrain vehicles. S*ociety of Automotive Engineers International Congress*, Detroit, Paper No. 930208.

Ritzel, K., & Donelson, T. H. (2001). Human factors gets cooking. *Ergonomics in Design*, *9*(1), 15-19.

Staton, N. A., & Baber, C. (1996). Factors affecting the selection of methods and techniques prior to conducting a usability evaluation. In: *Usability evaluation in industry*, Edited by P.W. Jordan, B. Thomas, B.A. Weerdmeester and I.L. McClelland, Taylor and Francis, London, pp 39-48.

Wilson, J. R., & Norris, B. J. (1993). Knowledge transfer: scattered sources to skeptical clients. *Ergonomics*, *36*(6), 677-686.

Wood, C. T., Arndt, S. R., Kelkar, R. & Lange, R. (1999). Children's use of various internal automobile trunk release mechanisms intended to reduce child entrapment risk. *Proceedings of the Human Factors and Ergonomics Society 43rd Annual Meeting*, 912-915.