Proc. of the European Safety and Reliability Conference (ESREL 2026)
Edited by José C. Matos, Paulo B. Lourenço, Michael Beer, Daniel Oliveira, Edoardo Patelli, Hélder S. Sousa, Rui A. Silva and Monica Santamaria
 Published by Research Publishing, Singapore.
doi: 10.3850/ESREL2026061419_esrel26-p26199-cd

Safety of machinery: how yearly recorded accident data relate to the fascination "vision zero"

Heinrich Moedden,

German Machine Tool Builders´ Association (VDW), Frankfurt am Main, Germany, email: h.moedden@vdw.de

The issues "risk assessment" and "tolerable risk" are causing conflicting reactions not only among health and safety experts. Experienced designers in the machinery sector are sometimes unsettled, too. The controversies are mainly about numerical representations of hazard "probabilities" and what they mean in the context of a machine design and its operation. Admittedly, theoretical risk assessment starts in the hypothetical "what if" domain, where theoretical risk can be estimated only logically in cause and effect (at the most), but not in an absolute scale. However, actual relative risk reduction effects between different yearly accident records can be calculated and compared quite exactly, because the real risk actually can be "measured" (relatively) precisely as by the records of Health and Safety representatives (in Germany BGHM and DGUV), as well as in individual records of machine tool builders. A typical question is being reiterated, when it comes to required upgrades in the design of certain safety functions in machine tools: „Is there any evidence in the operations field that indicates the need to upgrade this safety function, or is it only because of hypothetical fears?" And it also happened again and again that the alleged need for a required upgrade could not at all been proven by corresponding failures and related accidents with injuries. Therefore, this paper tries to support plausible risk considerations connecting theory and reality.

Keywords: accident data, risk, machine tool

1. Probability in Safety of machinery

The issues "risk assessment" and "tolerable risk" are causing conflicting reactions not only among Health and Safety experts. Experienced designers are sometimes unsettled, too. The controversies are mainly about numerical probabilistic representations. These were introduced in the field of general machinery safety, when the revised European Machinery Directive 2006/42/EG *[22]* extended the "hazard analysis" of former versions to a "risk analysis" by introducing the term "probability" in the expression: "*estimate the risks, taking into account the severity of the possible injury or damage to health and the probability of its occurrence".* Since this alteration in a legal text, simplified probabilistic methods as in ISO 13849-1 *[23]* are being developed. They encounter a well-proven practical state-of-the-art, which is merely based on qualitatively defined requirements. They were mainly focussing on hazards as such (and their countermeasures) rather than "risks, severities of injuries and their probability of occurrence". Nevertheless, on the background of customer demands for very high availabilities (which partly is equivalent to high inherent safety), it brought about a well-tried state-of-the-art following the three-step-reduction method of ISO12100 [24]. The state-of-the-art is defined on a non-quantitative descriptive background in harmonized safety standards in the Official Journal of the European Commission [22] since more than 20 years. However, the advantage of the quantitative probabilistic theory is clearly visible: the entire risk reduction process can be detailed in single quantitative factors showing the proportions to enable a more effective engineering ("Pareto principle"). Surprisingly, the transition from "qualitative" to "quantitative" requirements was not so easy, since the key term „probability" turned out to be ambiguous: subjective probabilities are disturbing the discussions, since many traditional experts claim that objective probabilities were missing or difficult to derive. Is this really so? This should be checked thoroughly, because it is obvious that verifiably founded probabilities, such as e.g. real findings in the operational field and logically deduced probability estimations are better than not scalable subjective gut feeling, speculation and pure hypothetical assumption. That is to say, objective probabilities are always more reliable than subjective probabilities. It is hard to believe, but for the time being, the normative frame for machinery safety does not contain a numerical risk model, which summarizes the single factors in plausible proportions to an overall risk, in order to e.g. compare theoretical results with empirical field data. As a consequence, fictitious hazards and actual risks are being mashed up again and again, so that in controversial discussions in the world of safety standardization (ISO 12100, ISO 13849-1 etc.), mostly the strongest gut feeling overtrumps logical considerations. If objective findings are to be taken as a basis, it is obvious that the sequence of the total annual figures for reportable accidents can be considered as random independent events in a population of comparable elements. Every year, different random effects cause the reportable accidents (different machines and operators are affected in different situations). Mathematical concepts seem to make sense if the annually recorded (machine-specific) accident data are interpreted as the overall result of a huge "random experiment" in a relevant observation framework (e. g. what is given by the DGUV statistics in Germany). Consequently, the annual accident statistics must be linked to a clearly defined "probability space" (also known as "sample space"). Several steps are necessary to apply the probability theory to the "random experiment" of yearly accidents. At first, the real accident records can be connected to some notations of the mathematical measure theory. Obviously, the number of accidents are the "measures" in a sample space. Then, these measures need to be calibrated such that a probability space is built:

Step 1: Define the sample space Ω of this random experiment with all possible outcomes.

Step 2: A measure space $\mathcal{F}$ is required, which contains the measurable sets (called events).

Step 3: The respective measure must be assigned to the events of $\mathcal{F}$.

Step 4: By appropriate scaling, the respective probability is assigned to the events of $\mathcal{F}$.

As a result, Health and Safety experts can monitor yearly accident records on a probabilistic basis, to check how close we are to the goal "vision zero" (risk).

2. Reference to accidents records

The accident numbers of machine tools (for metal working) in Germany are decreasing since the introduction of a new statistical framework of the European Union in the year 2004, and also before, see [28]. The predominant question often is, whether a state-of-the-art can be considered as "proven-in-use" to be safe, or if there are reports of accidents (or incidents) indicating the need for certain upgrades in the safety design.

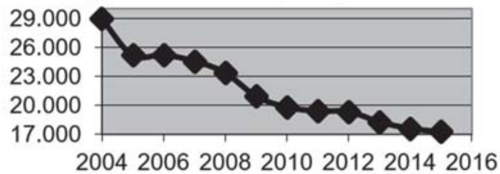

Figure 1: Reportable accidents of German machine tools from 2004 to 2015 (Source: DGUV, VDW)

Answering this question is only possible, if the relevant safety experts of BGHM (German Occupational Safety Organisation for metal-working machines) are involved, see [1] ,[2], [7], [11], [12] ,[17], [18], [19].

2.1 Separating accidents of machine tools

Most recently, the yearly report „Statistik Arbeitsunfallgeschehen 2024" reports in October 2025 a significant decrease of summarized accident data for the branches wood- and metal-working [18], [28]. For the separated numbers of metal-working machine tools (i.e. without wood-working, in the interval 2004 to 2015, see remark below Fig. 3), the situation of Figure 1 remains. The decreasing trend in the overall numbers of reportable accidents is also visible here. Noteworthy is that in 2015 "only" 17.235 reportable accidents are allocated to metal-working machine tools (out of the machine perspective). The delightful results in [18] in the overall numbers of wood and metal of are unfortunately different when focussing closer on the subsets of metal. For instance, in Fig. 2 the subset "new pension payments" is displayed for (metal-working) machine tools.

Obviously, since 2008 the numbers are oscillating up and down, e.g. 281 in 2014 and 350 in 2015; a stable decrease since 2008 is not visible in Fig. 2 and Fig. 3. Remarks: a) unfortunately, DGUV doesn't seem to be able to provide detailed accident statistic after 2015, because only summarized data are being published since then, as in [18], b) maybe this is because the interpretation limits of statistical findings of DGUV are an obstacle.

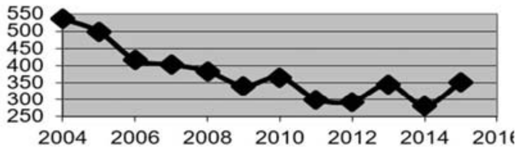

Figure 2: New pension payments for machine tools from 2004 to 2015 (Source: DGUV and VDW)

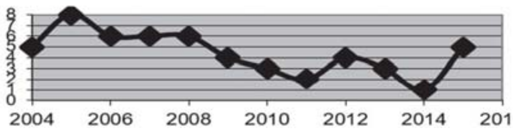

Figure 3: Fatal accidents for machine tools from 2004 to 2015 (Source: DGUV and VDW)

3. Accident statistics and probability space

Obviously, the sequence of yearly overall numbers for reportable accidents can be regarded as random independent events, since each year different random effects are causing the reportable accidents (different machines and operators are affected in different situations).

3.1 Random experiments, accident modelling

Mathematical concepts as in [3],[4],[5] and [8] seem to be useful for the reduction of real accident risks, if the yearly recorded accident data are interpreted as the overall outcome of a huge "random experiment" in a relevant observation frame (which e.g. is given by Occupational Safety (DGUV) Statistics in Germany):

I. the operation of an average number of α comparable machines during the actual record year;
II. an average number of β operators,
III. who are during an average number of γ hours busy in operating them.

Since the probability theory is based on the measure theory, some notations shall be explained graphically and vividly.

3.1.1 Basic terms

The term "probability" can be expressed in different ways [14]:

a) as a real number between 0 and 1, where 0 means impossible and 1 means a certain event; also

b) the expected frequency is used, which is the fraction of the number of relevant events over all possible events (e.g. expressing a statistical finding, empirical or theoretical); if this fraction is connected to a given period of time, it means the probability of an event per time;

c) where no statistical data exist, "probability" can express a degree of belief about facts (e.g. due to subjective "experience").

It is obvious that the latter might become a mere "gut feeling". This is the worst kind of a probability: maybe that is the reason, why William Feller emphasizes in the preface of [8]: "it is the purpose of this book to treat probability theory as a self-contained mathematical subject rigorously avoiding non-mathematical concepts".

Also the expected frequency is often misunderstood. For instance, if there is a lack of experience, e.g. when empirical data or theoretical findings are not available, it amazingly often happens that the *probability* of an event is incorrectly mistaken for a *mere possibility* of occurrence. In doing so, the probability is not calculated with respect to the correct reference frame as a fraction of numerator/ denominator; this error is called "denominator neglect" [6], [21]. I.e. the reference frame for the calculation of probability is omitted or ignored.

As an important logical fundament for quantitative probabilities, Kolmogoroff's axioms (1933) are based on an event space of elementary singletons. The entire probability theory can be developed from them. Extract from [4],[8] for the axiomatic probability definition (quote):

The "probability" is not defined as such. The modern theory rather uses the "probability" as a term, which has to fulfill certain axioms. The axioms established by Kolmogoroff are:

1. To every random event A a real number $P(A)$ can be assigned such that $0 \leq P(A) \leq 1$, which is called the probability of A. This

leans on the properties of relative frequencies.

2. The probability of the sure event E is $P(E) = 1$ (scaling axiom).

3. If $\{A_i, i \geq 1\}$ are random events, which are pairwise disjunct, i.e. $A_i \cap A_j = 0$ for $i \neq j$, then this axiom applies with the limes $n \to \infty$ (countable additivity axiom):

$$\mathbf{P}\left(\bigcup_{\mathbf{i=1}}^{n\to\infty} \mathbf{A_i}\right) = \sum_{\mathbf{i=1}}^{n\to\infty} \mathbf{P}\,(\mathbf{A_i}) \qquad \text{Eq. (1)}$$

3.1.2 Four steps to build a probability space

In order to take the bearings of an effective risk reduction, several steps are necessary to apply the probability theory to yearly accidents, which are seen as a "random experiment" (see [8]). To start with, the real accident records can be connected to some notations of the mathematical measure theory [4 b)]. Obviously, the number of accidents are "measures" in a sample space. Then, these measures need to be calibrated such that a probability space is built.

Step 1: Define the sample space Ω of this random experiment with all possible outcomes.

The entirety of all possible elementary outcomes ω_i, $(\omega_i \in \Omega)$ for every single machine and every single operator has a variety of numerous causes-to-effect relations. It spreads from technical failures over human errors to forces majeure risk (e.g. lightning stroke). So as regards the cause-to-effect relation, the elementary outcomes ω can be thought of as a countably infinite set of singletons $\omega_i = \{\omega_i, i \geq 1\}$. Nevertheless, the entirety of all possible elementary singletons, which are to be assigned to severities of injuries, can be divided in five subsets (i.e. resulting events in a record year, here sorted by their expected frequency of occurrence from high to low), as shown in Table 2.

In addition to this sample space Ω, there are some related events (e.g. further dimensions due to possible repetition): At the end of a record year in the above mentioned observation frame, every single operator in the basic population of β operators is going to be either in the fortunate subset A_1, or he/she was (once or more) lucky in subset A_2, or (once or more) unlucky in subsets A_3, A_4. Or it could even happen that he/she were in the mortal subset A_5. Accordingly for a record period, every single machine of the basic population of α comparable machines can be connected to subset A_1 or to one or more of the subsets A_2, A_3, A_4 or A_5. And finally, every single hour of the on average $\alpha \cdot \gamma$ hours can be allocated at least to event A_1, or to one of the other four subsets.

Subset of Ω	***Meaning***	***Example of one singleton $\omega_i \in A_j \subset \Omega$***
Event A_1	No hazardous event, i.e. undisturbed machine opera-tion (or standing idle), no hazards	Five days of automatic production from Monday to Friday without interrupts.
Event A_2	A hazardous event without causing an injury (i.e. a near accident occurred)	One Monday morning, a drilling tool broke. It was set free, but retained in the full enclosure.
Event A_3	A hazardous event causing an accident with slight or severe reversible injury	During mainten. work, an operator crushed his finger. After long medical treatment it healed.
Event A_4	A hazardous event causing an accident with a severe irreversible injury (pension payment)	After having defeated the safeguards of a turning machine, an operator's eye was hit by ejected swarf so heavily, that he was severely handicapped.
Event A_5	A hazardous event causing an accident with a fatal injury (pension payment to the relatives)	On a Friday after-noon, an operator was entangled by a CNC-lathe, when he was manually polishing the surface of the turning workpiece.

Table 2: Sample space Ω with all possible outcomes, examples given for singletons.

It has to be remarked that this sample space Ω is not absolutely "mathematically correct", because the fact is ignored that the basic populations of machines and operators presumably are slightly different from one year to the next. However, this "transition error" alters the findings below only gradually, but not substantially, because the conclusions remain the same. As regards real design practice, in [9] an (implicitly described) sample space for a certain range of products and the according event records is illustrated, which fits exactly to the explicit one in table 2.

Step 2: A measure space is required, which contains the measurable sets (called events).

The measure theory illustrates (see [4 b)]) that with a collection of measurable events $\mathcal{F} = \{A_i, i \geq 1\}$, we get the measurable space $(\Omega, \mathcal{F})$. A measure on $(\Omega, \mathcal{F})$ is a function $\mu: \mathcal{F} \to [0, \infty]$ such that:

i. $\mu(\emptyset) = 0$

ii. If $\{A_i, i \geq 1\}$ is a sequence of disjoint sets in $\mathcal{F}$, then the measure of the union (of countably infinite disjoint sets) is equal to the sum of measures of individual sets, i.e.

$$\mu\left(\bigcup_{i=1}^{\infty} A_i\right) = \sum_{i=1}^{\infty} \mu(A_i) \qquad \text{Eq. (2)}$$

The second property stated above is known as the *countable additivity* property of measures. By definition a measure can only be assigned to elements of $\mathcal{F}$. The triplet $(\Omega, \mathcal{F}, \mu)$ is called a *measure space*. μ is said to be a *finite measure* if $\mu(\Omega) < \infty$; otherwise, μ is said to be an *infinite measure*.

In particular, if $\mu(\Omega) = 1$, μ is said to be a *probability measure*.

Since an event is a subset (of comparable singletons) of the sample space Ω, to which a probability will be assigned, for the measurable subsets of the accident sample space follows: The disjoint sets in $\mathcal{F}$ are here $\{A_i, i = 3,4,5\} = \{A_3, A_4, A_5\}$ with the property

$$\mu\left(\bigcup_{i=3}^{5} A_i\right) = \sum_{i=3}^{5} \mu(A_i) = \mu(A_3 + A_4 + A_5) \qquad \textbf{Eq. (3)}$$

Step 3: Assign measures to the events of $\mathcal{F}$.

The measure μ can be understood as the overall number of all accidents of the type reportable (*R*) in the relevant observation frame above, since the subsets of severe accidents with pension payments (*PP*) and mortal accidents (*M*) are contained therein:

$$\mu(A_3 + A_4 + A_5) = \mu R \qquad \text{Eq. (4)}$$

However, a closer look to different severities requires a distinction of the accident frequencies of the subsets so that they are disjoint:

M =: number of all mortal accidents (remains): this number corresponds to event A_5 above.

*PP**=: number of severe accidents with pension payments (*PP*) minus fatal accidents: *PP**= *PP* – *M:* this number corresponds to event A_4 above.

*R**=: number of all reportable accidents minus the number of severe accidents with pension payments (*PP*) and minus the number of all mortal accidents (*M*):

*R** = *R* – *PP** – *M:* this corresponds to event A_3 above.

Now, the values *R**, *PP**, *M* can be derived from the yearly accident records. They can be assigned to the $\mathcal{F} = \{A_3, A_4, A_5\}$ following these principles:

$$\mu = R = R^* + PP^* + M \qquad \text{Eq. (5)}$$

Remark: Since the measurable space $\mathcal{F}$ is simple with only three $\mathcal{F}$ −measurable sets $\{A_3, A_4, A_5\}$, it fulfills the conditions of a Algebra, a σ −Algebra and a Borel Algebra (see [8],[10]).

Step 4: Assign probabilities to the events of $\mathcal{F}$.

The triplet $(\Omega, \mathcal{F}, \mathrm{P})$ is called a probability space (see [4 b)],[10]), if the following three properties (sometimes referred to as the axioms of probability) are fulfilled: a probability measure is a function $\mathrm{P}: \mathcal{F} \to [0,1]$ such that

i. $\mathrm{P}(\emptyset) = 0$.

ii. $\mathrm{P}(\Omega) = 1$.

iii. (Countable additivity:) If $\{A_i, i \geq 1\}$ is a sequence of disjoint sets in $\mathcal{F}$, then

$$\mathrm{P}\left(\bigcup_{i=1}^{\infty} A_i\right) = \sum_{i=1}^{\infty} \mathrm{P}(A_i) \qquad \text{Eq. (6)}$$

Here, we have the single probability measures $\mathrm{P}(A_1), \mathrm{P}(A_2), \mathrm{P}(A_3), \mathrm{P}(A_4), \mathrm{P}(A_5)$, which are strictly positive. Because of the limitations of the above defined random experiment of yearly accident records, we know that for every combination of α, β, γ the following equation holds: $\mathrm{P}(A_1) + \mathrm{P}(A_2) + \mathrm{P}(A_3) + \mathrm{P}(A_4) + \mathrm{P}(A_5) = 1$. But, we don't know the actual numbers α, β, γ. Obviously, these probabilities are not easy to determine, because the frame parameters α, β, γ of the basic population are not known. Thus, the measures *R**, *PP**, *F* of the events A_3, A_4, A_5 are only rough reference numbers, which can be plotted of the years.

3.2 Data put into an observation frame

So, for the sake of showing the proportions of $\mathrm{P}(A_1), \mathrm{P}(A_2), \mathrm{P}(A_3), \mathrm{P}(A_4), \mathrm{P}(A_5)$, some practical probability measures out of the record numbers *R**, *PP**, *M*, the values α, β, γ shall be estimated for above defined observation frame, to start with (see remark below):

$$\alpha \cong 500.000, \beta \cong 50.000, \gamma \cong 4 \qquad \text{Eq.(7)}$$

The average hours per day $ah_d = \alpha \cdot \gamma$ are then: $ah = 500.000 \cdot 4 = 2{,}000.000$. And per year with an average of about 220 working days: $ah_y = 2{,}000.000 \cdot 220 = 4{,}4 \cdot 10^8$.

The probability of an event A_5 can then be expressed as a relative frequency (rf):

$$\mathrm{P}(A_5) = \mathrm{rf}(A_5) = {}^{M}/_{ah_y} \qquad \text{Eq. (8)}$$

Accordingly, the probabilities of the events A_3 and A_4 are:

$$\mathrm{P}(A_3) = \mathrm{rf}(A_3) = {}^{R^*}/_{ah_y} \text{ and} \qquad \text{Eq. (9)}$$

$$\mathrm{P}(A_4) = \mathrm{rf}(A_4) = {}^{P^*}/_{ah_y}$$

The residual probabilities $\mathrm{P}(A_1) + \mathrm{P}(A_2)$ are then:

$$\mathrm{P}(A_1) + \mathrm{P}(A_2) = \qquad \text{Eq. (10)}$$

$$1 - (\mathrm{P}(A_3) + \mathrm{P}(A_4) + \mathrm{P}(A_5))$$

The accident record for machine tools of 2014 shall serve as an example (see DGUV):

M =1, *PP**=281-1=280, *R**=17.563-280-1=17.282.

$$\mathrm{P}(A_5) = \mathrm{rf}(A_3) = {}^{1}/_{4{,}4 \cdot 10^8} = 2{,}3 \cdot 10^{-9}$$

$$\mathrm{P}(A_4) = \mathrm{rf}(A_4) = {}^{280}/_{4{,}4 \cdot 10^8} = 6{,}4 \cdot 10^{-7}$$

$$\mathrm{P}(A_3) = \mathrm{rf}(A_3) = {}^{17.282}/_{4{,}4 \cdot 10^8} = 3{,}9 \cdot 10^{-5}$$

$$\rightarrow \mathrm{P}(A_1) + \mathrm{P}(A_2) =$$

$$1 - 3{,}9 \cdot 10^{-5} - 6{,}4 \cdot 10^{-7} - 2{,}3 \cdot 10^{-9} = 0.99996$$

In Figure 5 the proportions are illustrated according to the assumption of eq. (7). The light grey right column represents the probabilities of the subsets A_1 and A_2, where no injuries happen. The stepwise darker gray columns indicate the probabilities of the subsets A_3, A_4 and A_5, where accidents are reported as slight or severe reversible injuries, severe irreversible injuries or even fatal injuries.

Remark: Please take note of the fact that only the absolute values of eq. (10) should be questioned, since their relative proportions are largely independent of the presumptions made above in eq. (7). If absolute values were to be acquired, the assumptions in eq. (7) could be spreaded in terms of empirical worst case, average, best case as a histogram.

Because $\{A_i, i = 3{,}4{,}5\}$ is a sequence of three disjoint sets, eq. (6) is fulfilled

$$\mathrm{P}\left(\bigcup_{i=3}^{5} A_i\right) = \sum_{i=3}^{5} \mathrm{P}(A_i) = P(A_3) + P(A_4) + P(A_5) \qquad \text{Eq. (11)}$$

3.3 Fascinating vision of no more accidents

Now, as we have built a probability space based on a "σ −Algebra", we can have a closer look to the fascinating vision "zero risk". Based on the definitions 1. to 4. above, the zero-one-laws of the probability theory can be applied (see [8], [10]). They indicate that the probability of events of a certain type (here a set of the "limes superior") is either 0 or 1. That is to say: Those events happen either almost surely or they are almost impossible.

In particular, the Borel-Cantelli Lemmas seem to be suitable to check the decreasing trend of accident numbers, whether possibly the fascination “zero risk” can be realized in the future (see [27]).

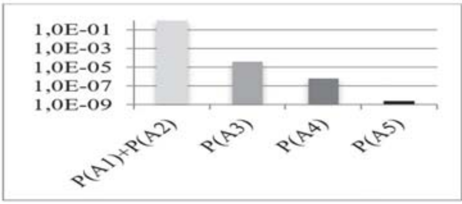

Fig. 5: Relative proportions in event probabilities are largely independent of assumptions in eq. (7).

As regards the application of the Borel-Cantelli Lemmas on the accident records, it is fortunate that they consist of scalar values summarizing comparable singletons. So, they resemble a sequence of values (a_n), which sum up a collection of $\omega_i \in \Omega$ that are assigned to a selected kind of events in the subset sequence A_n, this can be understand with the Matryoshka nested doll in Fig. 8.

Fig.8: Matryoshka nested doll (source: wikipedia)

The yearly accident records are nested decreasing subsets. This resembles the Matryoshka nested doll in Fig. 8, where the smallest innermost doll is the “intersection” of all dolls. See detailed explanation in [27]. Thus, the Borel-Cantelli lemmas can illustrate the vision “zero risk” mathematically with respect to yearly recorded real accident data.

4. Summary and Outlook

Admittedly, theoretical risk assessment starts in the hypothetical “what if” domain, where theoretical risk can be estimated only logically in cause and effect (at the most), but not in an *absolute* scale. However, actual *relative* risk reduction effects between different yearly accident records can be calculated and compared quite exactly, because the real risk actually can be “measured” precisely as by the DGUV records, as well as in individual records of machine tool builders. Therefore, this paper tries to support plausible risk considerations connecting theory and reality. Hopefully, it also helps to improve a common understanding of the term “probability”. Only then can the 1. Borel-Cantelli lemma be met, which leads the way to the fascinating vision “zero risk”, at least approaching it yearly step by step. For this paper, DGUV provided detailed accident statistics until 2015; since then only summarized data are being published, see [18]. Obviously, it is desirable to acquire the recent detailed DGUV data, too, such that the a.m. accident investigation of BGHM and DGUV is going to be continued meticulously. Of course, it is understandable that occupational safety experts are reluctant to draw conclusions about the causes of accidents based on the sometimes incomplete accident reports included in an annual report. However, considering that reducing accident clusters in the next reporting period (the following year) should remain an absolutely critical goal, it seems unacceptable to simply allow those prone to accidents to continue in the same pattern. To avoid this, it is essential to make the best use of the respective accident reports by at least plausibly narrowing down the causes of accidents (using methods of set theory). This is certainly better than, out of helplessness, making no attempt at all to combat the causes of accidents. For then the clusters of accidents would continue to occur.

VDW is offering support with this paper. This is a precondition such that a more complete Pareto diagram (than the one in Figure 12 of [27]) can be brought about, showing potential safety gaps in current design and operational practices, which need to be mended first. Subsequently, possible upgrades in the safety design against not significant hazards can be looked at: doing the first thing and not leaving the other option out. In addition, individual manufacturers of specific product ranges can monitor their own yearly records separately, such as convincingly demonstrated in [9]. Moreover, VDW is supporting the member companies accordingly in research projects [16] to make German machine tools as safe as reasonably possible.

Acknowledgement

Gratitude shall be expressed to Christoph Thomann (DGUV) for giving insight into the statistical framework of accident reports in Germany. Also to Ralf Kesselkaul (retired), Christoph Meyer and Christian Adler (BGHM) for the very useful preliminary conclusions from their accident investigation reports in table 1, which presumably entailed a lot of depressing details of human misfortune. Last but not least, thanks a lot to Dr. Sergei Kovalenko, who checked the mathematical part of this paper.

Symbols and other definitions

Symbol	Dim.sion	Meaning
α, β, γ	-	Parameters of the observation frame of accident statistics
μ	-	Measure of a subset in a sample space Ω
$\sigma, \mathcal{F}$	-	Indicator of a $\mathcal{F}$ - σ algebra
k_1, k_2	-	Adjustment parameter
Ω	-	Sample space
ω_i	-	Singleton of the sample space Ω
A_1 *to* A_5	-	Accident specific subsets of the sample space Ω
$A_i, P(A_i)$	-	General events in the sample space Ω and their probabilities P
R, PP, M	-	Number of accidents: reportable, pension payment, mortal
∈, ∉, ∀	-	Element of, not an element of, holds for all

References

[1] Adler, Christian: *Unfallanzeigen für Schleifmaschinen*, BGHM Hannover, 2015

[2] Adler,C.; Mewes D.; Herbst, P. 2013. *Ttrennenden Schutzeinrichtungen an Schleifmaschinen.* In: 4th European Conference on Grinding, 27.-28.11.2013. Bremen.

[3] a) Bauer, H.: *Wahrscheinlichkeitstheorie* (4. Auflage), de Gruyter Lehrbuch, 1991, sowie b) Bauer, H.: *Maß- und Integrationstheorie* (1. Auflage), de Gruyter Lehrbuch, 1990

[4] Blastland, M.: *The Tiger That Isn't – Seeing Through a World of*, profilebooks 2014

[5] Chinniah, Yuvin: Analysis and prevention of serious and fatal accidents related to moving parts of machinery, Safety Science 75 (2015) 163-173, www.elsevier.com, Canada

[6] Feller, William: *An Introduction to Probability Theory and Ist Applications*, Volume I, Third Edition, John Wiley & Sons, Inc. 1967;

[7] Heisenberg, David: *Produktsicherheit systematisch integrieren*, VDMA Nachrichten 04/2013.

[8] Jaganathan, K.: *Probability Foundations for Engineers*, *manuscript, University Madras,* 2015

[9] Kesselkaul, R., Meyer, C. 2016. *Priorisierung des Handlungsbedarfs (Prioritizing the Need for Action - Focus of Accident Occurrence).* VDW-Technologietag 2016. Dusseldorf.

[10] Meyer, Christoph: *Process observation operating mode: blessing or curse?* KANMAIL 2/2017, Kommission Arbeitsschutz und Normung

[11] Moedden, H., *Probabilities in Safety of Machinery – Risk Reduction Effects by … Fault Detection in the Process,* ESREL 2016 Glasgow, Scotland.

[12] Moedden, H.: *Probabilities in Safety of Machinery – Elements of a Risk Model and Comparison with Field Data*, VDW, Frankfurt a.M., Germany, ESREL Zurich (CH), 2015

[13] Montgomery; Runger, Hubble: *Engineering Statistics* (5th Edition), www.wiley.com, 2011

[14] Nowizki, N., P. Zeiler, B. Bertsche, Institute of Machine Components, University of Stuttgart, Germany,H. Moedden, VDW Germany: *Statistical Analysis of Field Data for a Proven-In-Use Assessment in the Machine Tool Industry according to ISO 13849,* ESREL 2016

[15] Nix, Douglas S. G.: The Relative Impact of Control *Reliability on Machinery Risk*, IEEE Product Safety Engineering Society, 2012

[16] DGUV, *Statistik – Arbeitsunfallgeschehen 2023*, Deutsche Gesetzliche Unfallversicherung e.V. (DGUV), Oktober 2025, Berlin, & DGUV-Project „Vision Zero": http://www.dguv.de/de/praevention/visionzero/index.jsp

[17] Preusse, C. 2005. *Manipulation an Schutzeinrichtungen an Maschinen*, St. Augustin: HVBG.

[18] Spiegelhalter, D.: *Norm Chronicles – Stories and Numbers about Risk*, profilebooks 2014

[19] *The European parliament: Machinery Directive 2006/42/EC.* And the Official Journal of the European Commission.

[20] EN ISO 13849-1, 2008. *Safety of machinery – Safety-related parts of control systems...* Germany; Beuth Verlag GmbH

[21] EN ISO 12100, 2010. *Safety of machinery – General principles for design – Risk assessment and risk reduction.*

[22] EN ISO 23125, 2010, *Machine tools safety – Turning machines* Berlin, Germany; Beuth

[23] https://en.wikipedia.org/wiki/Prevention_paradox

[24] Moedden, H., *Probabilities in Safety of Machinery: Borel-Cantelli Lemmas lead to a Prevention Dogma based on the Pareto principle*, 15th International Probabilistic Workshop, Dresden 2017

[25] Moedden, H., *Safety of machinery: three decades of impact testing of machine guards led to significant improvements,* ESREL 2026