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Document Version

Publisher's PDF, also known as Version of record

Publication date:

2001

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

As, S. V. (2001). *The measurement of accident-proneness*. s.n.

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The Measurement of Accident-proneness

Sicco van As

SOM-theme A: Primary processes within firms

Abstract

This paper deals with the measurement of accident-proneness. Accidents seem easy to observe, however accident-proneness is difficult to measure. In this paper I first define the concept of accident-proneness, and I develop an instrument to measure it. The research is mainly executed within chemical industry, and the organizations are pictured summarily. The instrument is validated in different ways with different outcomes. On the basis of these outcomes I conclude that the accident-proneness scale has only a limited validity, and each branch of industry probably requires another accident subscale. However for a comparison within chemical industry the instrument seems admissible.

1 Introduction

Many industrial processes have potentially disastrous outcomes for workers and the environment: 'industrial risks'. In this paper I will first define the concept of risk, because "[b]efore anything can be studied scientifically, it must be defined. This step, which sounds so easy, has been a stumbling block for accident research ever since its early days" (Hale and Hale 1972:11, Osborn and Jackson 1988:925). Here risk involves accident-proneness, which can be considered a performance measure. The research was mainly executed within chemical industry. In this kind of industry the potential results of an accident seem very clear and easy to observe (fire, explosion, etc.). The actual accident-proneness however is difficult to measure. My final goal is to develop and validate an instrument to do so.

2 Risk

A society must have a certain attitude about the future before it can incorporate the concept of risk into its culture. Two extreme views are possible: (1) people perceive the future as little more than a matter of (bad) luck or the result of random variations, and (2) people perceive the future as predictable and even controllable to some degree. For the second view it needs the realization that human beings are not totally helpless in the hands of fate, nor is their worldly destiny determined by God. In historical perspective this can be described as the transition from a mythological to a modern worldview (Peper 1998). Other authors state that both views are from all times and people tend to combine the different kind of explanations (Gijswijt-Hofstra, et al 1997). I would like to emphasize that at least a certain degree of '*Entzauberung*' (Weber) is needed to handle risk.

One speaks of risk because, in any particular instance, an accident may or may not occur; causative factors skew the probabilities of different outcomes (Graham and Rhomberg 1996:15). In the mathematical sense risk is the product of the probability

of an event and the consequences of it (result)¹. According to this mathematical approach another requirement to incorporate risk is the introduction of Arabic numbers. Because without numbers there are no odds or probabilities, and as Bernstein (1996:23) states: “without odds and probabilities, the only way to deal with risk is to appeal to the gods and the fates”.

The mathematical approach assumes the probabilities and consequences of (adverse) events to be produced (by natural processes) in ways that can be objectively quantified. However, in social reality objective identification of risks and quantification is impossible. Neither probability nor the consequences (or: expected value) can be quantified in a scientific way (cf. Pollak 1996). An objective identification, or quantification is impossible because of the inherent subjective nature of risk and the fact that the consequences are generally turned to political account. There is no such thing as a ‘real risk’ or ‘objective risk’ (Groeneweg 1994:47, Kunreuter and Slovic 1996:119). Who is responsible? What consequences are undesirable? How many US Dollars equal a human life?²

Frank Knight (Adams 1995:25, Bernstein 1996) demonstrates that in mathematics risk is ‘measurable uncertainty’ (‘you know the odds’), that is not in effect uncertainty at all (e.g. roulette³). The emphasis of sociologists on uncertainty (‘you don’t know the odds’) decouples risk from unrealistic assumptions like ‘decision making under conditions of perfect certainty’ or ‘decision making under the laws of probability’. It also decouples risk from a deterministic approach as Keynes (in: Bernstein 1996) shows by his comparison of roulette with ‘real life things’ like war: “[a]bout these matters, there is no scientific basis on which to form any

¹This interpretation of risk computes expected values by multiplying each possible result by the number of ways in which it can occur, and then dividing the sum of these products by the total number of cases; in formula $P \times R$.

²From out of ‘cultural theory’ (Schwartz, Thompson, Douglas, Wildavsky, et al.) Adams (1995) warns that “everyone will never agree about risk”. He distinguishes four perspectives: the individualist, egalitarian, hierarchist and fatalist perspective. In this view risk does not exist ‘out there’, waiting to be measured. Instead, human beings have invented the concept of risk to help them understand and cope with the uncertainties of life (cf. Weber 1949:81).

calculable probability whatever. We simply do not know!”. These words are hopeful: in a world where pure probability does not exist we are not prisoners of an inevitable future. Or: “[o]nly if there is uncertainty is there scope for responsibility and conscience. Without it we are mere predetermined automata” (Max Born in: Adams 1995:18). So it can be concluded that risks should be studied from a voluntaristic point of view.

From an organizational perspective risk is about problems of decision-making in the face of uncertainty. Here probability cannot be calculated in a quantitative way but it can only be described in relative terms like ‘more’ or ‘less’ (proneness). This view of probability points to the main difference between the mathematical and sociological approach of risk: the concept of uncertainty. Uncertainty refers to the complexity of social reality on one side, and to cognitive limitations on the other. The main reason for uncertainty however, is not just a lack of (quantitative) information about social processes or the limited capabilities to process this information, but especially the irrelevance of this information for future events. Not two serious accidents are the same because of the high variety and amount of contributing factors. History does not repeat itself exactly, the next accident will always be different from the one before because of anticipating agents, and always unexpected.

Nowadays, in sociology, definitions and interpretations of risk follow the ‘uncertainty approach’⁴. Here I adopt a broad definition from everyday English and everyday life. Risk will be defined as: ‘human activities that might cause an accident’. The words ‘human activities’ point at the role of a voluntaristic actor (or: agent) and distinguishes the concept from danger⁵; human action can reduce or increase the

³Even in case of roulette it can be argued that the consequences can not fully be quantified. The ‘fun of the game’ must represent a certain value for some people because otherwise no rational human being would ever visit a casino.

⁴This also includes economics. Except for ‘financial risk’, which is closely fitted with the mathematical view of risk. “Risk control in asset management is the ability to manage the uncertainty associated with the investment process. Fundamental to [financial] risk control is risk measurement, which can be thought of as quantification of the characteristics of risk” (Fong and Vasicek 1997:51).

⁵In literature many different concepts are used, with a slightly different meaning. E.g. danger seems to refer to the possibility that something unpleasant or undesirable might happen

probability (and size) of the damage. This definition fits closely the way in which the concept of risk is used within accident- or safety research (e.g. Heinrich 1959, Groeneweg 1994). It only involves ‘down-side risk’: problems or accidents, and not the opportunities. Here it equals ‘accident-proneness’⁶ (or: operational risk); which is conceived as the opposite of safety or reliability.

3 Accident-proneness

The definition of risk above does not solve all conceptual and measurement problems. The quantification of consequences is replaced by the problematic concept of ‘accident’. The subjective and political nature of risk still make it necessary to reach consensus about what we consider an accident. A more methodological drawback is that, because of prevention and anticipating agents, accident rates cannot serve as the sole measure of risk; if they are low, it does not necessarily indicate that the risk was low. It could be that a risk was perceived and avoided⁷. And, in practice, it is not a valid indicator of accident-proneness because there are not enough serious accidents within organizations. In such a situation the number of accidents is highly dependent on coincidence.

In the Netherlands the government has delegated (at least for a part) the responsibility for safety policy towards the workers and managers. The approach, on

without the intervention of an agent, e.g. getting struck by lightning while playing a game of football. The related concept of hazard seems to refer to the unpleasant results of technological characteristics (design, construction, material, etc.).

⁶This meaning of proneness is different from the one in the human error literature. The human error approach focuses on proneness as differences in personal attributes; so-called error-proneness, e.g. clumsiness (e.g. Hale and Hale 1972:15, Dwyer 1991:56-57). In this research accident-prone is considered to be an organizational instead of an individual (performance) characteristic.

⁷The ‘problem’ of anticipation is described by Adams (1995:30): “Risk is defined [...] as the product of the probability and utility of some *future* event. The future [...] does not exist except in the minds of people attempting to anticipate it. Our anticipations are formed by projecting past experience into the future. Our behavior is guided by our anticipations. If we anticipate harm, we take avoiding action”.

which the Dutch Health and Safety Act is grounded, is that employers and employees have a natural common interest in reducing risks. However, the implementation of safety regulations is accompanied by conflicts, and this way of governing on distance gives organizations the opportunity to deceive the authorities. A nice example of this phenomenon is the case of Tank Cleaning Rotterdam (Mascini 1999). It shows how a company with a highly respected registration system knew highly unreliable output indicators. Also organizational politics mentioned before, like 'blaming the victim', will lead to unreliable safety-indicators like LTI's (Lost Time Injuries), RWC's (Restricted Work Cases), and MTC's (Medical Treatment Cases).

That no objective demarcation of accident exists is supported by the observation within my field study (that will be discussed in the next section) that even the 'official' definition of accident varies over organizations within the same country (the Netherlands). For example within one organization an accident is always registered if someone gets hurt, while in another organization an accident is only registered if the victim is not able to do a substitute job (usually study). I define an (industrial) accident as a sudden disturbance within the primary process, as a consequence of unintended human action, that results in physical harm or serious damage to equipment or environment⁸. The element of duration (a 'sudden' event) distinguishes safety and accident from 'health' and industrial diseases as dermatitis, asbestosis, etc. In this paragraph I will distinguish different aspects of accident-proneness to work out the measurement problem and to fit close the broad definition of accident-proneness.

Accidents in primary processes have attracted much attention in literature and in practice. In the quest for potential sources of accidents especially two approaches are very popular: the technical error approach and the human error approach. The first is

⁸In system terms Perrow only speaks about an accident in case of damage to objects or people "that affects the functioning of the system we choose to analyze". By that he distinguishes between part, unit, subsystem and system. "An accident is a failure in a subsystem, or the system as a whole, that damages more than one unit and in doing so disrupts the ongoing or future output of the system. An incident involves damage limited to parts or a unit, whether

directed towards hardware and design aspects like engineering, construction and materials⁹. The second approach studies the errors made by individuals and is thus highly inspired by the psychological perspective. The latter is oriented towards intrinsic factors (cognitive biases, attentional limitations, etc.) that are viewed context-free (so task- and context-independent). The main goal of this psychological approach is the identification (and allocation) of so-called 'error-prone people'.

From a sociological point of view the difference between technical and human errors seems irrelevant because also these 'technical errors' can be interpreted in terms of human errors. Design, construction, etc. are not just characteristics of technology, but the results of different activities. People design, construct, choose the materials, implement, work with, repair or maintain technologies. Beside this theoretical consideration an empirical observation is that hindsight analyses of serious accidents overwhelmingly favor mistakes as the root cause (e.g.: Heinrich 1959:13, Leplat 1987:133-, Reason 1990, Adams 1995:16). The safety literature shows that accidents generally are caused by a combination of several mistakes on different levels of the decision making-process and these can be made for a long time before they become manifest by causing an accident (the incubation period).

Death seems the least ambiguous of all available indicators. But, as stated before, within the organizations under study there are simply not enough accidental deaths (within each organization at most one or two persons got killed during the last decade). As a consequence I need another measure of accident-proneness. Often used in practice - in ascending order of numbers but in descending order of severity - are fatal accidents, serious injuries, first-aid treatments, property damage and near-accidents. Other possible indicators of accident-proneness are the number of unplanned, and performance time between, outages, periods of time to shut down and start up a reactor, maintenance work (Hirschhorn 1993:138) and the limit of breaching the minimum five-mile distance between airborne planes (from the Federal

the failure disrupts the system or not" (1984:66). In practice however the difference between incident and accident is whether people interpret something as more or less serious.

⁹Here the goals are a 'foolproof' system, and to minimize human intervention, however "A common mistake that people make when trying to design something completely foolproof was to underestimate the ingenuity of complete fools" (D.N. Adams 1992).

Aviation Administration). These indicators are based on an expert consensus of what constitutes a risk or what is likely to indicate the onset of risky behaviors (Creed, Stout and Roberts 1993:70).

4 Organizations in chemical industry

The first empirical part of the research is carried out within eight different organizations (A - H). Here I will introduce the organizations in which the research was conducted. These are organizations within the Dutch exploration and chemical industry and they operate around different processes related to the exploration of gas, and the production of base - and functional chemicals. They are, as a joint venture or as a full daughter, part of multinational companies. The organizations will only be pictured summarily and, to preserve confidentiality, in random order and nameless.

The eight organizations can be described by some simple indicators (table 1). At first sight the most startling numbers are the ratio between executive and non-supervisory staff within organization D, and the one between production and maintenance within organization A. The last ratio could be explained by the fact that the maintenance department of organization A was actually working within three different organizations (A, C and G).

Table 1: Characteristics of the survey respondents

Organization	A	B	C	D	E	F	G	H	Total
Response %	56	60	72	39	65	52	65	76	56
Response #	44	36	29	81	52	83	36	75	436
Production*	21	26	21	45	41	55	29	54	292
Maintenance	20	8	5	30	6	23	5	15	112
Other**	3	2	3	6	5	5	2	6	32
Supervisory staff	15	13	12	41	15	30	13	27	166
Non-supervisory staff	29	23	17	40	37	53	23	48	270

*: includes shipping department. **: includes technology department and staff

The organizations under study can be described as complex and tightly coupled¹⁰, and know about the same degree of technology. The main chemical risks within these eight organizations are: high energy concentrations, high pressure, intoxication, poisoning, fire, and explosion. They have a comparable structure of positions, and similar departments can be distinguished: production, maintenance, and staff/technology.

5 Measurement

Based on the earlier observation that accidents are actually caused by mistakes, I will regard mistakes (including dangerous behavior and attitudes¹¹) as an aspect of accident-proneness. Of course another aspect are (near-) accidents itself. A near-accident (or 'near miss') is an incident that in other circumstances could have resulted in an accident. A methodological problem is that information about mistakes and near-accidents is highly dependent on beliefs and willingness to report. They are easy to hide, and people are willing to hide because they feel ashamed or afraid to be punished¹² and often they do not consider near-accidents worth reporting. In terms of the famous iceberg metaphor the mistakes are the part under water, the near-accidents are at the surface and the accidents are the part above the water.

The direct observation of the occurrence of accidents is practically impossible since they tend to be rare and unpredictable (Hale and Hale 1972:12). To overcome the reporting artefact somewhat I combined different aspects of accident-proneness and measured them anonymously by a questionnaire instead of relying on the official statistics. The main aspects of accident-proneness are (near-) accidents and mistakes.

¹⁰Because of chemical characteristics of the (raw) materials, it is not realistic to decouple different activities much further to reduce their 'detailed interdependence'.

¹¹For the use of mistakes, dangerous behaviour, and attitudes as 'alternative criteria for study' see: Hale and Hale 1972:13-4

¹²"For all non-fatal measures of risk there is a[n ..] intractable measurement problem, variously labelled shame, guilt, responsibility, liability, stupidity, or the Hawthorne effect" (J. Adams 1995:90).

To measure these different aspects, I combined two ‘subscales’: (1) items about the frequency and severity of (near-) accidents and about the ‘general’ safety within an organization and (2) items about the frequency and kind of mistakes made by colleagues (five-point Likert scales).

The survey items were applied to the situation within the chemical industry. In May 1999 this survey was sent to all employees within the production, maintenance and shipping sequences within organizations A - H, and their staff. The respondents were operators, (different kind of) engineers, shippers, support staff, supervisors, etc. 436 employees cooperated within the research (equals 56% response). The response can be qualified as a relatively high one.

Four items measured (near-) accidents and the employees’ general opinion about the safety within their organization, e.g.: ‘How many accidents did you witness within the last three years?’, and ‘Where you involved yourself?’ (total score: 0 - 17). Another six items measured mistakes and risk-taking behavior (by colleagues), e.g.: ‘many employees don’t have enough skills to fulfill their task in a safe way’, and ‘many employees push their luck too much’ (total score: 0 - 16). The ten items together comprise the ‘accident-proneness scale’ (Likert scales; Cronbach’s Alpha = .75; N 434, total score: 0 - 33, for full scale see appendix).

Table 2: Subscores, and accident-proneness (means)

Organization	A	B	C	D	E	F	G	H	Total
(near-) accident score	3.9	4	4	4.3	5.8	4.5	6	5.6	4.8
Mistake score	6	6.7	7	6.8	6.5	7.8	6.9	7.8	6.8
Accident-proneness	9.9	10.7	11	11.1	12.3	12.3	12.9	13.4	11.6

One-Way ANOVA: Accident-proneness: $F = 3.050$; $df = 7$; $Sig. = .004$

For an analysis at organizational level (table 2), several tests can be used. The F test is an extension of the two-sample t test and produces an analysis of variance for a quantitative dependent variable by an independent variable (organization A - H). It provides us with a value that represents the average sum of squares between the different groups divided by the average sum of squares within the groups. Many different tests can be used for post hoc pairwise multiple comparison tests. In this

research I used the Scheffe test and Sidak's t test. The Scheffe test is the most conservative test, which means that a larger difference between means is required for significance. The least significant difference pairwise multiple comparison test is equivalent to multiple individual t tests between all pairs of groups. Sidak's t test provides tighter bounds than the more commonly used Tukey's HSD or Bonferroni test. On accident-proneness the Scheffe test does not show any significant differences. But Sidak's t test shows significant differences between organizations A and H, B and H, and D and H.

6 Validation of accident-proneness

The accident-proneness scale is an equal weighted combination of the (near-) accident subscale and mistake subscale. The Cronbach alpha score of .75 can be interpreted as an internal content validation, it indicates that the two subscales measure one common factor (accident-proneness). An external, more qualitative, face validation of the accident subscale at organization level was executed by a comparison with about 100 spontaneous employee reports. The item about accidents witnessed within the last three years, was followed contiguous by the question whether the respondent could describe these accidents. These employee reports made clear that the respondents understood the concept of accident exactly the way it was meant by the researcher.

The spontaneous reports provided valuable descriptions of (near-) accidents. Examples were many small fires, more and less serious leakages, drop out of cooling-water, working on pipes that are still under high pressure, mechanical reactions under high pressure, railway tank cars that 'move by themselves', raising a scaffolding above a railway which is still in use, falling (heavy) objects, getting stuck between moving parts, inhaling gasses, getting products in the eye and against the body, etc. The results were burns and scalds, broken limbs and other parts, amputations, disablement and even fatalities.

It might be able to determine the index validity of the accident subscale by an external comparison at the level of branches of industry. At this level there are

enough serious accidents to make reliable comparisons. Therefore I asked other respondents in a separate survey (executed by CentERdata) in which branch of industry they were working, and to answer the questions from the accident-proneness scale. These data can subsequently be related to data at industry level from the Occupational Safety & Health Administration (OSHA) (table 3).

Table 3: Index validation by branch of industry

	OSHA-fatal	OSHA-LWD's*	Proneness	Accid.subscale	correct. (size)
Retail	2.6	20.0	11.2	2.1	16.6
Government	3.1	21.0	11.3	2.3	11.8
Chemical**			12.0	4.2	9.2
Manufacturing	3.4	29.6	15.4	4.6	13.6
Construction	14.6	44.4	14.7	3.3	18.4
Transportation	18.2	40.0	15.0	3.5	16.2
Agriculture	24.1	37.0	15.3	4.7	40.0

OSHA incidence rates represent the number of fatalities per 100,000 and LWD's per 10,000 full-time workers 1998. CentERdata N = 718 *: Lost workday cases (LWD's) include those which result in days away from work with or without restricted work activity **: OSHA data not available.

At first view both the OSHA numbers and CentERdata numbers are not surprising. At second view the accident-proneness scale seems to have only a limited index validity. In this 'external' validation by different branches of industry especially construction scores too low (14.7), manufacturing too high (15.4), and the differences between the different branches are too small. This could be expected because the accident-proneness scale should be adapted for two reasons: the first reason is a conceptual one. The proneness scale also involves a mistake subscale. This subscale should discriminate between different organizations, but not between different industries (naturally also employees within retail and government make mistakes, however with less disastrous outcomes). Nevertheless the accident subscale does not show to be highly valid either. On these items manufacturing still scores too high (4.6) and also on this subscale the differences between the industries seem too small.

The second potential reason for a limited validity are the differences in size between organizations. The OSHA data involve numbers per 100,000 full-time workers, while the accident-proneness scale involves items referring to the work organization of the respondents. It is reasonable to assume that employees within large organizations experience more accidents around them and have more colleagues making mistakes than employees within small organizations. After correction for the average organization size (table 3: correct (size)) within each branch of industry it could be a better indicator. For the reasons just explained I also double weighted the accident-subscale. However, this still resulted in scores of the respondents within retail and agriculture that seem too high (16.6 and 40.0).

I can conclude from table 3 that the accident-proneness scale only has a limited validity. So it should be realized that measuring accident-proneness probably requires another accident subscale for each branch of industry. It is likely that for a satisfactory use of one common scale there is too much difference between the definitions of an accident within different branches. On the other hand, from the qualitative comparison of the accident-proneness data with the employee reports and analysis of Cronbach's alpha, I conclude that the validity seems sufficient within the industry under study. Here the measurement of accident-proneness will be considered admissible for a comparison within chemical industry.

7 Conclusions

In the first part of this paper I analyzed the concept accident-proneness as a particular kind of (down-side) risk. Our definition of risk follows the ‘uncertainty’ approach and a simple definition was chosen: ‘human activities that cause an accident’; it equals operational risk, which is conceived as the opposite of safety. No objective demarcation of accident exists, and here it was described as a sudden disturbance that results in physical harm or serious damage.

Reliable safety-indicators are hard to find within the industry under study. Hindsight analyses of serious accidents overwhelmingly favor mistakes as the root cause of accidents. For this reason mistakes are regarded as an aspect of accident-proneness, just like (near-) accidents itself. Both aspects were measured anonymously by a questionnaire within eight organizations in Dutch chemical industry. These organizations were pictured summarily. A field- and desk research was executed to validate the instrument.

Cronbach alpha could be interpreted as an internal content validation. An external, more qualitative, face validation could be executed by a comparison with about 100 spontaneous employee reports. However an index validation by a comparison at the level of branches of industry showed only a very limited validity. An hypothesis for further research is that another accident subscale is needed for each branch of industry, because there is too much difference between the definitions of accident within different branches. On the other side, I also concluded that the validity of the accident-proneness scale is sufficient within the industry under study.

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Appendix: accident-proneness scale Dutch - English

original scale:

- S Veel medewerkers hebben niet genoeg vaardigheden om hun taak veilig uit te voeren.
- S Veel medewerkers hebben niet genoeg kennis of informatie om hun taak veilig uit te voeren.
- S Het gebeurt regelmatig dat medewerkers fouten maken.
- S Het gebeurt regelmatig dat medewerkers zich niet aan veiligheidsregels houden (vergeten van helm, veiligheidsbril, e.d.).
- S Veel medewerkers nemen grote risico's.
- S Het gebeurt vaak dat mensen taken doen die veiliger door anderen gedaan zouden kunnen worden.
- S Het is goed gesteld met de veiligheid binnen onze organisatie.

[toelichting: Met ongeluk bedoelen we een gebeurtenis waarbij milieuschade en/of materiële schade is ontstaan of waarbij zelfs mensen gewond zijn geraakt. We denken daarbij aan lichte en zware verwondingen en/of zelfs dodelijke ongevallen.]

- S Heeft u in de afgelopen drie jaar een ernstig bijna-ongeluk meegemaakt bij dit bedrijf?
- S Heeft u in de afgelopen drie jaar één of meerdere ongeluk(ken) meegemaakt bij dit bedrijf?
- S Zo ja: Betrof dit een ongeluk waar uzelf bij betrokken was?

translation:

- S Many employees don't have enough skills to fulfill their task in a safe way.
- S Many employees don't have enough knowledge or information to fulfill their task in a safe way.
- S It happens regularly that co-workers make mistakes.
- S It happens regularly that co-workers don't follow the safety regulations (they forget their hard hat, safety goggles, etc.).
- S Many employees push their luck too much.
- S Regularly co-workers do things that could be done safer by others.
- S Generally spoken the safety is fine in our organization.

[commentary: An accident is an event which results in environmental or material damage, or where people got hurt. We mean injuries and even fatal accidents.]

- S Did you witness a serious near-accident within this organization during the last three years?
- S Did you witness one or more accidents within this organization during the last three years?
- S If yes: Where you involved in the accident yourself?