On the effectiveness of safety measures

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1 INTRODUCTION

Safety measures aim to reduce risks but often require significant upfront investment. Therefore, evaluating their effectiveness compared to a no-measures baseline is crucial. While many companies claim safety is a top priority, they typically balance safety investments with an acceptable level of risk, aiming to meet standards while minimizing costs and maintaining social responsibility.

When societal safety is involved, risk acceptance must be justified through a clear understanding of the issues, especially since public resources often help fund safety efforts. Most costs, particularly in cases where the "polluter pays," fall on companies, making safety a political concern. Quantitative risk analysis is essential to understand the safety landscape and support informed decisions. Linking risk metrics to the cost and effectiveness of safety measures enables better prioritization. This requires a clear physical metric to quantify outcomes, such as individual or group risk, based on political or administrative definitions.

Risk management is already guided by international standards, such as the EU Seveso Directive, which governs chemical installation safety. Public debates typically focus on what is permissible under these norms. Within this framework, collective resources should be used efficiently to compare the impacts of various safety measures.

Few studies compare the effectiveness of alternative safety measures, especially regarding physical safety risks. Most focus on innovations enabled by technology (e.g., ERTMS in rail safety) or on established measures (e.g., fire-resistant coatings for LPG tankers). These are often assessed in absolute terms like accident probability reduction, but comparative analyses remain rare—particularly for urban areas near hazardous transport routes.

This article seeks to quantify the effectiveness of additional safety measures, beyond existing standards, using a general approach suitable for direct comparisons. It focuses on external safety and the analytical methods required for such evaluations, without addressing economic factors. The proposed analytical model of this paper can especially be applied for the process industry consisting of small probabilities and large consequences.

2 THE DEFINITION OF RISK

2.1 *Safety and risk*

Safety and risk are intrinsically connected. Safety encompasses various dimensions and, linguistically, is defined by the Dutch *Van Dale* dictionary as the state of being protected from danger. This definition implies that safety can fail, as "being protected from danger" suggests the presence of measures and provisions designed to mitigate risks. Furthermore, safety inherently includes a relative aspect, indicating "the degree to which" a situation is considered safe based on the measures implemented under specific circumstances.

Safety, therefore, can be understood as the absence of danger or risk in certain circumstances, aligning with *Van Dale's* description. The phrase *"danger is lurking"* highlights that danger may represent a state of potential threat, even in the absence of its actual realization. Conceptually, this positions danger closely to risk - a relationship evident in common language where these terms are often used interchangeably. To explore this connection, we interpret safety in this article as the outcome of measures either aimed at reducing the probability or at mitigating the effects of a failure.

The effectiveness of safety, as discussed here, pertains to the impact of safety measures in preventing or reducing risks. While safety often evokes a subjective feeling of being secure, regardless of actual risk levels, it is crucial to define the effectiveness of safety measures within the specific context. For example, Vlek (1990) emphasizes the importance of distinguishing between perceived safety and the measurable impact of safety interventions.

When quantifying the effectiveness of safety measures, the concepts of safety and risk become closely intertwined. Risk reduction, which can be demonstrated through quantitative risk analysis, serves as a measure of the safety achieved by these interventions. In this sense, the effectiveness of safety measures directly correlates with the definition and measurement of risk. Numerous frameworks and definitions of risk exist, as explored by Vlek (1990), Laheij (2003), Kaplan & Garrick (1981), Vrijling (1998), Jaeger et al. (2001), Klinke & Renn (2002), Krimsky & Golding (1992), Lewens (2007), Suddle & Waarts (2003), and Suddle (2023).

A general definition of risk, along with a widely accepted specific case of that definition, is presented below. These definitions provide the basis for evaluating the effectiveness of safety measures and their contribution to risk reduction.

2.1.1 *General definition of risk*

Risk (R) is defined as a function of the probability (P) of an event and its (negative) consequence (C), expressed as $R = f(P, C)$. In physical safety contexts, consequences may include damage, injury, or death, while probabilities typically refer to a defined time frame, such as one year. Each accident scenario combines a unique probability and consequence, contributing to the overall risk.

This relationship can be visualized using a **risk matrix** (see Table 1; Suddle et al., 2013), where probabilities and consequences are categorized into levels. Though subjective elements remain, this format allows for qualitative criteria to be converted into quantitative decision-making tools. Risk levels in matrix cells (e.g., “Unacceptable” or “Negligible”) help prioritize safety measures.

Table 1: Example of a risk matrix. The rows represent probabilities, and the columns represent consequences. Each cell indicates the risk level, which can be defined quantitatively or qualitatively depending on the application.

Consequence of a hazard / **Probability of a hazard**	***Small consequences (1)***	***Large consequences (2)***	***Extreme consequences (3)***
Highly unlikely (1)	***Negligible risk (1)***	***Acceptable risk (2)***	***Moderate risk (3)***
Unlikely (2)	***Acceptable risk (2)***	***Excessive risk (4)***	***Risk to be avoided if possible (6)***
Likely (3)	***Moderate risk (3)***	***Risk to be avoided if possible (6)***	***Unacceptable risk (9)***

The matrix’s structure is flexible—categories can be expanded for finer resolution. This helps visualize changes when mitigation efforts reduce accident probabilities, though greater detail demands more reliable data. For systems with multiple accident scenarios, the matrix captures the full risk profile, aiding comparison and prioritization of interventions.

2.1.2 *Specific definition of risk*

In specific cases, risk is also expressed as $R = P \times C$, the expected value of consequences (E(C)). For multiple scenarios, risk becomes the sum:

$$R = \sum(Pi \times Ci)$$

where Pi and Ci are the probability and consequence of scenario i, respectively. While precise, this formulation collapses risk into a single value, limiting compatibility with the matrix, which preserves a structured overview across categories.

Although individual risk can be normatively represented via expected values, the risk matrix remains the preferred tool for evaluating physical safety risks, especially when data are uncertain or qualitative input is required.

2.2 *Risk acceptance*

Societal risks arise from activities where benefits and risks are unevenly distributed across the population. Decisions about safety risks are part of a broader political and economic process, influenced by political priorities, economic constraints, and societal values.

Some risks, like flood safety, directly impact large populations. Safety measures—such as adjusting dike heights—often rely on parliamentary decisions about acceptable risk levels. Perspectives on evaluating such measures have evolved in recent years (Kolen, 2011).

When regulations define acceptable risk levels, understanding safety measure effectiveness is crucial for compliance. If standards aren't met, decisions on additional measures often hinge on cost-effectiveness.

In areas without explicit regulations, such as those guided by ALARA (As Low As Reasonably Achievable) or ALARP (As Low As Reasonably Practicable), assessing effectiveness helps prioritize measures that maximize risk reduction within reasonable budgets.

Safety management addresses risks from interrelated activities, from design to enforcement. It requires coordinated stakeholder action, supported by clear insights into the potential impact of proposed measures.

Assessing the effectiveness of additional measures supports evaluations of risk acceptability but does not define it. These assessments matter most when there's a clear intent to reduce risk, guiding decisions that improve safety outcomes.

3 SAFETY MEASURES AND EXPRESSING THEIR EFFECTIVENESS

3.1 *The safety chain*

The **"safety chain"** is a cognitive model used to discuss the effectiveness of safety measures. Rooted in a process model, it outlines key stages aimed at minimizing the consequences of risks by breaking down risk and crisis management into five phases:

- **Pro-action**: Focuses on reducing risks during the design and construction of infrastructure (e.g., roads, buildings, airports), aiming to prevent risks from arising.
- **Prevention**: Involves implementing rules and permits to reduce risk, such as enforcing fire safety regulations and building codes.
- **Preparation**: Addresses residual risks through disaster planning, training, and drills to ensure readiness for emergencies.
- **Response**: Once a disaster occurs, this phase minimizes consequences through actions at operational, tactical, and strategic levels.
- **Recovery**: Aims to restore pre-disaster conditions through reconstruction, evaluation, and improvements to avoid recurrence.

Originating from disaster and emergency management, the safety chain highlights the value of proactive risk management. Each phase helps reduce incident severity, with early-stage interventions typically being more cost-effective than later ones.

A practical example is the Betuwe route, used for transporting hazardous materials by rail to Germany. Challenges in emergency response along this route stress the need for proactive safety measures. However, the safety chain is not ideal for quantitative safety assessments, as assigning reliable probabilities to preparation and response actions is difficult.

This discussion shows safety measure effectiveness can be viewed from different perspectives and underscores the importance of clearly defining "effectiveness" in context. Upcoming sections will focus on quantitative safety expressions related to general and specific risk definitions.

Effectiveness is not only about risk reduction but also cost. Although this article doesn’t address economic aspects, they are essential in real-world evaluations. Additionally, the **failure probability** of safety measures must be considered, as it significantly influences overall effectiveness.

3.2 *Improving safety with safety measures*

Improving safety can be achieved in various ways, though the broader consequences of such measures aren't always reflected in risk parameters. For example, reducing highway speed limits would likely decrease annual deaths and serious injuries. A risk analysis model can estimate the reduction in injuries, and the safety gains can be expressed as fewer fatalities, life-years gained, or increased life expectancy. Economic factors can also be integrated to assess safety within a financial framework.

When risks are quantifiable, so is the effectiveness of safety measures. However, when risks are hard to quantify, evaluating safety measures faces the same limitation. In these cases, qualitative factors must be considered and valued, as such uncertainties often play a role in real-world evaluations.

It’s also important to recognize that added safety measures aren’t automatically effective. Their success depends on proper functioning. Thus, failure probability must be factored into effectiveness assessments—a low failure rate indicates reliability, while a high one raises concerns about the measure's trustworthiness.

3.3 *Type of safety measures*

Physical safety risks are typically expressed in terms of the probability of harm, such as deaths or injuries, resulting from a failing technical system. In external safety, hazardous scenarios involving dangerous substances pose health risks to people living near risk-generating areas. Other examples include rail and tunnel safety, where technical failures could harm those near these systems.

Controlling physical safety risks involves measures aimed at the technical system itself, either reducing the probability of failure or mitigating its effects:

1. **Source-oriented policy**: Focuses on addressing risk causes through permitting and enforcement. This policy minimizes the likelihood of technical failures that could result in harm. For example, improving system reliability to prevent hazardous releases.
2. **Environment-oriented policy**: Ensures the safest possible living environment through spatial planning. It aims to shield the vicinity and limit the severity of effects once failure occurs. For instance, a mist screen can reduce the concentration of toxic gas near a pipeline leak. This policy protects those affected by the incident, offering shelter, reinforcing buildings, or increasing the physical distance between danger and people.
3. **Disaster response**: Prepares for and manages emergencies, focusing on victim assistance. While often seen as secondary consequence-reducing measures, these are distinct when considered in terms of immediate disaster response.

From a safety effectiveness perspective, there are no inherent reasons to favor one measure over another. Practical factors, however, often guide the choice. For example, during the design phase, it's typically more cost-effective to implement safety measures within the system itself rather than relying on emergency response. Disaster responses are generally more expensive than prevention (Ale, 2023), so there is often a preference for addressing safety concerns at the source.

It’s crucial to specify the context when discussing safety effectiveness. Is the focus on overall safety, or on specific risks? The definition of risk and the scope of safety measures will determine this focus. Clear understanding of the specific risks and safety parameters is essential for evaluating measure effectiveness.

3.4 *Quantifying the effectiveness of safety measures*

How can the effectiveness of safety measures be expressed so that their utility and necessity can be assessed and discussed?

3.4.1 *Effectiveness based on the generic definition of risk $R = f(P, C)$*

Depending on the type of safety measure, it concerns either reducing the probability or limiting the consequences (or sometimes both). Thus, we must indicate the change the measure brings about. We note the change in consequence ΔC as:

$$\Delta C = C_0 - C_1$$

Where C_0 is the consequence without measure taken and C_1 is the consequence with the implemented measure taken.

Similarly, we can indicate the change in probability due to the measure. We note the change in the probability ΔP of an accident as follows:

$$\Delta P = P_0 - P_1$$

Where P_0 is the probability without a safety measures taken and P_1 is the probability with the implemented measure taken.

We use the following notation for the change in risk ΔR:

$$\Delta R = R_0 - R_1 = f(P_0, C_0) - f(P_1, C_1) = \Delta f$$

When only the probability of the risk changes due to a safety measure, it follows that $\Delta f = f(\Delta P, C_0)$. When only the consequence of the risk changes, it follows that $\Delta f = f(P_0, \Delta C)$.

The risk matrix represents the effectiveness of the risk reduction easily and clearly by visualizing the change in the probability-consequence combination from R_0 to R_1. Ale et al. (2016) showed how the ingredients of Risk and Consequences are converted into a risk matrix in which the boundaries of the classifications are quite political and often subjectively set.

Since we work with probability categories and consequence categories, effectiveness is naturally only visible if C_0 and C_1, respectively P_0 and P_1, fall into different categories. This is the limitation but also the strength of the risk representation. The strength lies in the fact that the matrix is based on what is deemed a meaningful distinction in risk categories for decision-making or judgment formation. A measure is therefore only judged to be sufficiently effective if it falls into a more favourable defined risk category of the matrix. Figure 2 illustrates how effectiveness can be expressed. In practice, the values of the (P, C) combinations are not stated in the matrix cell. This has been done here to make the example easier to follow.

3.4.2 *Effectiveness based on the specific risk definition R= P x C (risk as expected value of the consequences)*

If the risk is determined by a single accident scenario, the risk reduction, denoted as ΔR, due to a safety measure is calculated based on the change in either the consequence or the probability. If only the consequence is altered, the risk reduction ΔR can be determined using the following equation (3):

$$\Delta R = R_0 - R_1 = P_0.C_0 - P_0.C_1 \quad (5)$$
$$= E_0(C) - E_1(C)$$

If only the probability changes, then the effectiveness of the measure expressed in risk reduction ΔR is:

$$\Delta R = R_0 - R_1 = P_0.C_0 - P_1.C_0 \quad (6)$$
$$= E_0(C) - E_1(C)$$

Considering the probability that the measure does not work, as noted earlier, the risk reduction ΔR becomes:

$$\Delta R = R_0 - R_1 = P_0.C_0 - [P_0P_1.C_1 + P_0C_0 - P_0P_1C_0] \qquad (7)^{1}$$
$$= E_0(C) - E_1(C)$$
$$= P_0.P_1.(C_0 - C_1)$$

Expanding equation (7) results in: $\Delta R = P_0 \cdot P_1 \cdot (C_0 - C_1)$

Where:

- P_0 is the probability of occurrence of the event with consequence C_0;
- P_1 is the probability that the measure works when it is invoked when the event occurs; (1-P_1) is the probability that the measure does not work.

Table 2: Representation of the change in risk ΔR due to two measures, depicted in the matrix with arrows. Measure 1 only affects the consequences; $R_0 = (P_0, C_0)$ changes to $R_1 = (P_0, C_1)$, or $\Delta R = (P_0, \{C_0\text{-}C_1\})$. Measure 2 only reduces the probability of an accident scenario with consequences C_2 smaller than a; $R_0 = (P_1, C_2)$ changes to $R_1 = (P_0, C_2)$. Hence, $\Delta R = (\{P_1\text{-}P_0\}, C_2)$. Note that the risk here is formed by two scenarios or (P, C) combinations. Here, $R_0 = (P_0, C_0)$; (P_1, C_2) and $R_1 = (P_0, C_1)$; (P_0, C_2).

Consequence of a hazard ⇨ **Probability of a hazard** ⇩	***Small consequences (1)*** ***$C \leq a$***	***Large consequences (2)*** ***$a < C \leq b$***	***Extreme consequences (3)*** ***$C > b$***
Highly unlikely (1) ***$P \leq x$***	***(P_0, C_2)*** ***Negligible risk (1)***	***Safety Measure 1*** ***(P_0, C_1)*** ***Acceptable risk (2)***	***(P_0, C_0)*** ***Moderate risk (3)***
Unlikely (2) ***$x < P \leq y$***	***Safety Measure 2*** ***(P_1, C_2)*** ***Acceptable risk (2)***	***Excessive risk (4)***	***Risk to be avoided if possible (6)***
Likely (3) ***$P > y$***	***Moderate risk (3)***	***Risk to be avoided if possible (6)***	***Unacceptable risk (9)***

If the risk is determined by multiple accident scenarios *i*, then the general expression for the risk R is:

$$R = \sum_i P_i \cdot C_i = \sum_i E_i(C) = E(C) \qquad (8)$$

For each safety measure that intervenes in the probability and/or consequences of the event of scenario *i*, formula (8) can be elaborated analogously to equations (5), (6), or (7). The risk reduction ΔR simply follows from the difference R_0 - R_1 according to (8):

$$\Delta R = \sum_{0,i} E_{0,i}(C) - \sum_{1,i} E_{1,i}(C) = \Delta E(C) \qquad (9)$$

where $E_{0,i}$ represents the situation without measure '0' for scenario *i* and $E_{1,i}$ represents the situation with measure '1' for scenario *i*.

[1] The derivation is as follows: After the measure, two situations are possible for the consequences: C_0 or C_1. The probability of consequences C_1 occurring is $P_0.P_1$. The probability of consequences C_0 occurring is naturally $P_0(1\text{-}P_1)$. The expected value of the consequences with the measure is then $P_0.P_1.C_1 + P_0.(1\text{-}P_1).C_0$. Expanding this term yields the term within square brackets in equation (7).

4 A TEST CASE IN THE PROCESS INDUSTRY

In this chapter we present a test case -in which we use the proposed analytical model of the previous chapter- from the process industry or transport of hazardous materials through city centres consisting of small probabilities and large consequences.

4.1 *Basic conditions and basic data*

The basic conditions and basic data could be found in literature like, Scenarioboek externe veiligheid (2017), Person (2002) and CPR 18 (2000), which are presented in table 3. For illustration of the test case we round both the number of probabilities and consequences to whole numbers.

Table 3: Characteristics of hazards with their effect distances / effect areas and their probabilities.

Hazards **(see Scenarioboek externe veiligheid, 2017)**	**Effect Distances** **(see Scenarioboek externe veiligheid, 2017)**	**Probability range from literature** **[/wgn/km]**	**Reference**	**Probability for the test case of 1.000 km track** **[/wgn/1000km]**	**Number of fatalities for the test case** **(assumptions in relation to the effect distance)**
Pool fires	10 - 50m	$1.5{\cdot}10^{-9} – 3.8{\cdot}10^{-10}$	Person (2002)	$1{\cdot}10^{-6}$	10
Explosions (e.g. BLEVE)	200 - 400m	$1.2{\cdot}10^{-8} – 3.6{\cdot}10^{-12}$	CPR 18 (2000)	$1{\cdot}10^{-7}$	100
Release of toxic gasses	5 - 10km	$1{\cdot}10^{-10} – 6.6{\cdot}10^{-12}$	Person (2002) and CPR 18 (2000)	$1{\cdot}10^{-8}$	1000

We will now illustrate, using a numerical example, how the effectiveness of safety measures is expressed differently depending on the risk definition employed. We begin with the risk definition $R=P\times C$ and then expand to the definition $R=f(P,C)$. For both calculations, we use the following basic data:
In situation '0', without any additional safety measures, the probabilities P (based on a one-year period) and their corresponding consequences C expressed in terms of fatalities, are as follows:

- Scenario 1(e.g. pool fire), $P_{0,1} = 10^{-6}$; $C_{0,1} = 10$ fatalities
- Scenario 2 (e.g. BLEVE[2]), $P_{0,2} = 10^{-7}$; $C_{0,2} = 100$ fatalities
- Scenario 3 (e.g. release of a toxic gas) , $P_{0,3} = 10^{-8}$; $C_{0,3} = 1000$ fatalities

4.2 *The effectiveness according to R=PxC*

The risk R_0 as per the first term of the equation (9):

$$R_0 = \sum_i P_{0,i} \cdot C_{0,i} = E_{0,1}(C) + E_{0,2}(C) + E_{0,3}(C) = 3.10^{-5}$$

fatalities (annual average).

Implementing the Safety Measure A

Let's assume that a source measure A reduces the probability of scenario 2 (in our case the BLEVE) with a factor of 10. The probability after measure A, $P_{1,2} \mid A = 10^{-8}$. $C_{0,2}$ remains unchanged: 100 fatalities.

The new expected value of scenario 2, $E_{1,2}(C)$, due to measure A is then:
$10^{-8} * 100 = 1*10^{-6}$ fatalities (annual average).

R_1 (the second part of formula (9)) will be:

$$R_1 = \sum_i P_{1,i} \cdot C_{1,i} = E_{1,1}(C) + E_{1,2}(C) + E_{1,3}(C) = 2{,}1.10^{-5}$$

[2] BLEVE is an acronym for “Boiling Liquid Expanding Vapour Explosion”. A BLEVE is the consequence of the failure of a pressure vessel containing a liquefied gas.

The risk reduction ΔR with safety measure A follows from (9):
$3*10^{-5} – 2{,}1*10^{-5}$ = $\mathbf{9.10^{-6}}$ fatalities (annual average).

Implementing the Safety Measure B
Assume that a safety measure B reduces the probability of scenario 2 and 3 with a factor 5:

$E_{1,2} = E_{1,3} = 2.10^{-6}$ fatalities (annual average).
R_1 will be: $1{,}4*10^{-5}$ ($= 10^{-5} + 2*10^{-6} + 2*10^{-6}$)

The risk reduction ΔR after implementing safety measure B is:
$3*10^{-5} – 1{,}4*10^{-5} = 1{,}6.10^{-5}$ fatalities (annual average).

Mutual comparison of Safety Measure A and B
Based on the reduction of the expected value, safety measure B ($\Delta R = 1.6*10^{-5}$) *i*s more effective than safety measure A *(*$\Delta R = 9*10^{-6}$). The example is summarized in Tables 4 and 5.

Table 4: Probabilities and consequences of scenarios 1, 2 en 3 without taking safety measures and after taking safety measure A of B.

	scenario 1	**scenario 2**	**scenario 3**
	C=10	**C=100**	**C=1000**
$\mathbf{P_{0,i}}$	$1*10^{-6}$	$1*10^{-7}$	$1*10^{-8}$
$\mathbf{P_{1,i}\ \|_A}$	$1*10^{-6}$	$1*10^{-8}$	$1*10^{-8}$
$\mathbf{P_{1,i}\ \|_B}$	$1*10^{-6}$	$2*10^{-8}$	$2*10^{-9}$

Tabel 5: Risks of scenarios 1, 2 en 3 without king safety measures and after taking safety measure A of B.

	scenario 1	**scenario 2**	**scenario 3**	***R***	**ΔR**
$\mathbf{R_0}$	$1*10^{-5}$	$1*10^{-5}$	$1*10^{-5}$	***$3{,}0*10^{-5}$***	-
$\mathbf{R_1\ \|_A}$	$1*10^{-5}$	$1*10^{-6}$	$1*10^{-5}$	***$2{,}1*10^{-5}$***	$9{,}0*10^{-6}$
$\mathbf{R_1\ \|_B}$	$1*10^{-5}$	$2*10^{-6}$	$2*10^{-6}$	***$1{,}4*10^{-5}$***	$1{,}6*10^{-5}$

4.3 *The effectiveness according to R=f(P,C)*

We begin with the same basic data as in section 4.1. Visualizing R=f(P,C)R = f(P,C)R=f(P,C) with a risk matrix requires defining relevant probability and consequence categories for decision-making. The qualitative criteria have been converted to quantitative ones, which are an example. In real decision-making, these criteria are set by competent authorities (Ale et al., 2016). The risk matrix expresses risk in gradations of acceptability, as shown in Table 1. The categorization determines the relevance of safety measures regarding risk acceptability. This standardization aids in assessing the need for additional measures. Category definitions are usually set before evaluating measure effectiveness. When using the risk matrix, measures are effective only if they reduce risk to a lower category or (P,C) combination. This is the matrix's strength in decision-making and requires user consensus.

We illustrate this with the risk matrix in Table 6. Risk R_0 is represented by the framed (P,C) matrix cells, with three scenarios.

Measure A reduced the probability of scenario 2 from 10^{-7} to 10^{-8}. However, the consequence of 100 deaths remains unchanged. Measure B reduced the probability of scenarios 2 and 3 by a factor of 5. The effectiveness of measures A and B based on the risk matrix in table 1 is depicted in table 6.

The results indicate that measure A can be considered relevant, whereas measure B cannot, or at least, deemed insufficiently effective.

Table 7: Risk matrix based on quantified categories for the probability P and the consequences C of the risk. Risk is represented by three matrix cells outlined in red.

Consequence of a hazard ⇨ / Probability of a hazard ⇩	*Small consequences (1)* $C^1 \leq 10$	*Large consequences (2)* $10 < C^2 \leq 100$	*Extreme consequences (3)* $C^3 > 100$
Highly unlikely (1) $P^1 \leq 10^{-8}$	P^1, C^1	P^1, C^2 Measure A	P^1, C^3 Measure B
Unlikely (2) $10^{-8} < P^2 \leq 10^{-6}$	P^2, C^1	P^2, C^2 Measure B	P^2, C^3
Not unlikely (3) $10^{-6} < P^3 \leq 10^{-4}$	P^3, C^1	P^3, C^2	P^3, C^3
Not acceptable (4) $P^4 > 10^{-4}$	P^4, C^1	P^4, C^2	P^4, C^3

5 DISCUSSION AND CONCLUSION

The effectiveness of a safety measure can be demonstrated by evaluating its impact on risk reduction, assuming risks are quantifiable. Quantifying this reduction helps assess whether the measures achieve desired safety levels, which is crucial for decision-making. As shown, the choice of risk definition can lead to varying assessments of a measure's effectiveness.

In the risk definition R=(P×C)=E(C)R = (P \times C) = E(C)R=(P×C)=E(C), effectiveness is expressed as the average consequence over a given time period. In this definition, probabilities and consequences are weighted equally, potentially resulting in no significant differences when comparing measures. However, using the risk matrix as a more flexible form of the generic R=f(P,C)R = f(P,C)R=f(P,C) definition, the same measures may show different outcomes due to how probabilities and consequences are categorized and weighted.

The advantage of the risk matrix is that it visually highlights the relevance of safety measures based on predefined acceptance levels for different combinations of probability and consequence, aiding decision-making. A challenge, however, is that physical safety is not usually represented by societal acceptance categories in the risk matrix. When an acceptance level is quantitatively defined, it often reflects a standard that can be selectively applied to specific situations, implicitly allowing for varying levels of acceptance. Note that these acceptance standards are a political choice. The criteria used here are meant as examples.

To define the effectiveness of additional safety measures, it is necessary to precisely describe the accident scenarios they address. This allows for a clear demonstration of the overall impact. However, illustrating their effectiveness does not answer the crucial question of how much safety is sufficient to accept the associated risk. This remains a political decision, influenced by subjective perceptions of safety. While quantitative data can guide decisions, they also shape the public's feeling of safety, which can be influenced by the very numbers presented.

Finally, understanding the effectiveness of safety measures is crucial in evaluating their cost-effectiveness. Future articles will explore this topic further. The approach discussed here is, in the authors' view, applicable across the broader scope.

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