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Chapter 4

RISK EVALUATION AND ACCIDENT ANALYSIS

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ABSTRACT

Different types of risk evaluation are presented. They can be classified as either "objective" (normative, probabilistic, or criterion-referenced) or "subjective" (spontaneously formulated by individuals based on their own representations or beliefs). The structuring variables for each type are presented, along with the scope and limitations of each. The links between risk evaluation and accident analysis are also emphasized. In this area, we note not only that the lessons learned from prior accidents or incidents can help in understanding risks, but also that naive inferences about the causes of accidents can contribute to risk evaluation. The importance of each type of evaluation for managing safety and adopting safety-conscious attitudes and behaviors is also shown. Finally, the article concludes that these different types of evaluations should not be considered as opposing, for they provide different and complementary insights into safety diagnosis and risk prevention.

Key-words : risk evaluation, risk perception, beliefs, causal attribution, accident analysis

INTRODUCTION

Risk evaluation is of paramount importance today, not only because of new risks appearing in work and social environments, but also because of the catastrophic potential of large-scale risks generated by high-tech or high-risk industrial processes (biochemical, nuclear, ocean transport, etc.). Currently, there are countless risks that affect not only the employees of an organization (first-tier victims), but also the users of the system (second-tier victims), people living in the environment (third-tier victims), and sometimes future generations (fourth-tier victims) (see Perrow, 1984, cited by Weill-Fassina, Kouabenan, & De La Garza, 2004). The issue of risk evaluation is becoming increasingly important, for several reasons. First, there has been a marked evolution of attitudes and employer-employee relations in the field of risk management as it relates to work, health, and living conditions.

This evolution has been driven by advances in scientific knowledge and by recent legislation regarding safety. Risk evaluation has taken on the status of a mandate in Europe: a European directive dated June 12, 1989 made it obligatory for all manufacturing organizations.

It is equally important to consider the fact that risk evaluation actually brings concrete results: it has responded to major expectations about improved safety, particularly accident prevention. The likelihood that accidents will occur at both the individual and community scales is always determined on the basis of risk-evaluation analyses. Evaluation strategies make it possible to anticipate an accident event and prevent it, or to promote the idea that it is possible to control it. Beyond this, risk evaluation influences safety-related attitudes and behavior; it allows managers to set action priorities and evaluate the opportunities for -- and the usefulness of preventive actions. It also facilitates the understanding and implementation of preventive measures.

While it is common to determine the probability of accidental occurrences -- including those on the individual level -- based on overall risk evaluation, it is appropriate to question the adequacy of this method and the "transferability" of conclusions from one scale to the other. One can schematically distinguish objective (and/or normative) risk evaluation based on quantitative data (number of accidents or victims, estimates of risk severity, etc.) from subjective evaluation based on an individual's interpretation of the available information. Quantitative evaluations define "objective risk"; personal evaluations represent perceived risk and define "subjective risk".

This article examines a number of studies that can help clarify the foundations and principles of these two risk evaluation levels, while at the same time discussing their usefulness and limitations for analyzing accidents. The article also proposes a method for measuring and modelling the severity of risks. Particular attention will be paid to perceived risk and to assessing the usefulness of individual risk perceptions, such as the naive (or spontaneous) causal analyses people make regarding accidents. Finally, the link between accident analysis and risk evaluation will be discussed, and the importance of risk evaluation for safety and accident prevention will be shown.

Normative and Probabilistic Risk Evaluation

A Priori Evaluation of Occupational Risks (In Terms of Regulations)

Today, risk evaluation has become mandatory for European companies. European Directive No. 89/139/CE, dated June 12, 1989, sets forth the minimal requirements that must be implemented to promote health and safety improvements on the job. In application of this directive, the French law of December 31, 1991 made it mandatory for chief executives to implement a company-wide system of prevention (article L 230-2 of the Labor Law) and risk evaluation. An a priori assessment of occupational risks must be conducted to identify and classify the hazards to which employees of an organization are potentially subjected, for the purposes of determining the best action priorities and a plan for instituting preventive measures. The goal is to come up with an a priori diagnosis of the risk factors to which employees may be exposed, that is both systematic and comprehensive (Andéol, Guillemy, & Le Roy 2002 ; INRS, 2000). The risk-evaluation project should focus specifically on (1) the choice of production processes, job equipment, chemical substances or preparations (identifying hazards[1], analyzing conditions of exposure and employees' understanding of their tasks); (2) arranging or rearranging workplace or installations (access and circulation, information and communication channels, work-related constraints); and (3) definitions of jobs (constraints related to workstations up- and downstream, choice of tools). Exposure to identified hazards can be assessed using a wide variety of criteria, including but not limited to those drawn from accumulated scientific and technical knowledge, knowledge of the potential occurrence of an injury in this or that condition, operators' experience and skill, and observations of hazards. The process must be a structured one, and the results should be formally presented in a single document that is updated and submitted annually as well as whenever otherwise necessary (for example, when there is a major modification that affects worker health or safety) (Andéol-Aussage, 2002). This concern for preventive risk evaluation can also be found in the SEVESO II directive (No. 96/82/CE of December 9, 1996), which, among other things, recommends reducing risk at the source by performing a study of the hazards themselves and then another study of their impact. The objective of the risk study is to identify potential accidents likely to happen within an industrial facility, assess their consequences, and propose solutions for their prevention or control. The aim of the impact study is to analyze the direct or indirect, temporary or permanent effects of the installation on the environment and health. Note that the law creates a framework, but does not propose a specific methodology for evaluating risks. Several of these methods are presented below.

Probabilistic Methods of Risk Evaluation

By the sheer fact that it may or may not lead to consequences, both negative and positive, risk is a concept that inherently involves uncertainty. Even if it cannot be reduced to them, risk evaluation depends for a large part on the operations carried out to assess it "mathematically" in terms of a probability. The estimation of uncertainty plays such an important role in risk assessment that numerous models of risk evaluation have been qualified as probabilistic. This label may be over-extended here, in the sense that risk evaluation cannot be reduced to the mere probability *(p)* of occurrence of the event defined by the risk. In order to quantify risk, it is necessary to also consider the consequences resulting from each of the ways in which a risky situation might come to be. The possibilities are numerous and extremely varied, so much so that an immediate problem posed is how to design a scale that can quantify risk events. In some areas (natural risks in particular), a monetary scale is commonly used ; for example, one might say that the damages caused by a flood or hurricane have amounted to two million euros. However, this type of measure is not valid for all risks, namely, whenever the most direct consequences are not financial but bring purely personal values to bear (e.g., quality of life, a feeling of well-being, trust in the future, etc.). Economists confronted early on with this problem in decision theory resolved it by introducing a general reference to utility *(u)*, a sort of common unit of measure that allows analysts to quantify and therefore compare each of the consequences under study. In the area of risks, it is certainly conceivable that the utility level might be negative, such as when a manifested risk generates difficulties or causes harm, injury, or loss. Surrounding these notions, a first generation of probabilistic models applicable to risks was elaborated. These

[1] A hazard is defined here as the intrinsic capacity of a piece of equipment, a substance, or a work method to cause

models are based on expected utility. Expressed in statistical fashion, this measure designates the arithmetic magnitude of the product $p*u$, and provides an evaluation criterion for each state a given situation can take on ("state of the world"). A risky situation, whether treated or not, is likely to evolve in different ways, depending on its own dynamics and on circumstantial factors (environment, momentary conditions). Its different courses will be differentiated in the analysis by their probability of occurrence *(p)* and by the extent of their consequences *(u)*. The products thus obtained $(p*u)$ are then compared. Given that in matters of risk, the idea is to minimize the negative consequences, one will choose the mode of action for which the product $p*u$ is the smallest (minimizing negative effects). This type of probabilistic model is used to evaluate certain kind of risks ; for an engineer it would be industrial risks ; for a surgeon, it would be the risks involved in an operation (Grenier, 1990).

Despite -- or perhaps because of -- its formalized character, this approach runs up against three types of difficulties. First, it poses the problem of determining the reference values, that is, the values of p and u. Neither value is easy to quantify, although the respective difficulties must be delineated. As has been shown in numerous studies, mostly in cognitive psychology (Beyth-Marom, 1982, Yates, 1990), the processing of information involving some degree of uncertainty, such as a probability, is skewed by illogicalities and inconsistencies that invalidate the resulting numerical values. Evaluating the utility of consequences presupposes complying with complex, axiomatic properties which are often poorly understood by the people in charge of implementing them.

In addition, this approach implies that risk-generating situations are only viewed from the perspective of the harm they create or are likely to create. Yet reality is more complex, since such situations generally have a positive side which justifies their acceptance by the social group. This is obviously true for situations involving risks that are accepted by society (e.g., the production of electricity in nuclear power plants where the consequences are simultaneously positive and negative. This creates a situation of "mixed" values and hence the concept of "acceptable risk" (Fischhoff et al., 1981). Risk evaluation presupposes a cost-benefit analysis based on multiple references and weighting factors (Fischhoff, Slovic, & Lichtenstein, 2000). Relying only on p and u has proven inadequate.

Finally, this approach to risk evaluation presupposes that we be capable not only of dealing with objective values but also, and very often, with values that are personal. Personal values, very diverse in nature and involving repeated observations, include beliefs and fears about events of the past, present, and future that may or may not have actually occurred. To put these values in quantitative terms, the concept "degree of belief" as it is used in Bayesian statistics opens up numerous possibilities. However, subjective probabilities are evaluated in different ways. For some (Edwards & Phillips, 1964) they are relevant and rational, while for others they are not (Beyth-Marom & Fischhoff, 1983); yet one cannot rely on the arguments of the different users to determine who is right. What is more, the assessment of subjective probabilities has proven to be particularly sensitive to a number of contextual effects and to the conditions in which the information being processed appears.

damage to the health of workers.

Taxonomic Evaluation of Risks Based on Certain Indicators

Evaluation of risks on the one hand, and evaluation of accident probabilities on the other, have a number of things in common but are not completely interchangeable, since the facts utilized are different, the reference scales are distinct, and the strategies for handling the information are not the same. Other things being equal, risk is assessed in terms of a time frame (be it objective or subjective), i.e., it brings to bear information that can be granted a general status "in the long run". In contrast, the probability of an accident is linked to circumstantial factors, to a relatively specific conjunction of elements that turn a potential "threat" into a reality at a particular place and time. The overall problem posed is that of moving from a general, conceptually defined *framework,* to a particular *situation.*

More specifically regarding risks incurred in the nuclear industry, Van der Pligt (1992) noted that decision-making strategies are based increasingly often on a quantitative evaluation of risks, and that as a general rule, risk assessment proceeds in four stages: (1) assessing the risk, (2) evaluating the dose-response relationship, (3) evaluating the extent of exposure, and (4) characterizing the risk. *Risk assessment* involves examining the evidence of a link between an individual's exposure to a specific substance and its toxicity, and attempting, if possible, to arrive at a qualitative evaluation of the validity of this evidence. *Dose-response assessment* involves examining the quantitative relationship between specific levels of exposure to a dangerous product and its effects on the severity of the organism's reactions at each level. *Exposure assessment* seeks to determine what populations could be exposed to the toxic substance, their size and composition, and the amplitude, frequency, and duration of each possible avenue of exposure. Finally, *risk characterization* consists of writing up a synopsis of all available information that could help decision-makers reach conclusions on the nature of the concerned risks. This stage also includes an evaluation of the level of uncertainty involved, and the fundamental hypotheses brought to bear. The overall synopsis is critical for controlling and managing risk.

Currently, the indicators most often used for public risk are the average risk per person and the expected number of accidents. Another parameter that is sometimes appropriate for characterizing a risk is the overall accident rate, defined as the number of deaths for every 10^{-8} hours of exposure to the risk (Sage & White, 1980).

Similarly, in the area of highway safety, "risk is generally estimated by relating the total number of accidents or victims to a measure of exposure to danger" (Fontaine & Gourlet, 1994, p. 17). However, "if the choice of numerator poses few problems, the same cannot be said for the choice of denominator" (Fontaine & Gourlet, 1994, p. 17). In this excellent study, Fontaine and Gourlet showed how the choice of a unit of measure is crucial in all risk-evaluation operations. Exposure in highway safety can be calculated using one of several different indicators as the denominator : the number of inhabitants (often used for international comparisons and for risks as varied as accidents in the home, violent crimes, suicides, diseases, etc.), the number of vehicles, fuel consumption, duration of driving (time spent on public roads), or the number of kilometers traveled. The precision level of the estimates varies according to the indicator used. The authors contend that "kilometers traveled", a widely accepted measure, is the indicator that best reflects the mobility of road users. Relying on even this commonly-used criterion does have some limitations, though, in the sense that it "rests on the hypothesis that all kilometers are equal. And yet, driving one kilometer at night on a small country road is not comparable to traveling one kilometer on a congested urban street during rush hour, or to one kilometer on a freeway" (p. 19).

Furthermore, depending on what indicator is selected, one can arrive at some very different conclusions. For example, "evaluations of the risk of an accident according to the driver's sex based on several measures of exposure show that, depending on the indicator used, male drivers have a risk of bodily injury that is higher than that of female drivers (with respect to the populations or drivers), nearly equal (in terms of kilometers traveled), or even slightly less (if one takes property damage into account)" (p. 18). Evaluation of highway risk can also be done relative to the vehicle's characteristics (weight, power, vehicle age, etc.), the driver's characteristics (sex, age, etc.), the location or type of road (in or out of the city), and the type of collision. The choice of criterion will depend on the goal set for the evaluation and the desired degree of precision. In concrete terms, it is a probability calculated in very specific conditions that serves as the principal reference for determining risk.

Risk Evaluation by Severity of Consequences

Another strategy consists of quantifying risk by using an estimate of the consequences of an actual accidental event as the primary indicator. This type of evaluation is valid for situations such as workplace accidents, accidents in the home, and traffic accidents. A variety of factors can enter into the evaluation of a risk's impact: the type of consequence (economic, social, environmental, etc.), the conditions of risk-taking (voluntary or involuntary), the range of the risk, its spatial distribution (evenly distributed or not), its controllability, etc. In these situations, one characterizes risk in terms of its consequences first, before looking at its probability. For example, nuclear risk is generally characterized by its widespread consequences on both the temporal and spatial scales. The choice of this type of description is not neutral : it is generally used by opponents of this type of energy. On the other side, proponents of nuclear energy tend to characterize this risk in terms of its low likelihood of occurrence and the avoidance of other types of pollution.

In the area of workplace accidents, risk evaluation involves not only estimates of potential risks and of exposure to them, but also measures of the frequency and consequences of accidents that may ensue. The impact of accidents on the health of workers is examined in particular by looking at important statistics such as accidental deaths (number of people killed) and accidental morbidity (number and severity of injuries). This is generally limited to accidents involving at least one day's leave from work, not counting the day of the accident (albeit a very partial vision of reality -- approximately one out of every two accidents is reported). For the year 2001, statistics in France for all business sectors combined showed 737,499 workplace accidents with leave (a 0.8% decrease over 2000) resulting in 730 deaths before injury setting (no change over 2000). For the same year, the total number of accidents causing partial but permanent work disability was 43,078 (a decrease of 10.4%). The prevalence of accidents is also studied by looking at the evolution of certain indices such as the frequency rate[2], the frequency index[3], the severity level[4], and the severity index[5].

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[2] [Number of accidents with work leave] / [number of hours worked] x 1,000,000.
[3] Number of workplace accidents with work leave, per thousand employees.
[4] [Number of workdays lost due to temporary disability] / [number of hours worked] x 1,000.
[5] [Total rate of permanent disability] / [number of hours worked] x 1,000,000.

Statistics from the year 2001 (Bastide, 2003) indicate that France has seen a decrease in workplace accidents in terms of the frequency index (down 2.9%), but the frequency rate remained the same as in 2000 (24.6). By contrast, the severity rate of temporary disabilities increased (up 5%). In short, fewer accidents occurred in 2001 than in 2000, but the accidents that did occur were more serious.

However, note that accident frequency and direct risk are not the only aspects to consider in evaluating the consequences of a risk. Accordingly, the consequences of risks can be evaluated based on average cost of accidents, cost of compensation, or accident premiums, i.e., by evaluating the social and psychological consequences for the victim, his family, the organization, and the community (Kouabenan & Alladoum, 1997; Kouabenan, 1999).

In an attempt to establish a statistical model of severity in terms of statistical distributions, Cuny and Lejeune (1999a, 1999b) proposed a research orientation based on a summary index that includes estimates of different aspects of workplace risk severity (partial-severity values). Evaluating the severity of hazards not only helps in determining which ones should be targeted as high priorities for prevention, but can also be useful in comparing the impacts of different accidental events. To this end, the BARPI (French acronym for *Office of Analysis for Industrial Risks and Pollution*), a unit of the French Ministry of Ecology and Long-Term Development, established a scale in the early 1990's that can be used to rapidly produce summary estimates of industrial accident severity. The scale has six levels of severity defined as a function of 17 technical criteria, including an estimate of the quantity of material directly involved in the accident, number of victims (dead, seriously or slightly injured), extent of injuries within the organization or affecting third parties, damage to the environment (water or ground pollution, destruction of wildlife, etc.). In the opinion of the authors themselves, this type of scale obviously "remains perfectible" not only because its validity rests on the quality of information collected for each criterion, but also because it raises questions about the equivalence of the criteria used. Note that this scale is more suitable for large industrial accidents (according to the SEVESO II directives) and does not seem appropriate for characterizing ordinary workplace accidents or everyday accidents in the community.

A similar focus on risk-severity modelling can be found in Fontaine and Gourlet's (1994) work on highway risks. These authors defined severity as the likelihood of a driver being killed if he/she is an accident victim, and attempted to quantify the effects of certain explanatory variables on the severity rate. They suggest that evaluations should not be limited to overall severity, but should distinguish interior and exterior severity. Interior severity refers to safety inside a given type of vehicle; exterior severity represents the aggressiveness of vehicles towards other highway users. "The level of protection offered to the occupants of a class of private automobiles is estimated as the number of passengers killed in vehicles of that class, divided by the number of vehicles of this class involved in accidents with bodily injuries. Aggressiveness is measured in terms of the number of externally killed victims, i.e., other users of private automobiles involved in accidents with a vehicle of the given class" (p. 37). The authors stress the importance of considering the weight/power relationship when evaluating severity: "The most powerful vehicles, which are often the heaviest, have the highest rates of exterior severity, which means that they are the most aggressive relative to other users. Conversely, small vehicles are not as aggressive, but also protect their occupants less well" (p. 11). In sum, one is more vulnerable in a light vehicle and better protected in a heavy vehicle.

The different types of evaluation mentioned above are generally conducted by experts. However, non-specialists who directly face risks also perform risk evaluations which can also be useful for assessing risks and deciding how to prevent them.

Variables Underlying The Subjective Evaluation of Risk

Validity of Risk Evaluation by Ordinary Individuals

Perception and evaluation of risk have not always been approached using analytical methods. Very often, evaluation is done by referring to one or more dimensions which appear important. This seems quite obvious for occupational risks affecting the individual or the company (e.g. nuclear hazards), but it is just as clear-cut in sports or leisure activities (e.g. the simple act of pitching a tent or setting up an RV on a camping trip).

In general, risks are evaluated qualitatively rather than quantitatively. Risk evaluation is a concern not only of safety experts or specialists, but also of members of the general public, who are no longer willing to passively subject themselves to hazards. More and more, individuals want to have some say in the management of risks to which they could be exposed. This interest on the part of the general public is reinforced by fear engendered by the appearance of new risks or major catastrophes affecting the environment (pollution, the greenhouse effect), food products (mad cow disease, listeriosis in cheese, dioxins in chicken, hormones in veal, salmonella in eggs, etc.), industrial products (asbestos), as well as by the growing number of catastrophic events of all types (chemical, nuclear, aeronautic, maritime, etc.). Risks that were formerly tolerated or ignored are no longer so. Besides, "risk as it is understood and evaluated by statistical methods applied to large samples, does not necessarily coincide with risk as it is conceived of by individuals" (Leplat, 2003, p. 44). Moreover, several studies have shown that even if risk evaluations by experts and ordinary individuals (non-specialists) are based on very different rationales, the fact remains that both groups are susceptible to bias in their judgment of risk (Kouabenan, 1998, 1999, 2000a).

Clearly, perceived risk is more or less linked to its evaluation as tolerable or intolerable, manageable or unmanageable, beneficial or damaging. Safety represents the level of risk judged acceptable. In addition, not all risks are perceived or feared in the same manner, either within a given community or from one community to another. Some risks are the *raison d'être* for the jobs of certain individuals (fire fighters, rescuers), so one can logically expect different risk perceptions by these people than by those in danger or being rescued. Studies on this subject suggest that risk perception is a complex phenomenon that can be affected by social, psychological, physical, political, and cultural factors. Research on this issue has shown that perceived risk is determined by multiple variables linked either to the nature and dimensions of the risk itself, or to factors related to the individual characteristics of the risk-perceiving subjects. While the first aspect (risk dimensions) is often explicitly addressed, the second (perceiver characteristics) is only rarely touched upon as such. Let us attempt to review this topic below.

Subjective Evaluation of Risk in Terms of Risk Dimensions

Subjective evaluations of risk seem to be linked to certain characteristics of the risk, such as its familiarity, its probability of occurrence, its controllability, its perceived utility, its catastrophic potential (number of people affected), the nature and severity of its consequences (immediate vs. delayed effects), whether or not it receives media attention, and whether it is voluntary or involuntary, natural or technological. People perceive certain kinds of events as more risky than they really are; this magnification effect is usually seen with events that happen infrequently, that are unknown or unfamiliar, catastrophic, or involuntary. Events perceived as less risky are ones that are frequent, familiar, less catastrophic, or voluntary (Kouabenan, 2001a, p. 330) (see Figure 1).

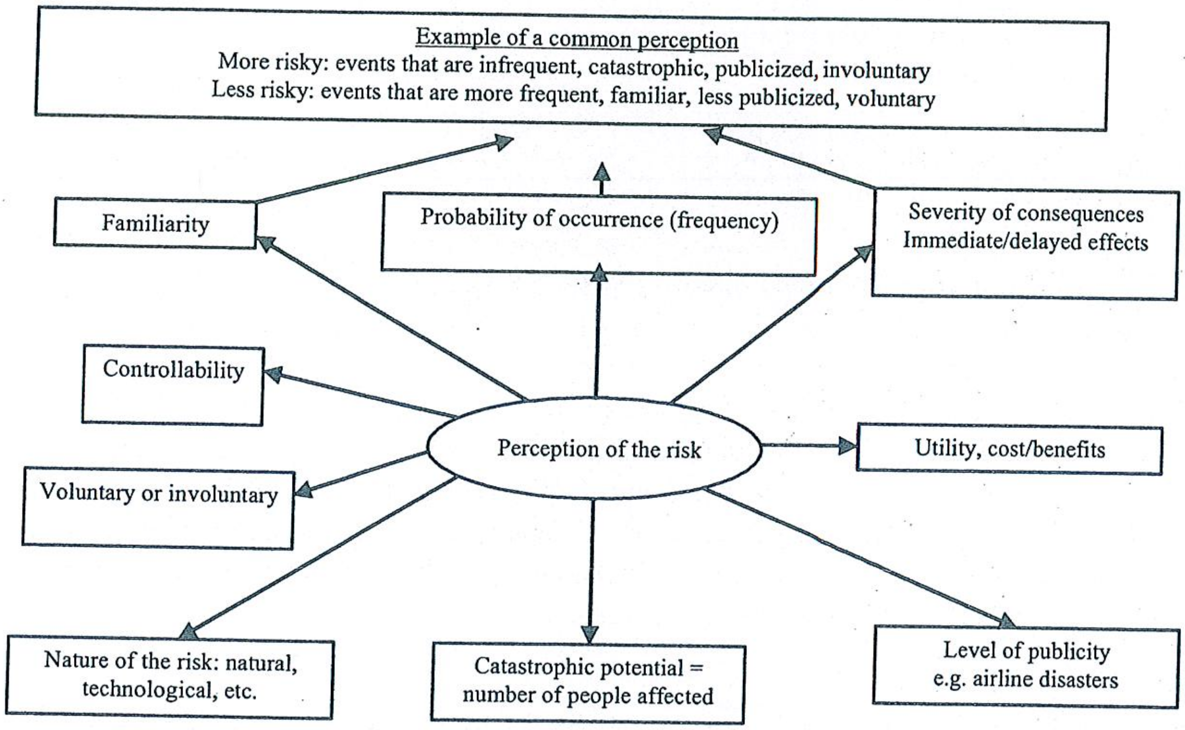

Figure 1 - Structuring by Characteristics of the Risk

Fleming et al. (1998), reporting a study by Zimolong (1985), noted that construction workers overestimated the risks related to occasional or hard-to-understand tasks, and underestimated the risks involved in tasks they performed frequently. In effect, we tend to underestimate known or familiar risks, while being inclined to overestimate risks that are rare but highly publicized. In comparing perceived with actual causes of death in France, Bastide and Pagès (1987) observed that overestimated causes are those that are known, particularly through the media (highway accidents, cancer, murders, etc.), whereas underestimated causes of death are those which go unnoticed (accidental falls) or are more commonplace (household hazards). We know that domestic risk is greater than the risk from highway or airplane accidents, but popular perceptions and fears run contrary to this fact. An example is the recent series of aviation accidents, which by way of the significance of their consequences and the media publicity they received, served to reinforce the idea (false of course) that one has a greater chance of dying in an airline accident than in any other situation. It seems that the number of people simultaneously affected by an accident, as well as the immediate vs. delayed consequences of the risk, also influence how it is evaluated. In this way, based on whether the risk affects a particular group or the community in general, one can observe totally different attitudes. One could almost speak of differential risk perception, depending on who is targeted (i.e., the targeted individuals' social status). Some time after the terrorist attacks of September 11, 2001 in New York, the risk of contamination by anthrax received as much or even more publicity in the West as did other, more common or more deadly risks (AIDS, drought or flood, famine, war, asbestos, toxic waste). Furthermore, voluntary risks -- those an individual chooses to assume, like the personal decision to smoke -- tend to be underrated as compared with involuntary or imposed risks -- those the individual has not chosen -- like living next to a power station (electric, nuclear). In the same vein, one can hypothesize that perceptions of technological or man-made risks (industrial hazards) differ from those of natural risks (earthquake, flood, drought). This assumption can be explained by the perceived controllability of the risk. Controllable risks tend to be evaluated as lower than risks seen as uncontrollable.

Finally, the perceived utility of a risk also seems to affect its evaluation, even if there is not always a link between evaluation of the risk itself and estimates of its utility (Wiegman, Gutteling, & Cadet, 1995). Studies have shown, for example, that "acceptance of risk is greater among young people because they lean toward greater expression of emotions such as aggression, the search for approval by others, sensations of pleasure, awakening of a sense of power and control, and validation of self-esteem" (Kouabenan, 1999, pp. 130-131). The practice of speeding, for instance, could be linked to the pleasure and feeling of power it gives the driver (see Rothengatter, 1988). In a study on the perception and acceptance of occupational hazards by employees exposed on the job (radiation protection specialists, firemen, insurance agents), Bellrose and Pilisuk (1991) noted that despite their awareness of the risks connected with their occupation, and despite their perception of these risks, they seemed able to tolerate them through various compensatory mechanisms, including their professional identity and the satisfaction it brings, being respected in the public eye, gaining prestige through heroism, earning higher salaries, etc.

Subjective Risk Evaluation In Terms of the Characteristics of the Perceiver

Risk evaluation can also be determined by personal or psychosociological variables (age, sex, experience, personality, motivation, culture, values, level of involvement in the risky situation, etc.), cognitive variables (information processing capacity, knowledge, how informed the person is, expertise), individual perceptions of the risk's target (oneself, others, society in general), and evaluations of one's personal exposure to the risk and ability to cope (perceived personal competence and vulnerability, precautions taken and control efforts made, etc.). It is also contingent upon certain socio-organizational variables (social or hierarchical position, job or involvement in the organization, social norms and pressures of the ingroup, etc.) as well as cultural, political, or strategic variables specific to the organization (corporate mission, corporate culture, safety consciousness, management, etc.) (Figure 2).

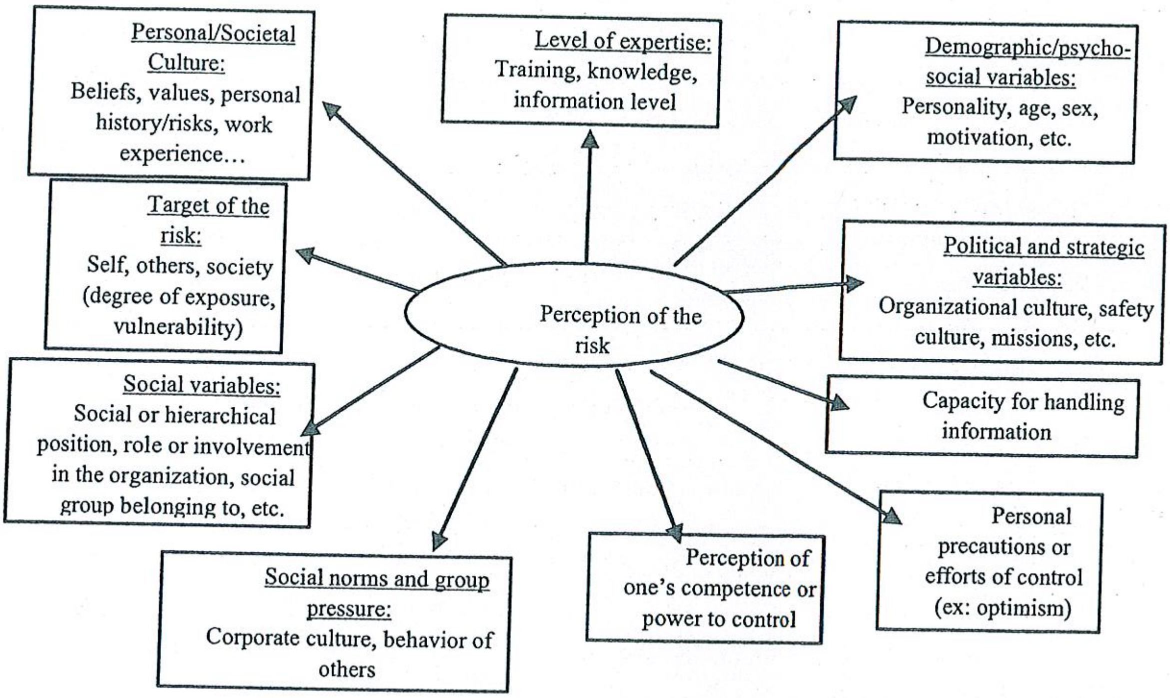

Figure 2 - Structuring by Characteristics of the Perceiver

In a recent study on the perceived risk of contamination by methicillin-resistant staphylococcus aureus, we were able to observe that the most experienced hospital staff members, and also the ones who had the most contact with patients, tended to underestimate the risk, whereas less well-trained or well-informed individuals, along with those who had already experienced a contamination, seemed to fear the risk the most (Kouabenan et al., 2003). A striking finding in this study was that those who had been contaminated in the past also overestimated their vulnerability to other risks present in the hospital environment (aggression, splattered bodily fluids, allergy, injury from handling heavy objects, needle pricks/cuts, etc.). A similar finding was obtained in a study on the perceived risk of highway accidents: accident victims tended more than non-accident victims to overestimate various risks presented to them (road accidents, accidents at work, violence in the street, burglary, unemployment, etc.) (Kouabenan, 2002). It seems as if the negative experience of a risk increases perceived risk by bringing to mind the possibility or probability of unfortunate occurrences. Inversely, prolonged exposure without identifiable or perceptible harm or damage may contribute to lowering the level of perceived risk. In another study dealing with the perception of health and environmental risks related to waste handling, we found that young people, city dwellers, and people with children were more sensitive to risks than the elderly, residents of rural areas, and persons without children. In addition, individuals whose job involved handling household waste were more sensitive to risk (less optimistic) than others (Viviani & Kouabenan, 1999).

Other studies have shown that risk perception is socially and politically constructed (see Kouabenan, 2001a). This is seen in the fact that individuals belonging to the same group or community perceive risk through a filter of group interactions and shared experiences that ends in a common culture of risk. This "culture" is based on a set of norms and beliefs held by the group members. "Some of these beliefs tend to undermine risks whereas others tend to exaggerate them. Some lead to acknowledgment of the unavoidability of risks whereas others foster the idea that certain, sometimes ritualised, practices can ward off destiny and make one able to face dangerous situations" (Kouabenan, 2001a, p. 231). Certain population groups or certain types of occupations that experience natural or non-natural catastrophes on a regular basis have a tendency to integrate disaster into their lifestyle and their view of the world. One can see this trend in countries that repeatedly suffer from earthquakes (Turkey, Greece, India, countries in Latin America, etc.) or floods. These populations seem to develop a culture of risk management generally based on solidarity and mutual assistance. Likewise, acts of bravery and defiance with respect to risk are often encountered in certain occupational areas such as the chemical industries, construction and public works, and metallurgy, where the risks are not only major but severe. This is the case in certain sports, too, where elite players are inclined to have a lower threshold of perception of risk. In these cases, risk-taking seems to be accepted as part of the job. Finally, risk perception varies according to the era, the generation, and the trials of life (war, dictatorship, unemployment, famine, drought or flood, slavery, forced labor, etc.) (see Kouabenan, 2001a). It is an established fact that young people do not perceive risks in the same way as older people (see Kouabenan, 1999; Bouyer, Bagdassarian, Chaabanne, & Mullet, 2001). Likewise, it is understandable that people who have known great catastrophes or ordeals in their life tend to underestimate risks or acknowledge them in a fatalistic manner.

Finally, risk evaluation can be skewed by certain cognitive distortions known as positive illusions in Taylor and Brown's (1994) terms. These distortions include the illusion of control (a feeling of personal control greater than one's actual control), bias of superiority or overconfidence (tendency to believe oneself more able or adept at coping with risks than the average individual), unrealistic optimism (tendency to believe that positive events are more likely to happen than they are in reality, and conversely, that negative events are less likely to happen than they are in reality), and the illusion of invulnerability (tendency to perceive oneself as unlikely to be affected by the disastrous consequences of a negative event). These illusions generally lead to the underestimation of personal risk.

Risk Evaluation and Accident Analysis

Analyzing accidents, incidents, and errors helps increase our knowledge of potential risks in a given situation. One can also evaluate risks based on an analysis of the activities and decision processes that accompany an individual's choice of a particular course of action, or based on after-the-fact explanations given by individuals for accidents in which they are either a victim or a witness.

Lessons Drawn From Previous Accidents

Accident analysis and knowledge of how accidents might have occurred can help us determine how reliable and safe a given socio-technical system is. A system that generates many accidents and/or incidents is, in principal, a system that entails a great number of potential risks. "In the 1990's, recourse to past experiences (REX) became a method of managing safety aimed at improving quality, safety, and reliability from a technical and/or human point of view. The purpose of this currently expanding tool is to provide a method of reflecting upon experience acquired during accidents and/or serious incidents that occurred in normal or disorganized situations, in order to recall the consequences and store the experience in memory for later use" (Weill-Fassina, Kouabenan, & De La Garza, 2004). Like "accident" and "incident", "risk" is a constructed concept. It "goes back to a series of accidents or events; it is inferred from accidents or events that have occurred or been judged similar in a given situation, during a given period" (Leplat, 2003, p. 38). Based on knowledge of the frequency and type of accidents occurring in a specific system, under specific circumstances, one can estimate the probability of certain types of accidents in that system or in identical or similar conditions. "Studies of safety and reliability are perhaps more focused on diagnosing existing situations from the perspective of damaging accidents and incidents, while studies of risk appear to be aimed more at prognosis and to be more sensitive to the uncertainty aspect of events" (Leplat, 2003, p. 37).

Activity Analysis, Error Analysis, and Risk Evaluation

"Risk can be conceived of and analyzed in reference to the activity that contributes to its production and of which it represents one of the characteristics" (Leplat, 2003, p. 44). It refers to the effects associated with a specific activity or course of action and any hazardous consequence that can result from that activity. "The presence of a risk would thus be the expression of a gap between the activity performed and the prescribed task: the operator does not fulfill the task requirements, if they exist and are relevant" (Leplat, 2003, p. 44). Note nonetheless that not all deviations from prescribed tasks necessarily introduce a risk. The prescriptions themselves may be maladapted, incomplete, or impossible to follow, or they may contain conflicting criteria, and by that token, be a source of risk. Another possible avenue for evaluating potential risks associated with an activity, then, is to analyze difficulties in task performance and identify dysfunctional areas, critical incidents, and sources of error. Error is regarded as a risk factor, just as risk is described as a error factor. Error can be considered as one of the precursors of accidents or incidents. However, the link between errors and accidents is not always an established one: not all errors lead to accidents, and likewise, the presence of errors is not invariably found in the chain of events leading to an accident. In any case, we can hypothesize that error is one of the important contributing causes of accidents. In order for the study of errors to be useful in risk evaluation, it should not be limited to the human component of a system, but should include the entire socio-technical system and the activities it generates. "Errors can reveal a maladapted man-machine system and the interface between them; at the same time, they can reveal to the operator his/her own limitations or the limitations of his/her competence in the prescribed task and thereby contribute to adapting the action control mode" (Weill-Fassina, Kouabenan, & De La Garza, 2004). Errors become a source of knowledge about the activity that produced them.

Risk Evaluation and Decision-Making

The available studies on this topic deal with the link between decision-making and safety. They generally seek to determine the consequences of individual decision-making on safety issues by analyzing the conditions under which individuals perform tasks. "The link between decision-making and safety is often evaluated by considering the subject's perception of risk, his/her assessment of it, and how accepting he/she is of the perceived risk" (Kouabenan, 2000a, p. 285). These studies, which draw from information theory, have given rise to several models of accident-causing processes. The typical approach is to model sequences of events leading to safe or dangerous actions. This allows one to more or less reconstruct the cause of an accident, starting from the decisional choices of the operator. Accidents generally result from the non-optimal processing of risk information and an unsatisfactory assessment of the actions likely to prevent them. According to Lagerlöf's (1976) model, for example, the probability that a latent risk will turn into an accident depends on how the concerned operator perceives and evaluates the risk and the decision he/she makes about it, as well as how that decision is influenced by various factors (risks linked to the physical and technical work environment, control factors related to the company, the work group, or the outside environment) (see Kouabenan, 2000a). In conclusion, and according to Oppe's (1998) definition, risk is directly linked to decisions made by the individual. Such decisions are generally preceded by an information selection and processing stage, a risk evaluation process, and a weighing of the advantages of various possible alternative actions.

Contribution of Naive Explanations to Risk Evaluation

The insights drawn from studies on naive explanations of accidents (Kouabenan, 1985, 1999, 2000a, 2000b; Kouabenan et al., 2001), that is, spontaneous explanations of accidents given by individuals who are not specialists in safety or accident analysis, can provide some indirect answers to the issue of risk evaluation. Causal attributions made by individuals can reflect their risk-evaluation process. We know that causal attributions are based on representations and beliefs held by individuals, and are influenced by several variables specific to the victim, the analyst, the accident's characteristics, the analyst's evaluation of the probability of being confronted with the risk (situational relevance), and so on. We also know that causal attributions are generally defensive. The solely internal nature of these attributions leads to the underestimation or overshadowing of external factors, and thus to a partial -- in both senses of the term -- diagnosis of the causes of accidents and their associated risks. A similar process occurs when external or fatalistic explanations are favored ; in such cases, internal factors are undermined or underrated. In either case, objective risk increases because it is incorrectly evaluated. As with explanations of accidents, one can assume that objectivity in risk evaluation is impeded by what is at stake, by personal or strategic motivations. However, naive explanations are not always biased or defensive; they can reveal a number of true organizational dysfunctions, difficulties in applying job procedures, insufficient or unsuitable work tools, communication problems, etc., and in doing so, can draw attention to the risks linked to these flaws and shortcomings (see Kouabenan, 1999, for more details).

Risk Evaluation and Self-Protective Behavior

Risk evaluation is not an end in itself. It is rather a very important stage in defining preventive actions and adopting safe behavior. The fundamental goal of risk evaluation, whether normative or subjective, is control -- that is, the pursuit of greater mastery of the socio-technical environment and dependable operation of the man-machine system.

Normative Evaluation of Risk and Safety Management

Quantitative and/or normative risk evaluation allows us to locate risks, determine "danger points" for safety, find flaws in tools or materials often involved in accidents, identify dangerous equipment or installations, and diagnose poor job task organization or defects in the man-machine system as a whole. These different elements provide decision-makers with information that helps them determine whether or not to implement preventive actions and how to guide those actions and define their targets and methods. In particular, they facilitate decisions as to whether the top priority in preventive efforts should be choosing the production processes, job equipment, substances or preparations; arranging or rearranging workspaces or installations (physical dimensions of workstations, coordination of activities, traffic, information and communication systems, etc.); defining different jobs (pace, operating mode, physical and social environment); selecting the appropriate tools for the task and for the worker; training employees; setting up individual or collective safety equipment; launching campaigns to disseminate information and increase safety awareness, and so forth. Evaluating the severity of accidents and risks allows us to grasp the extent, cost, and immediate vs. delayed nature of their consequences, and therefore to set action priorities and plan preventive measures. Probabilistic evaluation of risks helps in foreseeing potential risks, taking measures to prevent them from occurring, or mitigating their repercussions, in short, guarding against them.

Subjective Risk Evaluation and Safety-Conscious Attitudes

Subjective evaluation affects an individual's relationship to risk and his/her safety-related attitudes and behaviors, whether in a positive or negative manner. Examining subjective evaluation improves our understanding of individuals' decisions and chosen actions, i.e., why in certain cases people take precautions, while in others they neglect certain apparently essential measures: in short, why people take risks or adopt risky behaviors. Even if not all perceived risks are avoided, the lack of awareness or underestimation of risks can lead to risk-taking or unwise negligence. Clearly, moderate optimism can have a beneficial effect on behavior insofar as it reinforces a feeling of control, self-confidence, and a certain faith in one's self-efficacy for managing risk. Unrealistic optimism, on the other hand, and most of the positive illusions described above generally lead to the underestimation of personal risk. People who hold such illusions tend to falsely believe that they can control the situation or that they are out of the range of exposure to the risk. As a result, they adopt behaviors that are in fact risky, or they neglect precautions they might otherwise take. These biases or illusions can also help us understand the failure of information/awareness campaigns. Such campaigns might not raise much concern in individuals who entertain these biases or illusions. If the message sent out by a campaign does not match the individual's own evaluation of the risks being attacked, there is little chance that the individual will feel concerned. According to Slovic et al. (1981), "subjective judgments, whether by experts or lay people, are a major component in any risk assessment. If such judgments are faulty, risk management efforts are likely to be misdirected" (p. 17). In a study conducted following the accident at Chernobyl, Dolinski, Gromski, and Zawisza (1987) noted that individuals who saw themselves as invulnerable had a tendency to neglect precautions, while those who were pessimistic were inclined to take more self-protective measures than the "optimists". This shows why taking the average individual's subjective evaluation of risks into account strongly facilitates our understanding of risk and people's willingness to get involved in preventive actions.

Subjective Evaluation of Risk and Safety-Conscious Behavior

It is hypothesized that people's subjective evaluations of risks can affect their behavior. Awareness of risk can disturb one's feeling of control, generate fear and anxiety, or in certain cases, arouse pleasure (Cadet et al., 1987). In recent years, we have witnessed how food consumption was affected by fears related to the discovery of potential health risks in certain foods or meats (mad cow, listeriosis, etc.). Other examples are the impact on the airline business of the 9-11 attacks, and the negative reactions and sudden public scrutiny of chemical installations located near residential areas following the accident at the AZF plant in Toulouse (September 21, 2001). These types of fears can reflect realistic or unrealistic -- even exaggerated -- perceptions of risk. Their consequence is a tendency toward overly self-protective behavior, even to the point of behavioral inhibition. People sometimes prefer not to talk about the risk of an accident. Although the link between risk perception and behavior cannot always be proven, several models have been developed to describe the adoption of safety-conscious or self-protective behavior based on people's perceptions and beliefs, particularly in the field of health psychology (see Kouabenan, 2001b). These models try to pinpoint the conditions that might lead individuals to adopt safety-conscious behavior, to give up harmful behaviors, or to avoid involvement in risky actions. They have been applied to preventing behaviors related to various risks and to promoting healthy conduct (quitting smoking, early cancer screening, safe-sex practices, vaccinations, wearing seat belts, getting treatment for alcoholism, etc.). They can also be applied to the prevention of various types of accidents. Models based on value expectancy are among the most widely studied. In these models, four processes always enter into the adoption of self-protective behavior: (1) awareness of the negative consequences of an event and a desire to reduce them, (2) believing that these negative consequences are likely to happen, (3) believing in the effectiveness of a particular action for lowering the probability of an aversive event's occurrence or reducing its impact, and (4) evaluating the costs and benefits of the required action (Weinstein, 1993). While on the one hand, perception of a risk's severity, or of one's vulnerability to it, would seem to discourage maladaptive behaviors, on the other, it seems that self-efficacy and the perceived efficacy of preventive measures are what drive adaptive behaviors. Validation studies have revealed that self-efficacy is the factor that best predicts behavior. This fact can be useful in risk-awareness campaigns for devising prevention messages that will incorporate the shared representations and beliefs of the target audience, in view of enhancing the relevance of its members' perceptions. Thus, the insights gained in the area of risk perception and subjective evaluation are useful not only for diagnosing safety, but also for drafting effective messages on risk and its prevention.

Conclusion

The risk evaluation procedures presented in this article should be thought of as complementary rather than opposed. Each has some advantages but also some limitations. Combining two or more methods will necessarily enrich our knowledge of risks and accidents. Statistics on accidents in the workplace point out the business sectors most at risk, the main causes of accidents, the material elements involved, the major locations at stake, the nature and severity of injuries, the population groups with the greatest exposure, the danger points that threaten safety, etc. They thus permit better targeting of preventive actions. We agree with Leplat (2003) in saying that frequency-based risk-evaluation methods pose several problems, due not only to the choice of denominator, but also because of the rarity of accidents, a fact that leaves only a small number of cases available for study, particularly in systems where many safety devices are in effect. This problem can be circumvented to some extent by including near-accidents or incidents, but as the author noted, their predictive value -- i.e., their link to actual accidents -- is problematic. Using accident statistics has the further drawback of ignoring interactions between variables, and especially of not taking the environment where the accident occurred into account. Moreover, looking solely at accidents that result in work leave prevents us from benefitting from the wealth of information provided by mere incidents, or accidents involving only property damage, both more frequent and perhaps more informative because they elicit fewer defensive reactions. Analyzing work activities and the most common errors and malfunctions fills in this gap by approaching risk from the standpoint of the individual's choice of a course of action, and of the conditions under which he/she performs tasks. However, human activity is extremely varied; it does not easily reveal its laws and depends extensively on the skills of operators and their capacity to recover from errors. Moreover, it is important to avoid limiting risk to the gap between a prescribed task and the actual task. Finally, taking subjective evaluation into account allows us to grasp risk evaluation from the subject's point of view. Subjective evaluations, which incorporate individual beliefs and values, can provide insight into how individuals perceive and estimate risk, permit a better understanding of particular attitudes toward safety, and help us promote involvement in preventive actions. To reach these objectives, we must be sure to take into account people's expectations and cognitions and to ably exploit the biases that arise from their personal evaluations in order to prevent those biases from triggering risk-taking or risk-defying behavior.

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