Human Factors and Ergonomics in Consumer Product Design

Uses and Applications

Edited by
Waldemar Karwowski
Marcelo M. Soares
Neville A. Stanton

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Preface

Human factors and ergonomics (HF/E) is a unique and far-reaching discipline that focuses on the nature of human–artifact interactions, which are viewed from a unified perspective on science, engineering, design, technology, and management of human-compatibility systems (Karwowski 2005). The HF/E discipline promotes a holistic, human-centered approach that considers physical, cognitive, social, organizational, environmental, and other design-relevant factors. As such, HF/E aids designers by raising their awareness of the full scope of knowledge required when designing consumer products, and plays an important role in facilitating a better performance of consumer products in general. HF/E-based design of products encompasses a wide variety of consumer preferences, and accounts for differences in such preferences due to factors such as age, gender, or health issues.

Every day, we interact with thousands of consumer products. As users, we expect these products, no matter how simple or complex, to perform their expected functions in a safe, reliable, and efficient manner. Unfortunately, this is not always the case, as designing consumer products that satisfy human needs and expectations is not an easy task. The design process that involves the application of HF/E principles and knowledge strives to achieve the above goals and, at the same time, reduce the risk of product malfunction or failure, reduce the potential for accidents, and contribute to overall product acceptance and utility, all while reducing the total product life cycle cost.

The goal of the human-centered design paradigm as applied to consumer products is to improve levels of user satisfaction, efficiency of use, increase comfort, and assure safety under normal use as well as foreseeable misuse of the product. It is in this context that we are very pleased to present the second volume of the *Handbook of Human Factors and Ergonomics in Consumer Product Design*. The motivation to produce this *Handbook* was to facilitate wider acceptance of HF/E as an effective body of knowledge for improving quality of life and safety for millions of users of consumer products with a variety of needs and expectations. In this *Handbook*, consumer products are defined as those goods used by the general public without any special training, skills, or supervision. Consumers are individuals of any age, gender, or physical condition with varying educational, cultural, and economic backgrounds. The consumer products are usually used in or around the home, in a social setting, rather than in a workplace environment with commercial needs.

Currently, there is substantial and convincing evidence that the application of HF/E knowledge can improve critical product features. These features include: ease of use, learning, efficiency, comfort, safety, and adaptability, all of which meet the needs and contribute to consumer satisfaction. Therefore, this *Handbook* aims to offer a comprehensive review of the HF/E state of the art relevant to design, development, testing, evaluation, usability, and use of consumer products. The *Handbook* also aims to provide a comprehensive source of information regarding new methods, techniques, and software applications for consumer product design.

The second volume, *Human Factors and Ergonomics in Consumer Product Design*: *Uses and Applications*, contains 29 chapters divided into three sections. Section I contains seven chapters that discuss challenges and opportunities in the design for product safety. Among other topics, these chapters consider such issues as consumer risks and hazards and tools for their assessment, accident analysis, user welfare, design of consumer product warnings, design of technology for safe patient handling, and ergonomics of consumer packaging. Section II, which contains eight chapters, focuses on the critical aspects of human-centered design for usability. The chapters in this section discuss user perspective on design, user empathy, and other aspects of user research, as well as assessment and testing of the usability of various systems, consumer e-health, and the organizational context of design.

Section III contains 14 carefully selected case studies of human-centered design. These chapters involve the discussion of the analysis, design, and development of a media player, mobile phones, headgear, supermarket checkout, an interactive kiosk, self-assembling products, office chairs, school furniture, and personal hygiene products. The presented case studies include application of a variety of innovative approaches that incorporate HF/E principles, standards, and best practices of user-centered design, cognitive psychology, participatory macro-ergonomics, and mathematical modeling. These chapters also identify many unique aspects of new product development projects, which have adopted a user-centered design paradigm as a way to attend to user requirements.

We hope that this second volume will also be useful to a large number of professionals, students, and practitioners who strive to incorporate HF/E principles and knowledge in the design of consumer products in a variety of applications. As was the case with the first volume of the *Handbook*, we hope that the knowledge presented in this volume will ultimately lead to an increased appreciation of the benefits of the HF/E discipline by ordinary consumers of the myriad of products used every day, and increase the HF/E literacy (Karwowski 2007) of citizens around the world.

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Editors

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Neville A. Stanton, PhD, was appointed chairman in human factors in the School of Civil Engineering and the Environment at the University of Southampton in February 2009. Prior to that, he held a chair in human factors at Brunel University (since September 1999). Previously, he held a lectureship and then readership in engineering psychology at the University of Southampton (since September 1993). Professor Stanton was also a visiting fellow at Cornell University during 1998. He has published over 140 peer-reviewed journal papers (including papers in *Nature* and *New Scientist*) and 18 books on human factors and ergonomics. In 1998, he was awarded the Institution of Electrical Engineers Divisional Premium Award for a co-authored paper on engineering psychology and system safety. The Ergonomics Society awarded him the Otto Edholm medal in 2001 and the President's Medal in 2008 for his contribution to basic and applied ergonomics research. In 2007, The Royal Aeronautical Society awarded him the Hodgson Medal and Bronze Award with colleagues for their work on flight-deck safety. He also acted as an expert witness for Network

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Section I

Design for Product Safety

1 Reducing the Risk to Consumers: Implications for Designing Safe Consumer Products

Damien J. Williams and Jan M. Noyes

CONTENTS

1.1 INTRODUCTION

The term "consumer product" refers to a wide variety of products (Hedge 2001), ranging from relatively simple products (e.g., cigarette lighters, washing-up liquid, and cosmetics) through to "white goods" (e.g., toasters, refrigerators, and washing machines) and "brown goods" (e.g., televisions, DVD players, and camcorders), to more complex technologies (e.g., aircraft and cars). In general, these products serve to protect, support, and/or replace particular activities, or extend consumer capabilities (Kanis 1998) and ultimately improve quality of life. While consumer products usually have very specific purposes or functions (Bonner 2001), they may also be used in unintended ways (i.e., the intended use of washing-up liquid is to wash dishes, but it is often used as a general cleaner; van Veen, van Engelen, and van Raaij 2001), which can result in an increased risk of injury or death. Indeed, each year, millions of injuries and thousands of fatalities can be attributed to consumer products (Rider et al. 2000; Gagg 2005). For instance, Baber and Mirza (1997) identified the small but significant risk that white goods pose to users. Consequently, while consumer product designers must strive for usability, given the importance of product design in consumer safety (Gagg 2005) and the expectation among consumers with regard to the safety of the diverse range of products they encounter daily (van Duijne, Kanis, and Green 2002), there is also a need to minimize as far as possible any hazards or risks (Benedyk and Minister 1997) and to produce safe products.

An accident resulting from an inadequately designed consumer product could have far-reaching implications. First, and most importantly, it can have an impact on the consumer directly (physical, psychological, financial harm). Second, it can have an indirect impact on the manufacturer. For instance, the recall of a product that is labeled “unsafe” may damage the manufacturer’s reputation. As an example, on June 22, 2010, the Trading Standards Institute announced the recall of the 8-Sheet Diamond Cut Shredder purchased from Asda as a result of a potential safety issue identified in testing, which showed “there may be a fault in the plug that could cause an electric shock” (see http://www.tradingstandards.gov.uk/advice/advice-recall-list.cfm). Further, on June 24, 2010, following 47 reports of incidents/injuries (including a child who was found unconscious, eight reports of scratches and bruises, and one child who sustained a broken collarbone), the Consumer Product Safety Commission in cooperation with Jardine Enterprise Ltd. announced the recall of various models of drop-side cribs due to entrapment, suffocation, and fall hazards (see http://www.cpsc.gov/cpscpub/prerel/prhtml10/10275.html). These events can also have financial implications through lost income, criminal prosecution, or a (successful) product liability claim (Page 1997). Therefore, not only is there a moral requirement to assess the safety and safe usage of consumer products, but it is also in the best interests of the designers and manufacturers to undertake a process that reduces the occurrence of accidents involving products.

The aim of the current chapter is to identify how a consideration of the risk posed to consumers through consumer product use can be achieved and subsequently applied to the design of consumer products. To begin, the importance of risk in human behavior is identified; however, the way in which risk is conceptualized in the design process can influence how risk is approached and, ultimately, the designers understanding of the risk(s) faced by the consumer. Consequently, the issue of risk conceptualization (objective vs. subjective) will be addressed, followed by ways in which these different views of risk can be investigated in order to inform consumer product design (objective: accident statistics and exposure estimates vs. subjective: psychometric approach and usage-centered approach). These methodologies will then be considered within the typical approach to safety design (a hazard control hierarchy) and finally some possible barriers (risk transference and risk compensation) to the implementation of safety measures in consumer product design will be discussed.

1.2 RISK AND BEHAVIOR

Accidents involving consumer products are often attributed directly to consumer’s risky behaviour (Ryan 1987). The perception of risk plays an important role in decision making and subsequent behavior (Williams 2007a): those who make erroneous assessments of risk are also likely to make sub-optimal decisions, which could lead to unsafe behavior and human error (Rundmo 2001). Such behavior may be initiated through inaccurate assessments of risk based on ineffective product design (i.e., physical characteristics and accompanying information and warnings); however, it is argued that when undertaking routine tasks (e.g., the use of consumer products), people may not worry about risks, nor even think about them (Wagenaar 1992). Consequently, under these circumstances, accidents may not be attributable to the (mis)perception of risk (Wagenaar 1992). Even from this perspective, given the number of accidents associated with consumer product use, it becomes evident that consumer product design plays an important role (Gagg 2005). Moreover, an understanding of risk perception is considered relevant to safety design as it *may* affect behavior, which can influence the likelihood of an accident (Rundmo 1996).

While an understanding of the risks faced by consumers (be they real or perceived or indeed, if they are raised to a level of conscious awareness at all) would facilitate the implementation of safety measures and mitigate the risk to which the consumer was exposed, the way in which risk is conceptualized during design could influence the understanding of the potential risk faced by the consumer. The following section will briefly discuss the issues surrounding conceptualization of risk and identify the implications for consumer product design.

1.2.1 Conceptualization of Risk

A sharp distinction has been made between experts (i.e., risk assessors) and non-experts in terms of what constitutes a risk (Williams 2006). The traditional approach to the conceptualization of risk, particularly in scientific risk analysis, is to define risk as quantifiable and objective (Naoe 2008)—a mathematical value (Barki, Rivard, and Talbot 1993; Hoegberg 1998)—known as the probabilistic approach. With reference to consumer products, risk (of injury) is typically represented as a ratio between an accident or injury rate and a measure of exposure (Weegels and Kanis 2000). It is believed that these probabilistic risk assessments are based on "real risks" characterized as objective, analytic and rational, whereas anyone who does not subscribe to this approach is said to have an erroneous "risk perception" that is, it is subjective, hypothetical, emotional and irrational assessments of risk by Slovic (2007).

In questioning the suitability of the concept of real risk, Hansson (2005) identified seven pertinent myths:

1. Risk must have a single, well-defined meaning.
2. The severity of risks should be judged according to the probability-weighted averages of the severity of their outcomes.
3. Decisions on risk should be made by weighing total risks against total benefits.
4. Decisions on risk should be taken by experts rather than laymen (*sic*).
5. Risk-reducing measures in all sectors of society should be decided according to the same standards.
6. Risk assessments should be based only on well-established scientific facts.
7. If there is a serious risk, then scientists will find it if they look for it.

Indeed, a number of limitations have been identified with the probabilistic concept of real risk. First, the value derived by an expert merely considers past events (Rehmann-Sutter 1998); thus, a risk with a small probability gives no assurance that a statistically low event will not happen in the near future. With regard to accidents involving consumer products, Hayward (1996) indicated that there are not enough fatalities, for example, to deliver a reliable measure of risk. Secondly, not only is there a large degree of variation between experts' judgments of the same risk (Brehmer 1994), probabilistic risk assessments often differ from actual frequencies by at least two orders of magnitude (Shrader-Frechette 1991). Thirdly, the probabilistic view typically defines the physical impact, which neglects other important consequences (i.e., financial, psychological, and social) and issues that are not easily quantifiable (e.g., human element in exposure rate and human error). Finally, real risk neglects the large number of factors that influence those individuals facing the risks (Rehmann-Sutter 1998; Bohnenblust and Slovic 1998). Consequently, there would appear to be two limitations associated with a reliance on objective risk: (1) the degree of uncertainty with regard to the reliability of its use; and (2) the apparent neglect of a number of factors that are important in enabling a complete understanding of risk.

A large body of research from the psychometric paradigm, largely initiated by the seminal paper by Fischhoff et al. (1978), has demonstrated the complex, value-laden nature (Cross 1992) of non-experts' view of risk (see also Morgan et al. 1985; Kraus and Slovic 1988; Mullett et al. 1993; Sjöberg and Torell 1993). Through the use of factor analytic techniques, a number of underlying factors of risk have been identified (e.g., voluntariness, timelessness, knowledge about the risk, controllability, newness, catastrophic consequence, and dread). These factors have been grouped into four dimensions:

1. "Dread risk," which includes "perceived lack of control, dread, catastrophic potential, fatal consequence, and the inequitable distribution of risks and benefits" (Slovic 1987, 283).
2. "Unknown risks," which are "unobservable, unknown, new, and delayed in their manifestation of harm" (Slovic 1987, 283).

3. The number of people exposed to a given risk.
4. "Unnatural and immoral risk," which includes notions of tampering with nature and moral issues (Sjöberg 2000).

Despite the apparent limitations of the psychometric paradigm (see Millstein and Halpern-Felsher 2002 for a discussion) such findings provide the beginnings of a psychological classification system for risks (Slovic, Fischhoff, and Lichtenstein 1984) that may help improve our understanding of what constitutes a risk (Williams 2006) from the perspective of the consumer.

Hence, in order to develop safe consumer products, it is essential that designers and manufacturers recognize the complexity of the consumer, because even if they could calculate accurately the (objective) risk involved, it is their subjective perceptions that motivates behavior (Mitchell 1999). This is not meant to imply that probabilities are not important, but rather to indicate that numerous other subjective factors, beyond the objective scientific measures associated with risk of injury, are fundamentally important to the consumer's conceptualization of risk and subsequent behavior. Bernstein (1998) noted that risk-averse choices are based on a consideration of consequences without regard to the probability, while "foolhardy" choices are based solely on probability without regard to the consequences. Hence, any consideration of risk in the design process should necessarily incorporate the two elements of probability and consequence (Bernstein 1998) that correspond to the different ways in which risk is conceptualized; as a synonym for danger or threat (subjective risk) or a statistical value (objective risk) (Oppe 1988).

1.2.2 Risk in Consumer Products

1.2.2.1 Objective Risk

There are two primary ways in which the risk to consumers can be identified through objective methods—analysis of accident statistics and estimates of exposure. Each will be dealt with in turn.

1.2.2.1.1 Accident Statistics

One approach to identify the risk associated with consumer products is through the review of accident statistics. Such data are often held to be a key element in risk assessments (Rider et al. 2000). Three recent papers will be considered that report analyses of accident statistics and the implications for the design of safe consumer products.

1. Eye injuries—A broad range of consumer products are a significant cause of eye injuries. Recently, McGwin and colleagues utilized data from the Consumer Product Safety Commission's (CPSC) National Electronic Injury Surveillance System to identify all consumer product-related eye injuries in children (aged under 12 years) between 1997 and 2006 (Moren Cross et al. 2008) and adults between 1998 and 2002 (McGwin et al. 2006). There were apparent differences between the sexes and across the age spectrum in both studies. Nonetheless, the top 10 products among children were: sports equipment, household cleaning chemicals, toys, furniture, desk supplies, "other" chemicals and compounds, swimming pools and related equipment, toy guns, tools/hardware, and lawn and garden equipment. In adults, the top 10 products were: welding equipment, household cleaners, basketball (activity, clothing, or equipment), workshop/grinders/buffers/polishers, saws, adhesives, lawn mowers, bleaches, hair brushes/combs/curlers, and (ironically) eye protection devices. Moren Cross et al. note that the findings provide guidance concerning which categories of consumer product should be the target of preventative measures; however, McGwin et al. noted that many factors play a role in the occurrence of eye injuries, including the product's inherent risk to cause injury, behaviors to minimize the risks, and the frequency with which a product is used, which are not available when considering accident statistics. Indeed, while analysis of the accident statistics identifies the clear need for

manufacturers to add or strengthen safety measures (i.e., warnings, safety guards, etc.) in order to minimize the potential for eye injury, it does not provide any specific information to indicate what measure(s) should be used or how to implement them.

2. Scooter injuries—In recent times there has been an increase in injuries related to the use of unpowered scooters in the United States. Parker, O'Shea, and Simon (2004) reviewed 469 unpowered scooter-related injury reports compiled by the CPSC between January 1995 and June 2001. Most of the injuries were found to occur in older children and young adolescents; however, there were instances of injury in young children and adults. A broad spectrum of injuries was reported with the most frequent injuries including lacerations (26%), fractures (22%), and contusions (16%). Of these injuries, 24 (5.1%) required hospitalization and 15 were fatal. These findings led the authors to conclude that there was a need for improved safety awareness, with a particular emphasis on the use of protective equipment. Once again, however, no specific recommendations (i.e., content of safety awareness campaigns, or the type of protective equipment to be used) could be made for reducing the risk of injury posed by the use of unpowered scooters based solely on a consideration of the accident statistics.
3. Baby walker injuries—In response to the high number of baby walker injuries treated in U.S. hospital emergency departments associated with falls down stairs, the CPSC worked with industry to develop a voluntary standard to address the stair-fall risk. In order to evaluate the effectiveness of this standard, Rodgers and Leland (2008) conducted a thorough analysis of annual baby walker emergency department injury rates between 1981 and 2005. It was found that the requirements in the standard introduced in 1997 reduced the baby walker injury rate by approximately 60%, and the stair-fall injury rate by as much as 75%–80%. Moreover, a cost-benefit analysis indicated that the standard resulted in an overall benefit of $173 per walker, as a result of the reductions in the costs of injuries. While the study clearly demonstrates the success of the standard, which resulted in a relatively simple, effective, and inexpensive product modification, in terms of substantially reducing the risk of stair-fall injuries (Rodgers and Leland 2008), there were still a large number of injuries attributable to baby walkers and specifically stair falls for which the standard did not address. Moreover, there was no means of identifying the cause of the remaining accidents, and hence, the steps required to further reduce this risk.

The three examples reported here demonstrate the utility of accident statistics in evaluating the effectiveness of the real-world implementation of safety measures and the identification of risks in product use (van Duijne, Kanis, and Green 2002) albeit after accidents/incidents have occurred. Thus, the data can provide warnings about the presence of previously unidentified risks (van der Sman, Rider, and Chen 2007) and the need for intervention in order to improve the safety of products; however, there are a number of limitations in terms of possible safety recommendations based on accident statistics. First, the studies only report injuries treated in hospitals, which neglects those injuries treated in other settings, thereby potentially underestimating the risk associated with some products (Moren Cross et al. 2008). Secondly, it is not always possible to specify the cause of the accident or to locate the precise details about the accident (see van Duijne, Kanis, and Green 2002), which means that recommendations for interventions are very broad (i.e., safety awareness). For instance, one of the safety recommendations made by McGwin et al. (2006) was the use of eye protection while using certain consumer products; however, they found that eye protection devices were a significant cause of eye injuries. Consequently, a more detailed follow-up analysis is required following the identification of risk to consumers through accident statistics. Finally, the very nature of accident statistics means that accidents/incidents have already occurred, thereby requiring a reactive approach to "fix" the problem. What is required is a preventative approach that would reduce the risk of an event occurring in the first place.

1.2.2.1.2 Exposure Estimates

Exposure to the risk posed by consumer products is an issue that consumers can readily control; they can choose whether to allow the product into their home, how/where it is stored, and how/where/when it is used (Girman, Hogdson, and Wind 1987). Nonetheless, as outlined earlier, an important step in any (objective) risk analysis is the quantification of exposure to a given product (van Leeuwen and Hermans 1995; Hayward 1996). Hayward illustrated this through an investigation of 76 consumer products (kitchen, do-it-yourself, and household appliances) that were known from accident data to be involved in a high number of accidents. The overall measure of risk adopted for this study was the number of hospital-treated injuries per hour that the product was in use (number-of-injuries-per-hour-of-use). A number of limitations were identified with this approach. First, it is difficult to generate a parameter that accounts for injury severity (i.e., fatal or varying degrees of non-fatal injuries). Secondly, in this instance, the measure of exposure was calculated by multiplying the number of occasions per year on which the product was used and how long the product was used on the most recent occasion. Consequently, this is reliant on the most recent use of the product being representative of the general use of the product. Further, it may not be possible to pinpoint exactly the duration of use. For instance, the task of vacuuming may be broken down and spread across an entire day. Finally, given the importance of the (intended and unintended) actual use of consumer products in determining risk of injury, such a simple model does not account for additional factors that influence the risk associated with a product.

A large variety of everyday consumer products expose the consumer to various chemicals (e.g., textiles, televisions, computer equipment, and cosmetics) (Peters 2003). Sanderson et al. (2006) identify three routes by which contact with chemicals can occur as a result of intended and unintended usage, including: inhalation following emission into the air, dermal contact through spillage, and oral contact as a result of mouthing and subsequent ingestion (see also Steenbekkers 2001). Indeed, information about chemical constituents and exposure data play an important role in risk reduction (Steinemann 2009). Consequently, in order to ensure the safety of these products, risk assessments need to consider both the intrinsic hazard of constituents (Loretz et al. 2005) as well as exposure levels (i.e., concentrations) and the dose (i.e., milligram per day or milligram per kilogram per day) of any chemical that could potentially reach humans (van Leeuwen and Hermans 1995); however, Steinemann (2009) found that there is relatively little information available on the chemical constituents of many products, particularly fragranced consumer products (e.g., air fresheners, laundry supplies, personal care products, and cleaners). In addition to a consideration of the type of product and the emission and distribution of the chemicals, an exposure assessment should also take into account the influence of human behavior on contact with the chemicals (Lioy 1990; van Veen 1996). Indeed, it has been acknowledged that the consideration of consumer behavior is as important in exposure assessments as measures of exposure concentrations and the type of product (Weegels and van Veen 2001; Steenbekkers 2001).

One group of consumer products that rely on reliable exposure information in risk assessment includes cosmetic and personal care products (see Loretz et al. 2005, 2006, 2008). Indeed, millions of consumers use cosmetic and personal care products on a daily basis and human systemic exposure to their ingredients can rarely be prevented (Nohynek et al. 2010). A number of techniques have been employed to generate product exposure data (most usefully, the amount of product applied, and the frequency of use) to assess consumer use practices that would be useful in safety assessment. One method is the completion of detailed diaries of usage. For instance, Loretz and colleagues required participants to keep diaries recording detailed daily usage information over a period of 2 weeks for widely used cosmetic products (facial cleanser, hair conditioner, and eye shadow; see Loretz et al. 2008) and personal care products (spray perfume, hairspray, liquid foundation, shampoo, body wash, solid antiperspirant; see Loretz et al. 2006). In addition, the products were weighed at the start and on completion of the study in order to determine the total amount of product used. Nevertheless, this approach is somewhat limited in terms of generating a valid view of behavior as people do not always accurately or honestly report their behavior. By contrast, Weegels and van Veen (2001) utilized diaries, in-home observations, and direct measurements to study exposure to chemicals in a number of consumer products (dishwashing detergents, cleaning products, and hairstyling products). The mixed methods approach enabled an investigation of the type of actual contact, duration, frequency, and amount of use, and provided a clearer understanding of product usage.

In general, these and other similar studies (e.g., Weegels 1997; Riley et al. 2001; Loretz et al. 2005) have identified a large intra- and inter-individual variation in the use of the products; however, there was also evidence that people had developed a particular routine in the use of some products. Nonetheless, Weegels and van Veen (2001) concluded that by utilizing a number of different methods of data collection, they were able to get a more valid insight into product usage and therefore consumer exposure (see also Steenbekkers 2001). For instance, they noted that diary accounts were useful in collecting coarser information (i.e., frequency, duration, purpose, and amount of products used), while observations and home visits enable the collection of finer information (i.e., specific information regarding product use, and the specific measurements regarding amount used and duration). While the use of observational data enables a more valid account of product usage than the diary method, the behavior displayed may still differ from "real-world" behavior (see Garland and Noyes [2006] for a critique of the use of observation as a research methodology). Consequently, no matter what method is utilized, there may be a degree of inescapable uncertainty regarding the validity of the resulting data.

Due to the paucity of direct exposure data, such information is often estimated from mathematical models that describe the emission and distribution process and exposure factors (e.g., product use), which can provide a basis for conducting risk assessments (McNamara et al. 2007; van Veen, van Engelen, and van Raaij 2001; van Veen 1996; Riley et al. 2001; Matoba and van Veen 2005; van Veen et al. 1999). For instance, McNamara et al. developed a predictive model of European exposure to seven cosmetic products (body lotion, shampoo, deodorant spray, deodorant non-spray, facial moisturizer, lipstick, and toothpaste) by analyzing the usage profile (generated from market information databases and a controlled product use study) of frequency of use and amount of product used for a large European sample (44,100 households and 18,057 habitual users, comprising males and females). While such models are more complex than the one used by Hayward, in terms of accounting for user behavior and other compensatory actions, there are still issues with the calculation of the necessary parameters. For instance, while the emission and distribution process can be constant for a given product, exposure factors can be highly variable. In addition to the intra- and inter-individual variability in product use, other factors, including compensatory actions such as room ventilation, cannot be considered constant (either in terms of duration of use, positioning, or the power of the equipment). With regard to the intra- and inter-individual variation in product usage, Weegels and van Veen (2001) suggested that the quantification of this variability could be used to define "worst-case" or more extreme uses of a product for use in exposure assessments. Nonetheless, the lack of consideration of the variability in behavior represents a simplified view of exposure. Thus, risk assessment is still in search of methods, data, and models that can ultimately account for the large variability in human behavior (van Veen, van Engelen, and van Raaij 2001).

Deriving precise measures of exposure is a difficult task because the process is different for the various types of consumer products and because of the number of factors that influence exposure. In particular, the general lack of information with regard to actual product use severely hampers exposure estimation for consumer products (Weegels and van Veen 2001). Moreover, there appears to be a general lack of consideration for the variability in the parameters used to calculate exposure (i.e., duration of use, nature of use, injury severity, compensatory actions [ventilation], etc.). This creates a simplified view of the risk associated with a product, often at the level of worst-case scenario or the more extreme end of the usage spectrum.

1.2.2.2 Subjective Risk

Consumer behavior with a given product is determined largely by their perceptions of the risks associated with that product (Young, Brelsford, and Wogalter 1990; Wogalter, Desaulniers, and Brelsford 1986, 1987). Thus, safety solutions may fail if they do not take into account the perceptions and attitudes of those affected (Williamson et al. 1997). Furthermore, the possibility that consumers may incorrectly perceive the level of risk associated with a given product highlights the importance of understanding the perceived riskiness of the product (see Slovic, Fischhoff, and Lichtenstein 1979; Brems 1986). For instance, if a consumer perceives a lower degree of risk than is actually present in a given product, this could lead them unwittingly to act in an inappropriate/unsafe manner. Consequently, steps need to be taken during product design in order to overcome such misperceptions. Two general approaches exist to the study of risk perception associated with consumer products—the psychometric approach and the usage-centered approach. These will be dealt with in turn.

1.2.2.2.1 Psychometric Approach

Empirical research into risk perception of consumer products has largely been undertaken through a psychometric approach, which attempts to uncover the underlying components that influence product risk/hazard perceptions through the analysis of the outcomes (often made on a Likert scale) of a variety of questions using a number of statistical techniques (e.g., regression analysis, factor analysis, principal component analysis, analysis of variance, and correlation analysis). For instance, early work by Slovic, Fischhoff, and Lichtenstein (1979) demonstrated that while a small but measurable subjective component of risk influenced perceptions of risk, the objective component ultimately determined people's perceptions of risk associated with various products and activities. By contrast, Wogalter, Desaulniers, and Brelsford (1986) revealed that the subjective component (in particular severity of injury) played the primary role in shaping people's perceptions of risk. Similarly, Young and Wogalter (1998) showed that injury severity information accounted for the greatest proportion (78%) of the variance in perceived hazard.

Despite the apparent contradictions in the research findings reported in the literature, a number of studies have suggested that both objective and subjective risk components may influence perceptions of risk. For instance, Vaubel and Young (1992) examined the underlying dimensions associated with perceived risk for 40 consumer products (e.g., hair dryers, lighter fluid, whirlpool/hot tubs, and bicycles). Analysis of participant responses to 17 questions for each product, using principal component analysis, revealed that both subjective (i.e., degree to which potential risks were known and the immediacy of their onset) and objective (i.e., magnitude of the potential harm) aspects of risk play a role in risk perception, along with the person's familiarity with the product. Indeed, the relationship between familiarity and perceived hazardousness has been found previously (Godfrey et al. 1983; Godfrey and Laughery 1984; Wogalter, Desaulniers, and Brelsford 1986); however, it is highlighted that the relationship is more complex than intuition might suggest. Furthermore, Vaubel and Young found that each component was significantly related to participants' ratings of intention to act cautiously with a product.

The extent to which the outcomes from the psychometric approach can inform consumer product design has been questioned. For instance, it is argued that the psychometric approach is only suitable for uncovering opinions on risk as the analysis of questionnaire responses provides a very restricted interpretation of people's risk perception (van Duijne, Green, and Kanis 2001; Weegels and Kanis 2000). Hayward (1996) noted that perceptions of danger are an unreliable guide to the actual risk of injury associated with a product as it is driven by an over-reliance on characteristics of the products (i.e., the sharpness or power of the products) rather than on an assessment of the type of situations that can arise during product use, and the likelihood of occurrence. Consequently, it could be argued that the outcomes of the psychometric approach offer little in the way of usable information to support the design of safe consumer products as it does not enable any insight into risk perception associated with actual product usage.

Although the limitations identified with the psychometric approach are valid, it must be noted that none of the researchers have suggested that the outcomes of the psychometric approach could be informative for actual product design. Rather, the implications of the findings have often been directed at enabling an understanding of consumer perception of product risks in order to provide insight into the type of information that might be useful in the design and provision of warnings. Indeed, warnings that communicate appropriate and inappropriate product usage through labels and instruction manuals are a common approach to communicating risk information (Lesch 2005, 2006; Hancock, Fisk, and Rogers 2005) and improving safety (Hedge 2001). There is, however, evidence that warnings (and other product information) are not often noticed (see Trommelen 1997; Trommelen and Akerboom 1994) or understood by consumers (Hancock, Fisk, and Rogers 2005) or are ineffective (lack of appropriate information; Presgrave et al. 2008). Wogalter (2006a, 4) highlights the fundamental role of adequately designed warnings in the design process, stating that: "if a warning is absent or defective, then the product may be considered defective." Consequently, in instances where warnings are deemed necessary, it is not sufficient simply to provide a warning; it must be meaningful and communicate the correct information (Williams 2007b). Indeed, there is substantial human factors literature on the issues surrounding the provision of salient, well-designed warnings that attract attention and convey the appropriate risk information (Williams and Noyes 2007; Wogalter 2006b; Rogers, Lamson, and Rousseau 2000; Edworthy and Adams 1996; Wogalter, Dejoy, and Laughery 1999; Laughery, Wogalter, and Young 1994; Wogalter, Young, and Laughery 2001), which has a role in reducing the risk to users of consumer products.

1.2.2.2.2 Usage-Centered Approach

In consumer product use, numerous factors influence the consumer's perception of risk. In order to gain insight into the process of risk perception associated with consumer products, and provide designers with information that will assist in the development of safe products, it is necessary to consider the interaction of the consumer and the product. Kanis (1998) referred to this as usage-centered design.

One area of particular interest in product safety is the influence of featural and functional characteristics of a product on the way it is used (Weegels and Kanis 2000; van Duijne, Green, and Kanis 2001; Norman 1988; Laughery 1993). This relates to the concept of an open and obvious risk in which the design or function of a product communicates the risk (Laughery 1993). For instance, the teeth of a hand saw conveys the risk of injury through being cut, and the red glow emitted by a cooker hob when in use conveys the risk of being burnt; however, Laughery notes that numerous products do not convey such information and the risks faced by consumers are hidden (whether it is in the actual design or in the ineffective warning labels or instruction manuals). In such cases, consumers may not take proper precautions when using the product, which will increase the risk of injury (Williams, Kalsher, and Laughery 2006). For instance, Weegels and Kanis (2000) cite an example of an accident involving a metallic wastepaper basket. It was reported that the rim of the basket did not feel sharp, but when a user moved their hand along the rim while emptying the basket, they sustained a deep cut. It was concluded that the user might have emptied the basket in another way, had the risk posed by the rim not been hidden. Consequently, as usability problems can evoke unsafe situations (van Duijne et al. 2007), the investigation of the relationship between user activities and featural and functional product characteristics can reveal the role of risk perception in consumer product use. This will subsequently enable the identification of focal points for consideration in the design of safe consumer products (Kanis 2002).

A study by Weegels and Kanis (2000) utilized in-depth interviews with victims of consumer product accidents (involving kitchen utensils, do-it-yourself products and personal care items) and accident reconstructions in order to provide information about the risks perceived by users during product use. A number of interesting issues were identified. First, the majority of participants were simply unaware of the risk that had contributed to the accident. Secondly, product features did not adequately reflect the product's actual condition, which led participants to believe that there was no risk involved in the use of the product. Weegels and Kanis noted that these findings identify the influential role that featural and functional characteristics can have on consumer product use and consumer safety; however, they note that only those people involved in accidents with consumer products participated in the study, which limits the understanding of how the product is used by different people, such as those not involved in accidents. Further, the findings were based on interviews and accident reconstructions carried out a number of days after the actual accident. Consequently, participants could have simply forgotten some important details about the accident or they may have been selective in what they told the interviewer or fabricated information (i.e., false memories, Loftus and Pickrell [1995]; see Mazzoni and Vannucci [2007] for a review of the factors that can influence the recollection of autobiographical memories) so as not to appear to have caused the accident through their own negligence or stupidity. Thus, while the methods employed could provide insight into the role of risk in product use and the causes of accidents, there is a strong possibility that some relevant material was missed.

An alternative approach employs a common tool in consumer product evaluation—user trialing (Baber and Mirza 1997). This enables the identification of the variation in the actual usage of a given product by potential consumers (Kanis and Vermeeren 1996). For instance, in a study by van Duijne, Kanis, and Green (2002), observations of the use of a chip pan and a food blender were compared to the accident statistics for each of the products. In general, there was a degree of similarity between the two sources of information; however, it was noted that as a result of the necessary interpretation of the circumstances of the accidents, the descriptions from observed usage appeared to be more consistent with potential consumer actions. Furthermore, user trialing was able to show how risk perceptions were related to product characteristics. For instance, it was reported that when using the food blender, participants were aware of the risk of hot food being ejected at speed, but overlooked the more serious risk associated with putting their hand into the blender to remove food from the blades.

In an earlier study by van Duijne, Green, and Kanis (2001), participants were observed (video-recorded) and subsequently interviewed about the use of a number of common do-it-yourself products (hand saw, a chisel and hammer, an electric drill, and a screwdriver) while making a halving joint. This combination of observed product use and participants' previous experience provided interesting insights into how participants' perceived and evaluated risk when using the tools. First, it was noted that risk perception was difficult to observe in tool usage; it was suggested that this may be because the risk did not reach conscious awareness. Secondly, it was inferred through participants' personal experience that there was acceptance of a degree of risk and the occurrence of minor injuries.

The studies reported here (van Duijne, Green, and Kanis 2001; van Duijne, Kanis, and Green 2002; see also van Duijne et al. 2008) identified the same two issues: first, most participants were unaware of the risks posed by the products; secondly, safety was not necessarily the primary motivator in the use of the products, rather that most user actions were guided by the products afforded "ease of use" and the goals of the task. Consequently, in order to reduce the occurrence of even minor injuries, it is necessary to make the risks associated with a given product open and obvious, through either the provision of appropriate warnings or appropriate use cues (Kanis, Rooden, and Green 2000). For instance, van Duijne et al. (2008, 118) conclude that "by emphasising the characteristics of a product that trigger a perception of risk, users may become more alert to risk in usage."

In conclusion, knowledge about actual consumer activities is a useful aid in the (re)design of safe products and the prevention of accidents (see van Duijne et al. 2007). Indeed, a usage-centered approach enables a consideration of the effect of (potential) consumers' perceptions and evaluations of risk on product use (van Duijne et al. 2008). Further, such an approach can be undertaken during the design process (see McRoberts 2005) using related products, models, or prototypes (van Duijne, Kanis, and Green 2002). The knowledge gained can reveal subtle ways in which featural and functional product characteristics influence consumers, which would provide designers and manufacturers with insights into the requirements necessary to generate design solutions that assimilate the variation in user activities in order to prevent risks to consumer safety.

One limitation with the body of work associated with the usage-centered approach is that it involved mainly Dutch participants. Therefore, it is possible that the outcomes were specific to that subset of consumers. Consequently, given the global market of many consumer products, in order to gain real insight into potential use and misuse of products, it would be necessary to consider different types of consumers who might come in contact with the product (i.e., experienced and inexperienced, the elderly, the young, different cultures, physically and mentally impaired, etc.). Nonetheless, this work highlights the utility of the usage-centered design approach in reducing risk to consumers.

1.3 APPROACH TO SAFETY DESIGN

Increased attention has been given to the design of artifacts (products, equipment, environments, and services) that individuals encounter (Laughery and Hammond 1999) as a result of the moral concern for their welfare and because of the increase in litigation and personal injury claims in the developed world. A standard approach to dealing with risks and enhancing safety is through the process prescribed by a "hazard control hierarchy" (Sanders and McCormick 1993). Many such schemes exist (e.g., Laughery and Hammond 1999; Lehto and Clark 1990), which share the same fundamental approach to creating a product/environment that is inherently safe through the removal of hazards or their reduction to a level that is insufficient to cause harm (Clark and Lehto 2006). Dejoy, Cameron, and Della (2006) indicated that each of the steps in a hazard control hierarchy lie on a passive–active continuum. Passive measures provide automatic protection for the user through the removal, control, or alteration of the hazard through design/re-design or other steps that prevent exposure, such as the implementation of safety guards (Leonard 1999; Rogers, Lamson, and Rousseau 2000). By contrast, active measures require the user to engage or refrain from certain behavior(s) in order to avoid possible harm, which are implemented through training and warning people. It is not always possible or even viable to design-out risks as this can reduce the utility of the product/environment (Clark and Lehto 2006); accordingly, passive measures are becoming more commonplace and, in particular, warnings are frequently used to inform users of potential risks (Lesch 2005). Consequently, there is a particular need for both approaches to subjective risk, as outlined here: the outcomes of the usage-centered approach would identify the target functional and featural characteristics of a product that would need passive measures, while the psychometric approach could facilitate the design of warnings and enable the provision of active measures.

Despite the importance of warnings and the ease with which they can be provided (Dejoy, Cameron, and Della 2006), they are first and foremost injury control interventions (Laughery 2006) and not a remedy for poor design (Wogalter 2006a). Consequently, it is essential that passive measures are carefully implemented where possible in order to eliminate or control hazards, and that active measures, in the form of warnings, should be used as a supplement rather than a substitute (Edworthy, Stanton, and Hellier 1995; Rogers, Lamson, and Rousseau 2000; Trommelen 1997; Frantz, Miller, and Lehto 1991; Lehto and Salvendy 1995; Lehto 1992).

1.4 BARRIERS TO DESIGNING FOR PRODUCT SAFETY

A successful consumer product will facilitate a balance between exposing the consumer to an acceptable level of risk and depriving the consumer of useful services and features (Hecht 2003). Within risk management, the idea of acceptable risk as the basis for design (Vrijling, van Hengel, and Houben 1998; Naoe 2008) is based on the *de minimis* principle in which risks are reduced to a level that is insufficient to cause harm (Clark and Lehto 2006), meaning there is (effectively) no risk at all (Sandin 2005). Comar (1979) stated that the *de minimis* approach should promote understanding about how to deal with risk in the real world; encourage the provision of risk estimates; focus attention on actions that can effectively improve health and welfare; and avoid attempts to reduce small risks while neglecting larger ones. In this sense, the *de minimis* approach is primarily concerned with the probability of an outcome: a *de minimis* risk has a sufficiently small probability to make it negligible (Peterson 2002). There are a number of ways through which the *de minimis* approach can be implemented.

1. The *specific number view* in which a risk is considered *de minimus* if its probability falls below a certain, arbitrary number.
2. The *non-detectability view* through which a risk is *de minimus* if there is no scientific confirmation of its manifestation.
3. The *natural-occurrence view* considers a risk *de minimis* if its probability does not exceed the "natural" background levels of the type of risk.

Although, the *de minimis* principle has largely focused on objective risk levels consistent with the expert, probabilistic approach, Peterson (2002) acknowledged that there is nothing to exclude negligible risks being discussed in subjective terms. The usage-centered approach could provide a way in which to identify negligible risk, as was the case in the study by van Duijne, Kanis, and Green (2002), who identified an acceptance of the occurrence of minor injuries as a necessary part of the task. Further, Davey and Dalgetty (2007) noted that some product characteristics are an inherent part of design due to their function or purpose, and the risks associated with the characteristics are well known and accepted (e.g., hot water from the hot tap, hot steam emitted from a boiling kettle, and a sharp blade of a kitchen knife). Consequently, the *de minimis* principle could theoretically be applied to all consumer products in order to understand and manage both objective and subjective risks; however, it is possible that through the re-distribution of risk (Keeney 1995) any safety measure would merely transfer the risk to another source or action. In particular, measures to manage objective risk might be affected by the process of risk transference, while measures to manage subjective risk might be affected by the process of risk compensation. These two issues are briefly dealt with in the following sections.

1.4.1 Risk Transference

Within the field of risk regulation, it has been reported that attempts to control one risk unavoidably increases another risk (Cross 1998). While the concept of risk transference does not relate specifically to consumer products, it does identify the possibility that attempts to manage mainly objective risks could simply re-distribute the risk. Cross identifies three routes through which risk transference can occur. These are

1. *Substituting or using alternative substances or activities*. For instance, Cross (1996) noted how the change from gas fueled cars to electric cars was seen as a way of tackling the growing risk of pollution; however, this action simply transferred the source of pollution from the car to the electric generating plant, which was also suggested to increase the risk of lead exposure.
2. *Foregone benefits*. For instance, Cross (1996) noted that risk to health associated with pesticide residue could cause consumers to avoid fresh produce, which would be far more risky to their health.
3. *Remediation efforts*. For instance, Graham and Wiener (1995) noted that as a result of government requirements for minimum mileage requirements, manufacturers were required to produce smaller cars, which were associated with an increase in road deaths.

While risk transference is associated with risk regulation, which is often based on objective risk estimates, it is also evident that the re-distribution of risk associated with risk transference is applicable to consumer products. Considering the possibility that consumers deliberately put their hand in a food blender to remove food stuck around the blade (see van Duijne, Kanis, and Green [2002] for observational data that support the occurrence of this action), Baber and Mirza (1997) identified two potential measures to prevent this action. The first involved fitting interlocks on a cover over the blender aperture in order to prevent consumers putting their hand into the aperture. The second involved the standardization of the depth and size of the blender aperture to prevent consumers from reaching down to the blade. Baber and Mirza noted that while the first solution would be more expensive to implement, the second might lead consumers to transfer the risk to another behavior through the use of other objects such as a wooden spoon, thereby risking injury from flying splinters if the wooden spoon came in contact with the rotating blade. Consequently, while concerted efforts may be made to reduce the risk to consumers, it is possible that the safety measures may merely act to re-distribute the risk (Keeney 1995). Thus, it is necessary that the designer(s) and manufacturer(s) consider the consequences of implementing safety measures, and design with these in mind.

1.4.2 Risk Compensation

The implicit belief in risk management is that risk can be reduced through the use of appropriate safety measures (Stanton and Glendon 1996). Despite this, empirical evidence from the driver-safety literature suggests that individuals have an innate, predetermined level of acceptable risk, and when confronted with a risk that is lower or higher, they will act in manner to maintain their desired level. One way in which this will occur, which is consistent with the idea of risk transference, is for the risk to be transferred from "regulated" to "unregulated" behavior (Jackson and Blackman 1994). A potential consequence of this re-distribution of risk is that the effect of any safety measures may be negated (Weegels and Kanis 2000).

Specific explanations for the consistent finding that drivers respond to the addition of safety measures (e.g., anti-lock brake system, seat belts, and air bags) or a change in legislation (i.e., mandatory seat belt use or helmet use on motorcycles/bicycles) with risky behavior (see Jackson and Blackman 1994; Horswill and Coster 2002; Stanton and Pinto 2000; Hoyes et al. 1996; cf. Lewis-Evans and Charlton 2006; Scott et al. [2007] who failed to find compensatory behavior in other risky domains) have been attempted via two models. First, Pelzman (1975) proposed the risk compensation theory (RCT), which simply suggested that when the risks associated with a certain behavior decrease, individuals would compensate by taking greater risks through another behavior. For instance, when individuals are provided with a protective device (e.g., bicycle helmet or seat belt), they will act in a riskier manner because of the sense of increased protection, thereby nullifying the protection afforded by the device (Thompson, Thompson, and Rivara 2002). However, the theory does not indicate the degree of compensation. By contrast, risk homeostasis theory (RHT; Wilde 1982, 1988, 1989) explicitly predicts that any reduction in the level of risk (real or perceived) following the implementation of safety measures, would cause the individual to re-distribute the risk around other behaviors (Stewart 2004), thereby returning to the original combination of risk and reward (Hoyes 1994; Dulisse 1997). The consequences of this are that any attempt to manage risk would be continually thwarted (Stewart 2004).

While the main body of work on RHT and RCT has been largely associated with driving behavior, Noyes (2001) notes that the possibility of some compensatory mechanism presents disturbing theoretical implications if people are found to operate in a similar way in other aspects of their life. There is some evidence that people do behave in a manner consistent with RHT within other domains (see Hoyes 1994; Desmond and Hoyes 1996; Hersch and Viscusi 1990). Viscusi and Cavallo (1994) reported a field study investigating the influence of a lighter with child-resistant features on risk beliefs and precautions. It was found that the inclusion of child-resistant features reduced perceptions of risk and there was some degree of compensatory behavior; however, the child-resistant features were found to reduce fire-related injuries by much more than any diminished precaution taking (i.e., allowing children to play more freely with the lighter than before the safety features were added). This suggests that some degree of compensatory behavior *may* occur when safety measures are added to consumer products (see also Viscusi 1984; cf. Walton 1982). Indeed, Wilde (1998, 91) states that "the mechanisms involved in risk homeostasis are probably universal" and would therefore apply across domains.

Compensatory behaviors could be considered a natural reaction through which people attempt to regain control of their environment (Stanton and Glendon 1996); however, Hedlund (2000, 87) stated that "I believe the evidence is overwhelming that every safety law or regulation is not counterbalanced by compensating behavior." Nonetheless, the paucity of research concerning the effect of reducing risk associated with consumer products through safety measures limits the extent to which reliable conclusions can be formed. Moreover, despite evidence supporting the occurrence of a mild degree of compensatory behavior (see Stetzer and Hofmann 1996; Viscusi and Cavallo 1994) contrary to Wilde's (1998) assertion of the generality of the homeostatic mechanisms, recent evidence shows that no such compensation occurs in a number of domains (see Lewis-Evans and Charlton 2006; Scott et al. 2007), suggesting that it may actually be domain specific. Nonetheless, until the theory is robustly tested in the domain of consumer product design, there is a theoretical possibility that consumers *might* react to safety measures in a compensatory fashion such that alternative risky behaviors result from perceptions that a product has become safer. In this case, it would be necessary to consider these barriers to safety design to ensure that risk is dealt with in an appropriate manner to safeguard the consumer and those potentially affected by consumer product use.

1.5 DISCUSSION

The most effective consumer products enhance usability, in the sense that they are easy to use as they assimilate consumer behavior and, at the same time, prevent injuries and accidents (see Stanton 1997). Considering the risk to consumers is a particularly important step in designing safe products. To do this, it is first essential to consider the conceptualization of risk (objective vs. subjective) employed during design as neglecting the role of either type would necessarily mean that important safety issues will be overlooked. For instance, the consideration of objective risk is necessary in identifying products that pose a risk to consumers (accident statistics) and the extent of the risk (exposure data). Given the large number of chemicals that can be emitted by consumer products, exposure data are a crucial element in any risk assessment. Nonetheless, there is increasing acknowledgment of the importance of the human element (compensatory actions and product use) in estimates of exposure. Consequently, consumers' perceptions and evaluations of risk and their resulting behavior are an important element in the consideration of both subjective and objective risk. Hence, the different approaches to risk provide different kinds of information applicable to the improvement of consumer product safety.

While there is a substantial body of literature relating to issues relevant to the risk (and safety) debate, these are distributed across a vast number of domains. For instance, while risk transference and risk compensation are theoretically important in consumer product use and design, most of the work is concentrated in other domains. Consequently, given the role that risk plays in the use of consumer products, it is necessary that research addresses the relevant risk issues that may influence the design of consumer products.

In conclusion, the most effective approach to designing usable consumer products is to implement human factors principles as early as possible, rather than as reactive measures to usability problems. This should also be the approach in designing for safety, wherein a preventative approach is adopted such that risk and safety issues are given appropriate consideration, prior to product release. Given the difficulties experienced by the human factors discipline in terms of designers and manufacturers implementing appropriate usability considerations throughout the design life cycle, it is likely that the preventative approach to safety design will face the same lack of acceptance; however, given the potential financial risks associated with the release of an unsafe product, designers and manufacturers might be encouraged to adopt the principle of preventative safety design with a little more haste.

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2 Consumer Product Risk Assessment

Aleksandar Zunjic

CONTENTS

2.1 INTRODUCTION

Product risk assessment is performed in order to assess the safety of products in relation to the consumer. According to the Technical University of Liberec, risk is a probability of accident occurrence and the possible consequences that might occur under certain circumstances or during a certain period (Duffey and Saull 2008). Unlike risk assessment of technical systems, assessment of risk in the system man - product is based primarily on the prediction of the effects of hazards in relation to humans. In this regard, according to the UK Department of Health, risk is the probability, high or low, that somebody (or something) will be harmed by a hazard, multiplied by the severity of the potential harm (Duffey and Saull 2008).

Data indicating the number of accidents while using different products are alarming. For example, the U.S. Consumer Product Safety Commission (CPSC) points to the fact that in 1999, 205,850 playground equipment-related injuries were treated in U.S. hospital emergency rooms (CPSC 2001). In the United States, approximately 8700 injuries from home exercise equipment occur annually in children younger than 5 years (Abbas, Bamberger, and Gebhart 2004). The top ten consumer products involved in domestic work accidents in the European Union (EU) (for the period 2002–2004) are: kitchen knife, household ladder, drinking glass, lawn mower, stick, wheeled shopping bag, chair, slicing machine, fats and oils, and tins (Zimmermann and Bauer 2006). In addition, the top ten consumer products involved in play and leisure activity (for the period 2003–2005) are: bicycle and accessories, equipment in playground, door, rolling sports equipment, chair (bench), toys, table, bed, ball, and gymnastic and body-building equipment (Angermann et al. 2007). Injuries that occur during the use of consumer products are in the range from minor cuts to fatal outcomes.

In the United States, concerns about hazardous consumer products have led to the passage of the new Consumer Product Safety Improvement Act of 2008 (Rider et al. 2009). Similarly, in order to build a system for controlling product safety, the EU has adopted Directive 2001/95/EC on general product safety (GPSD), which establishes a community rapid information system (RAPEX) for the fast exchange of information between the member states and the commission on measures and actions concerning consumer products that pose a serious risk for the health and safety of consumers (EC 2004).

2.2 CONSUMER PRODUCT RISK ASSESSMENT METHODS

The selection of an appropriate procedure that can be applied for the assessment of risks is vital for consumer product risk assessment. There are dozens of methods that can be applied for the assessment of risk in technical systems. However, these methods have very limited application in the system man - product because they do not include humans. Such methods are concentrated on the detection of possibilities for the occurrence of failure, as well as the risk assessment in relation to technical systems.

A relatively small number of methods are applicable to the system man - product. In the EU, the official method for consumer product risk assessment is RAPEX. This method is described in detail in DTI (2007), as well as in the growing number of EU Commission documents. Practical application of this method is presented in Floyd et al. (2006), where some weaknesses of this method are also observed.

In order to overcome the shortcomings of the existing methods for risk assessment, the ergonomic product risk assessment (EPRAM) method has been developed. This new method will be presented here for the first time.

2.2.1 Ergonomic Product Risk Assessment Method

The first step in the implementation of the EPRAM method for product risk assessment consists of gathering the necessary information that will be used as a basis for the risk assessment. Information that should be collected primarily relates to

- Analytical and/or statistical data related to the defective parts of products or some of their functions
- Data on the number of accidents that occurred as a result of defective products
- Information regarding the circumstances under which the accident occurred
- Other information that may be of importance for the risk assessment

The analytical data relating to the malfunction of some parts of the product can be obtained by applying some of the many methods for the risk assessment of technical systems, such as HAZOP, FMEA, FTA, and others. In fact, data collected by these methods can be used as a basis for identifying hazards in the system man - product. It should be noted that none of this methods in practice are used for risk assessment in relation to humans.

Application of methods for the risk assessment of technical systems is not necessary for the implementation of the EPRAM method if there are statistics related to the malfunction of certain products. For example, it is known from practice and the available statistical data that the airbags on a particular type of vehicle do not deploy because of a technical failure. In this case, the collection of statistical data related to this phenomenon is sufficient to identify risks in the system man - product. Moreover, the collected statistical data about the malfunctioning of products reveal defects in the products that methods for the risk assessment of technical systems previously failed to detect (e.g., in the product design phase).

It is desirable to collect data concerning the number of accidents that occur as a result of defective products. In fact, these data reveal the dimension of the problem. However, such data are often difficult to find because, in most cases, there is no developed system for the collection of such data of general social significance. Still, there are a small number of organizations dealing with the collection of such information in a systematic manner.

Collection of data regarding the circumstances under which the accident occurred may be important for two main reasons. First of all, the collection of these data is of interest to identify hazards. The product can function correctly under certain conditions. However, under certain circumstances that have not been taken into account in the design phase, the product can become defective and endanger consumers. In addition, the collection of this data is relevant for determining the probability of occurrence of risk events. Other circumstances and environmental conditions that have had an impact on the occurrence of an accident also belong here. These data can also be unavailable.

The second step in the implementation of the EPRAM method consists of the formal identification of all the risks associated with the use of the products and descriptions of the scenarios that lead to the possibilities for the occurrence of accidents. One product may be defective for several reasons. For example, a car may have a faulty airbag, but also the brakes can block under certain circumstances. Therefore, in this case there are two identified risks. For each of the identified risks, a scenario should be written that relates to the occurrence of risky events. For example, a side airbag is not activated in a case of strikes to the car from the opposite side. In addition, the brake remains blocked if a person acts on the pedal with great force. Therefore, for each identified risk it is necessary to create a scenario that describes the possibility of accident appearance and injuring of users. This scenario should also include a description, i.e., the kind of injuries that a consumer sustains when using the product. A description of the injury may be based on existing statistical data related to the use of the product, or it may be based on the evaluation by assessors of the type of injury that may occur as a result of the use of the product in a way that is described in the scenario.

In order to identify hazards, in addition to the implementation of analytical methods for the risk assessment and collection of statistical data, expert assessment can be used. In practice, risk assessors often perform a risk assessment based on the expert identification of risks. In this case, in order to identify hazards, it is necessary to consider in particular the following general sources of risks associated with the use of products:

- Risk of fire
- Risk of explosion
- Risk of falling due to slippery and uneven surfaces
- Risk of electric shock
- Risk of mechanical injury
- Risk of acceleration effects
- Risk of effects of noise
- Risk of effects of high or low temperature
- Risk of chemical hazards and toxicity
- Risk of evaporation
- Other risks associated with use of the products in an inadequate way

It is essential that for each potential risk, the evaluator identifies the hazards that can lead to the occurrence of an accident. For this purpose, it is necessary that the evaluator considers all possible conditions under which the product can be used. Therefore, it is essential that the evaluator identifies the hazards and describes a scenario that could lead to the occurrence of an accident and injury.

The third step in the implementation of the EPRAM method determines the probability of occurrence of injury during the predicted life of a product. There are several factors that influence the probability of injury. These are

P_1: The probability that the product is defective and dangerous, or will become defective and dangerous during use, or it can be used in such a way that the risk can lead to user injury.

P_2: The probability that the product does not have adequate safeguards, which may prevent the occurrence of injuries.

P_3: The probability that a hazard is not obvious while using the product.
P_4: The probability that the product does not have adequate warnings to alert the user to danger.
P_5: The probability that vulnerable persons (children, elderly, handicapped, disabled) can use the product.
P_6: The probability of product usage (exposure to the risk).
P_7: The probability that there are other environmental factors that can affect the prevention of injury (e.g., persons who can help in preventing the injury from happening, the existence of other circumstances that may prevent or reduce an injury).

The total probability P for the occurrence of injury is equal to the product of probabilities that contribute to the occurrence of injury, i.e.,

$$P = P_1 \times P_2 \times P_3 \times P_4 \times P_5 \times P_6 \times P_7. \tag{2.1}$$

According to this formula, the probability of occurrence of an injury is equal to 1 (100%), if

- The assessor estimates that the product is defective or it will become defective during its working life
- The product does not have adequate safeguards that may prevent the occurrence of injury
- The hazard is not apparent to the user
- The product does not have adequate warnings to alert the user to danger
- It is certain that vulnerable persons will use the product
- The user is exposed to the hazard every day (on a continual basis)
- There are no other circumstances that may contribute to the prevention of injuries

The fourth step in the implementation of the EPRAM method is determining the severity of possible injuries. It is necessary to classify the kind of injury described in the scenario into a particular group of injuries, depending on the severity of injury. For the purpose of the EPRAM method, injuries are classified into three groups.

The first group consists of *slight* injuries. This group comprises injuries that are characterized with $<2\%$ incapacity. These injuries are usually reversible and do not require hospital treatment. The slight group of injuries consists of

- Minor cuts
- Minor fractures

The second group consists of *serious* injuries. This group of injuries comprises injuries that are characterized with 2%–15% incapacity. These injuries are usually irreversible and require hospital treatment. The group of serious injuries includes:

- Serious cuts
- Loss of finger or toe
- Damage to sight
- Damage to hearing

The third group consists of *very serious* injuries. This group includes injuries that are characterized with $>15\%$ incapacity. These injuries are usually irreversible. The group of very serious injuries includes:

- Serious injury to internal organs
- Loss of limbs
- Loss of sight
- Loss of hearing

This classification of injuries is adopted to ensure consistency with the classification of injuries adopted by the EU within the RAPEX method for product risk assessment. Such a classification also facilitates a comparison of results of product risk assessment obtained by using the EPRAM and RAPEX methods.

The fifth step in the implementation of the EPRAM method is the final assessment of the risks of using the product. This assessment is performed on the basis of the calculated probability for the occurrence of injury *P* and performed classification of injuries according to the severity. In order to assess the risk, the diagram shown in Figure 2.1 is used.

Figure 2.1 shows that there are nine areas (indicated by numbers from 1 to 9) for the purpose of the assessment of risk. These areas are

1. Unacceptable risk
2. Very high risk
3. High risk
4. Increased risk
5. Moderate risk
6. Low risk
7. Very low risk
8. Extremely low risk
9. Risk is negligible

The vertical axis of the diagram indicates the probability of injuries, which can range from 0 to 1. On the horizontal axis, there are three groups (slight, serious, and very serious) in relation to which an injury is classified. Risk assessment is performed by pulling the vertical line depending on the severity of injury to the area that corresponds to the probability of occurrence of injury.

Depending on the assessed risk, it is necessary to undertake appropriate measures for eliminating or reducing the risk. The risk that corresponds to area 1 in Figure 2.1 is of the type that requires immediate withdrawal of products from the market and suspension of sales. Risks in areas 2 and 3 indicate the necessity of taking urgent measures to reduce the risk, within a certain short period of time, proportional to the risk. The risk reduction in area 4 is less urgent, but it is necessary. The risk in area 5 on the diagram does not require urgent resolving. However, measures to reduce risks in this area are recommended in a certain medium period of time. Risks that belong to areas 6 and 7 in Figure 2.1 are at a very low level. Reducing the risks in these areas is recommended in a long period of time. The community or its competent authority makes the decision about the necessity of risk reduction in this area. Risks in areas 8 and 9 do not require special treatment. Their elimination is optional and has a voluntary character.

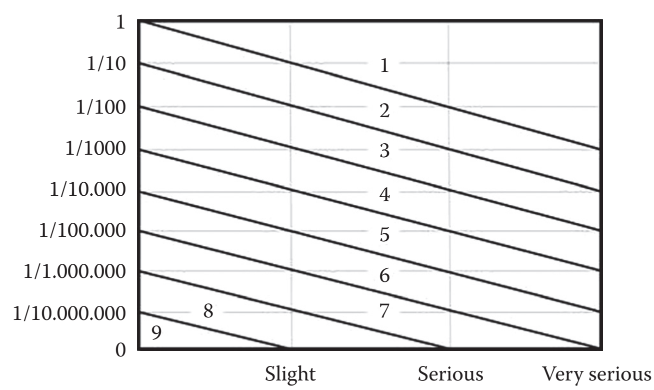

FIGURE 2.1 Diagram of the consumer product risk assessment.

2.3 EXAMPLE OF CONSUMER PRODUCT RISK ASSESSMENT

The application of the EPRAM method will be presented with an example. In order to compare the results of risk assessment, the RAPEX method will also be used.

2.3.1 Example of Product Risk Assessment by the Ergonomic Product Risk Assessment Method

2.3.1.1 Step 1

According to the National Electronic Injury Surveillance System (NEISS), over two-thirds (67%) of all injuries involving home equipment in the United States occurred on swings (CPSC 2001). This finding indicates that the swing is a potentially risky product. Therefore, it is necessary to assess the risk that comes from using swings.

2.3.1.2 Step 2

Two main hazards with using swings have been identified. The data indicate that a number of accidents in the United States emerged as a result of the chain breaking on swings during use. The resulting fall of the children from a swing caused injuries related to serious cuts and fractures. Additionally, use of a heavy seat may cause injury when a child is hit by a moving swing. In this case, bruising is the type of injury that is a result of this danger.

2.3.1.3 Step 3

Foremost, it is necessary to first determine the probability of occurrence of an injury as a result of the chain breaking. For this purpose, it is necessary to determine component probabilities that affect the overall probability of occurrence of injury. In this case we have

- The probability of the chain breaking is not great. Therefore, the probability that the product is defective and dangerous, or will become defective and dangerous during use is $P_1 = 0.05$.
- Given that the swings do not have special protection preventing the chain breaking, the probability that the product does not have adequate safeguards that can prevent injury is then $P_2 = 1$.
- Given that the chain breaking is not a predictable phenomenon for the user, the probability that the hazard is not obvious while using the product is $P_3 = 1$.
- Given that swings do not have a warning on the occurrence of chain breaking, the probability that the product does not have an adequate warning so that the user is aware of the danger is $P_4 = 1$.
- Bearing in mind that swings are primarily intended for children, the probability that the product can be used by vulnerable persons is $P_5 = 1$.
- The estimated probability of exposure to this kind of danger for the average consumer is $P_6 = 0.55$.
- There are some mitigating circumstances that may affect the reduction of injury. For example, the swing is positioned on grass instead of on concrete ground. Taking this into account, the probability that there are no other environmental factors that can affect the prevention of injuries is $P_7 = 0.8$.

Probability of occurrence of injuries during the predicted life of the product is

$$P = 0.05 \times 1 \times 1 \times 1 \times 1 \times 1 \times 0.55 \times 0.8 = 0.022.$$

Now it is necessary to determine the probability of occurrence of an injury as a result of the child being hit by a heavy seat. In this case, the component probabilities that affect the overall probability of injury occurrence are

- The probability that the swing can be used in a risky manner (so that the seat of the swing can hit the child) is $P_1 = 1$.
- The probability that the swing does not have adequate safeguards, which can prevent the hazard of hitting is $P_2 = 1$.
- Children are, to some extent, intuitively aware of the danger of a moving swing seat. Therefore, the estimated probability that the danger while using the product is not obvious is $P_3 = 0.3$.
- Given that swings do not have a warning in relation to this type of hazard, the probability that the product does not have an adequate warning that can warn the user to the danger is $P_4 = 1$.
- The probability that the product can be used by vulnerable persons is $P_5 = 1$.
- The estimated probability of exposure to this kind of hazard for the average consumer (a child in this case) is $P_6 = 0.55$.
- There are certain environmental factors that can affect the prevention of injuries. For example, an adult may be placed in the vicinity and monitor use of the swing. In this sense, the adult can prevent the child from entering into the path of movement of the seat (dangerous zone), thereby preventing injuries. Taking this into account, the probability that there are no other environmental factors affecting the prevention of injuries is $P_7 = 0.5$.

Probability of occurrence of injuries during the predicted lifetime of the product in this case is

$$P' = 1 \times 1 \times 0.3 \times 1 \times 1 \times 0.55 \times 0.5 = 0.0825.$$

2.3.1.4 Step 4

In relation to the type of injuries that are described in the scenario, their classification will be conducted. Since, in the first case (breaking of the chain) the child may suffer serious cuts and fractures, these injuries are classified as serious. In the second case (stroke of the seat), bruises are injuries that are classified in the group of slight injuries.

2.3.1.5 Step 5

The final risk assessment for both cases will be performed by using the calculated values of P and P' as well as the diagram shown in Figure 2.1. By drawing a vertical line from the serious injury location up to the value of $P = 0.022$, we get a point located in zone 1 of the diagram. Therefore, the risk that originates from the chain breaking is assessed as an unacceptable risk. In the other case, by pulling the vertical line from the location of slight injury up to the value $P' = 0.0825$, we get a point located in zone 2 of the diagram. Therefore, the risk that originates from the heavy seat is assessed as a very high risk.

Given that the risk from the chain breaking is estimated as unacceptable, it is necessary to promptly withdraw the product from the market and to suspend sales. This conclusion is consistent with the procedure of the U.S. CPSC. In 2000, the CPSC recalled 7000 play sets due to chain swings breaking during use.

In the second case, the risk of hitting that originates from the swing chair is assessed as very high risk. Therefore, it is necessary to take urgent measures to reduce the risk. Let us now consider the extent to which some of the activities for risk reduction could affect the risk assessment in this case. One of the possible measures that can be taken is to set up warning signs. By adequate marking of a risk zone in which a second child should not be in during swing usage, and placing appropriate labels or warning signs, the probability, P_4, would amount to 0.01 instead of 1. In this case, as a result of effective warning, the probability of occurrence of injury would be equal to $P_1' = 0.000825$. Based on the implementation of this measure, the risk would be significantly reduced. In that case, the risk would match zone 3 of the diagram (high risk).

In the next iteration, it is necessary to consider taking additional measures to reduce the risk. One of the possible measures consists in educating children about the dangers related to the use of swings. By way of effective implementation of this measure, the probability that there are no other environmental factors that can affect the prevention of injury would amount to 0.05 instead of 0.5. In this case, as a result of environmental factor changes, the probability of occurrence of injury would be reduced to $P_2 = 0.0000825$. Accordingly, the risk would be further reduced. In that case, it would match zone 4 of the diagram (increased risk).

In the next iteration, the risk could be reduced by using some design changes. In this sense, the use of lighter materials for the production of seats and their coating with soft material (e.g. rubber) would affect the reduction of injury severity. Two possible cases will be considered, bearing in mind that not all serious injuries are of equal weight and all slight injuries are not equally serious.

In the first case, by using the lighter material, weight of injuries is to some extent reduced, but injuries can still be classified as serious. Now suppose that the severity of injuries is located in the middle of the interval between the vertical lines, with signs slight and serious in Figure 2.1 (which essentially correspond to the limits of the intervals). By drawing the vertical line from the point on the horizontal axis of the diagram, which is located in the middle of the mentioned interval, up to the area that corresponds to the probability of injury P_2', we get a point on the chart that is located in area 5 (moderate risk). This kind of risk does not require urgent resolving.

In the second case, we can suppose that the effective design solution significantly reduced the seriousness of injuries (e.g., by coating the seat with rubber). Now suppose that the injuries are at the level that corresponds to the middle of the interval, which is in the range from the vertical axis at the beginning of the coordinate system, up to the vertical line that corresponds to the border of slight injuries. By drawing the vertical line from the point that is located at the mentioned location up to the probability P_2', we get a point on the chart that is located in area 6 (low risk). Deciding on the need for further risk reduction is the responsibility of the community or its competent authority. This level of risk is practically tolerated in most cases.

2.3.2 Example of Product Risk Assessment by the Community Rapid Information System Method

For the same example, the risk assessment will be carried out by the RAPEX method. First, the risk assessment for the case where the chain may break will be carried out.

As a result of a child falling due to the chain breaking, injuries occur (serious cuts and fractures) that, based on the table for assessing the severity of injury, correspond to the group of serious injuries.

We can estimate that the criterion "probability of hazardous product" has a value $<1\%$. We estimate that the criterion "probability of health/safety damage from regular exposure to hazardous product" has the value "hazard may occur under one improbable or two possible conditions." Based on these two values, from the table for assessing the gravity of the outcome, we read that the probability of harm has a "low" value.

Based on the first table for risk assessment, the value "overall gravity of outcome" also has a "low" value. We adopt that children from 3 to 11 years are among the vulnerable group of users. Based on the table for the final risk assessment, taking into account the values for the overall gravity of outcome and the existence of a vulnerable group of users, we get the value "moderate risk" as the final risk assessment.

If the competent institution made a decision about taking action in this case on the basis of the application of the RAPEX method for risk assessment, then they would come to the conclusion that it is not necessary to take rapid action. Such a decision would be contrary to the CPSC decision on the recall of 7000 swings.

Now, using the RAPEX method, we can evaluate the risk in the case of hitting a child with the seat. Injuries that occur as a result of hitting a child with the seat can be characterized as a bruising. Based on the table for assessing the severity of injury, this kind of injury belongs to the group of slight injuries.

The value for the criterion "probability of hazardous product" in this case is 100%. We estimate that the criterion "probability of health/safety damage from regular exposure to hazardous product" has the value "hazard may occur under one improbable or two possible conditions." Based on these two values, from the table for assessing the gravity of outcome, we can read that the probability of harm has a "high" value.

Based on the first table for the risk assessment, the value "overall gravity of outcome" has a "moderate" value. We adopt that children from 3 to 11 years are among the vulnerable group of users. Based on the table for the final risk assessment, taking into account the values for the overall gravity of outcome and the existence of the vulnerable group of users, we get the value "serious risk" as the final risk assessment.

Although we cannot consider that, using the RAPEX method, the final risk assessment of hitting a child with the seat is generally overestimated, this assessment seems overrated in relation to the assessment "moderate risk," regarding the case of the chain breaking. Reversed values of risk assessment results when using the RAPEX method in these two cases would, to some extent, more realistically fit.

2.4 CONCLUSION

Consumers are often not aware of the fact that most products that they use daily are potentially hazardous. A product that worked correctly can become defective, thereby endangering the consumer. In addition, a product can be used in a risky manner. Designers should bear this in mind when designing the product.

In order to assess the risk that originates from a product, methods for risk assessment are commonly used. For every product, it is necessary to make a risk assessment in order to determine the level of vulnerability of consumers. Providing such information is of particular importance not only for consumers, but also for manufacturers and sellers. If the conclusion of a risk assessment is that the product generates unacceptable risk, it is necessary to initiate the procedure for its withdrawal from the market.

There are several methods that can be applied to consumer product risk assessment. The method that has very broad application is the RAPEX method. This method is applied in the member countries of the EU. In some ways, this method includes the requirements prescribed by the European Commission regarding risk assessment. However, methodologically, these requirements (criteria) are not adequately covered in all cases. One of the main disadvantages of this method is that during the risk assessment, it is not possible to include at the same time the risks that come from using the products by the vulnerable persons, and the risks that come from the lack of adequate warning or protection (and the risks that occur when the danger is not obvious). In other words, according to this method, when vulnerable people use the product, the risk does not depend on the fact that the product has appropriate protection and warning signs, or that the hazard may be obvious (e.g., open flame). If the protection is adequate and works in 100% of cases, then the risk is zero. However, this fact could not be taken into account if the risk assessment for vulnerable persons was performed by the RAPEX method.

In this chapter, the new EPRAM method for consumer product risk assessment is described. This method includes all the requirements prescribed by the European Commission regarding consumer product risk assessment. In addition, by using the criteria of the environment (surrounding), this method also includes other possible factors that have a potential impact on the risk assessment. It does not have the shortcomings that the RAPEX method possesses. Also, the application of this method enables quantifying of each criterion that can affect the risk assessment. If all numerical data that affect the risk assessment are exact and known, its accuracy is theoretically absolute. If all the data needed for the risk assessment are not known, this method allows performing an expert evaluation of these values (as with other methods of risk assessment). However, it is more sensitive than the RAPEX method, since, instead of several levels that are available to the qualitative assessment of some criteria that affect the risk, the EPRAM method allows a virtually infinite number of levels for the evaluation of some criteria (according to the range of *P* values). In addition, its use is relatively simple.

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

Kenneth R. Laughery and Michael S. Wogalter

CONTENTS

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.