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IEC - A NEW ERGONOMIC METHOD FOR RISK IDENTIFICATION AND ASSESSMENT

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Abstract Conventional approaches to measuring system safety and reliability (e.g., FMEA or FTA) are mainly concerned with component failures, and do not pay much attention to risks due to ergonomic deficiencies of the interface in dynamic interaction with the user. The paper introduces a novel ergonomics-based approach, Interaction - Effect - Consequence (IEC), which has been created to identify and quantify safety risks in a comprehensive manner. The methodological framework is grounded on the detailed mapping of the causal chain Interaction (I) - Effect (E) - Consequence (C). The analysis starts with the definition of interaction (I) based on five modalities: intended use, misuse, abuse, other possible uses (including intuitive errors because of poor affordance), and combined use (simultaneous, multiple interactions). In each modality, the effect (E) is calculated as the functional or structural system response, which results in the ultimate consequence (C) to the user, the object (system), and the environment. According to these parameters, the risk level (R) is determined as the product of the probability of interaction (V_i), the probability of injury or damage (V_d), and the severity of consequence (D). The method was tested on a case study of a hotel thermostatic shower mixer. The IEC method identified latent hazards that classical analytical methods are not able to detect, by examining 144 combinations of control element states. The IEC approach offers a new, quantitative instrument to ergonomists, engineers and designers, allowing identification of emergent risks at the early stages of development, thereby shifting the focus of safety from mere mechanical reliability to the intuitiveness and predictability of human-object interaction.

Keywords: IEC method; ergonomics; risk identification; risk assessment; human–object interface; human-product interaction; latent hazards; product safety; machine safety; FMEA; FTA; HAZOP.

1. INTRODUCTION

In modern ergonomics, engineering and product design, the evaluation of system safety and reliability is imperative. Traditional risk management approaches are based on structured methodologies that are designed to identify potential failures before they occur in operation. Among the most common techniques used in industrial practice are Failure Mode and Effects Analysis (FMEA), Fault Tree Analysis (FTA) and Hazard and Operability study (HAZOP).

Failure Mode and Effects Analysis (FMEA) is an inductive, "bottom-up" technique where each component of the system is systematically analyzed for ways the component may fail and what the effects of those failures may be to the function of the entire system. According to Carlson [1], FMEA is mainly concerned with defect prevention by identifying and mitigating known or potential failure modes in design or manufacturing processes. Although effective in the domain of hardware reliability, this method often treats the human factor as just one of the possible causes of failure ("human error"), without deeper analysis of cognitive processes and ergonomic factors that lead to mistakes.

The second dominant approach, Fault Tree Analysis (FTA), is based on a deductive, "top-down" approach. It begins with some undesirable top event (i.e., explosion, injury) and, using the logical diagrams (Boolean logic), looks for the basic causes leading to that event. Ericson [2] states that FTA is important to understand complex interactions between different system failures, but its application is often static and relies on the assumption that component failure rates and human errors are known probabilities in advance. This method also does not explicitly consider ergonomic factors that may cause undesired events in an organized and explicit way.

In the process industry, the HAZOP method - Hazard and Operability study - is often used. According to Crawley and Tyle [3], this method uses guide words such as "more", "less", "none", etc., to determine deviations from designed parameters. Although HAZOP deals with operability, it is more concerned with physical and chemical processes (flow, pressure, temperature), and operator interaction with the interface is often secondary.

Despite the wide range of applications, these approaches reveal substantial limitations when applied to the analysis of direct human-object interaction in dynamic environments. The main disadvantage of traditional methods is their techno-centric view. They mostly see failure as a result of physical component malfunction or random human error (accidental lapse). However, they hardly analyze systemic errors that occur when a device is technically functional but not ergonomically adequate, putting the user in a situation of "forced error." Consequently, existing approaches lack a systematic framework for analyzing how interaction itself can generate hazards even when the technical system is fully functional.

Existing methods do an inadequate job of modeling two important aspects of interaction:
1. Effects of unexpected object response as a consequence of human-object interaction. These are situations where the user, because of poor affordance, correctly performs the wrong action (e.g., presses a button that looks like a slider in the manner of activating a slider), but the system responds in a way that the user cannot predict.
2. Object failure by interaction inducement: Traditional methods often do not consider that the very attempt at interaction under stressful conditions (panic, misunderstanding of the interface) can result in the application of excessive force and physical damage to the device (breaking controls, forcibly turning valves), which creates new safety risks.

Given these shortcomings, there is a need for a new methodology that puts interaction itself at the center as a generator of risk. This paper proposes the IEC method (Interaction - Effect - Consequence), an ergonomics-based method for hazard identification and safety assessment that considers the user's cognitive-motor action, the system's technical response, and the resulting consequences for humans and material assets.

2. IEC METHOD

The Interaction - Effect - Consequence (IEC) method, presented here for the first time, is an ergonomics-based method for assessing the safety of products, machines, tools, devices and systems. Unlike traditional methods that focus on component reliability, the IEC method puts the human-object interface at the center of analysis as the critical point where risks emerge. The basic assumption of the IEC method is that safety risk does not result from the failure of technical devices alone, but as a result of the complex interaction between the actions of the user (intentional or unintentional) and the response of the system.

2.1. Procedure for Applying the IEC Method

The implementation of the IEC method is carried out through six steps. These steps will be defined and explained in the following sections.

2.1.1. Step 1 – Decomposition of the Interface and Identification of Interaction Zones

The first step requires a physical analysis of the object. The goal is to list all contact points (touchpoints). This includes:

a) Active zones – elements intended for control, such as controls and displays.
b) Passive zones – parts of the object that the user touches for support, carrying, or accidentally (housing, pipes, protective grids, etc.).

The result of this step is a list of interface elements that proceed to further analysis.

2.1.2. Step 2 – Defining the Modalities of Interaction (Input Variable – I)

For each zone identified in Step 1, the ways in which the user interacts are mapped. The method includes consideration of five modalities of interaction:

1. *Intended use*, strictly according to instructions.
2. *Misuse*, as a result of unintentional lapse (slipping, loss of concentration, etc.).
3. *Abuse* involving the application of excessive force (using tools instead of hands, forceful handling due to frustration, etc.).
4. *Other possible uses*, such as:
   - intuitive use contrary to design (the user "assumes" a function due to poor affordance)
   - using the object as support (non-standard physical interaction)
   - errors due to unclear/nonexistent instructions, and others.
5. *Combined uses* involve simultaneous use of two or more interface elements (e.g., left + right hand at the same time), which is crucial for detecting systemic conflicts.

2.1.3. Step 3 – Prediction of Effects by the Object (System Response – E)

For each defined interaction modality from Step 2, the response of the object itself is analyzed, i.e., the effect it produces. The effects are considered in two ways:

a) Functional response – Does the controlled system respond to the interaction as expected? Is the wrong function activated? Does the system produce an unexpected output (e.g., an unintended change of parameter)?

b) Structural response – Does the interaction lead to breakage, jamming, or physical damage to the device (failure induced by interaction)? Does the interaction cause any unexpected effect?

2.1.4. Step 4 – Identification of Consequences (Output Variable – C)

This step involves analyzing the final outcome of the effects from the previous step across three key domains:

a) Consequences for humans – physical injuries (burns, cuts, sprains, etc.), as well as psychological effects (stress, fear, panic, etc.).
b) Consequences for the environment – impact on the surroundings in which the object is located (e.g., flooding, slippery floor, electrical short circuit, etc.).
c) Material losses – economic damage resulting from the destruction of the object itself or surrounding property.

2.1.5. Step 5 – Formation of the IEC Matrix and Risk Assessment

This step is the most complex and includes several sub-steps.

- *Determining the scale for assessing the probability of interaction (V_i)*

By applying the scale shown below, the likelihood is evaluated of the user performing the described action, i.e., engaging in interaction with the object or interface element (e.g., pressing a button).

Assessment	**Description of probability V_i**
5	Almost certain
4	Often
3	Occasionally
2	Rarely
1	Very rarely

- *Determining the scale for the probability of injury or damage* V_d

The scale shown in Table 1 is used to assess, if the interaction occurs, how likely it is to result in injury or damage.

Assessment	**Probability of injury/damage** V_d	**Criterion**
5	Certain	If the interaction occurs and the effect takes place, injury is inevitable (there is no time or possibility for an avoidance reaction).
4	High	High chance of injury/damage, with little possibility of avoidance (quick reaction required).
3	Moderate	There is a 50/50 chance of avoiding injury or damage. It depends on the circumstances.
2	Low	Actual injury is unlikely. Minor discomfort is possible.
1	Impossible	The effect has manifested, but it cannot lead to injury.

Table 1. Scale for assessing the probability of injury or damage.

- *Determining the scale for severity of consequence (D)*

By applying this scale, the severity of injury or damage is determined.

Assessment	**Injury or damage (D)**	**Criterion**
5	Catastrophic	Fatal outcome, permanent disability, or enormous material damage (fire, flooding of an entire floor).
4	Critical	Severe injuries (second- and third-degree burns), fractures. Medical assistance required. Significant material damage.
3	Serious	Minor injuries (first-degree burns, sprains), sick leave. Moderate material damage.
2	Minor	First aid, bruises, stress, minor material damage.
1	Negligible	Discomfort, no injuries, no material damage.

Table 2. Scale for assessing the severity of injury or damage.

- *Formation of IEC matrices (tables) for individual interface elements*

For each individual interface element, a separate IEC matrix is formed, which has the tabular form shown below. This matrix serves to present the data collected in the previous steps in a concise form and to conduct a risk assessment for each individual interface element.

1. Interface element	**2. Mode of interaction (I)**	**3. Effect from the object (E)**	**4. Consequence (C)**	**5. V_i**	**6.V_d**	**7. D**	**8. Risk level (R)**
Identification of the part of the object with which interaction (contact) is established	Description of the specific user action (intended, incorrect, misuse, combined, other actions)	System response to the action (technical feedback, change of state, breakage, absence of reaction, etc.)	Description of damage to the user, environment, or property	Assessment (1-5)	Assessment (1-5)	Assessment (1-5)	Calculate $R = V_i \cdot V_d \cdot D$ (1-125)

Table 3. IEC matrix for individual interface elements.

- *Formation of IEC matrices (tables) for paired interface elements*

These matrices are used to examine the effects that occur when a person acts on two or more control elements (e.g., during normal use, or in a state of panic, haste, or an attempt to compensate for an error). Thus, the effects and consequences that arise when two or more interface elements are activated by the user are examined here. In the case of simpler products with fewer interface elements, a single such matrix is sufficient, whose form is shown below (Table 4). In the case of complex systems, multiple such matrices are formed to examine the impact of combined activations of interface elements, which may have different effects from those that occur when interaction is established only with individual interface elements.

In this case, V_i is the probability of combined activation of interface elements (combined interaction, i.e., that two or more interface elements are active at the same time). It represents the probability of coincidence, that is, the chance that two or more independent states occur at the same moment. V_d is the probability of injury or damage occurring during such combined interaction (simultaneous activation of two or more interface elements), while D is the assessment of the level of damage resulting from interaction with multiple interface elements (during combined activation).

1. Paired interface elements	**2. Description of simultaneous interaction (Icomb)**	**3. Combined effect on the object (Ecomb)**	**4. Consequence (C)**	**5. V_i**	**6. V_d**	**7. D**	**8. Risk level (R)**
Defining paired interface elements	Description of action on I_1 + description of action on I_2 +...	System response to conflicting or synergistic commands	Final effect on the user and the environment	Assessment (1-5)	Assessment (1-5)	Assessment (1-5)	Calculate $R = V_i \cdot V_d \cdot D$ (1-125)

Table 4. IEC matrix for paired interface elements.

• *Assessment of risk level R*

For each individual interface element, or paired interface elements, the calculation of the risk level R is performed according to the formula

$$R = V_i \cdot V_d \cdot D$$

The maximum risk can have a value of 125, while the minimum risk can have a value of 1. In Table 5 the classification of risk is given in relation to the calculated value for R.

Risk level	**Range of values (R)**	**Risk category**	**Visualization of risk level**	**Description and required measures**
I	1 – 8	Negligible	🟩	**Acceptable risk.** No additional measures are required. The existing design is adequate.
II	9 – 18	Low	🟨	**Tolerable risk.** The risk is acceptable, but consideration of inexpensive improvements (e.g., better instructions, clearer markings) is recommended if economically justified. Monitoring is required.
III	19 – 45	Moderate	🟧	**Conditionally acceptable risk.** Corrective measures are required within a defined time frame. The design must be reviewed to reduce the probability of interaction (Vi) or introduce protective mechanisms.
IV	46 – 90	High	🟥	**Unacceptable risk.** Immediate intervention is required. The product must not be used until the

			🟥	risk is reduced. Engineering modifications (redesign) or physical barriers that prevent dangerous interaction are necessary.
V	91 – 125	Critical	🟥	**Unallowable risk.** Stop using the product immediately. The system has fatal design flaws where serious injury or major damage is almost guaranteed during normal or foreseeable use. Mandatory redesign of the interface.

Table 5. Risk level assessment according to the IEC method.

The boundaries of risk zones are determined on the basis of the analysis of the geometric progression of the product of factors (V_i V_d D), using the principle of the "safety cube" (2^3) for the lower threshold, the principle of the cumulative effect of frequent interaction for moderate risk, and the principle of the "double high factor" for high risk, with the introduction of a qualitative priority clause, which automatically increases the risk in the event of catastrophic consequences (D = 5).

2.1.6. Step 6 – Risk evaluation and redesign recommendations

Based on the completed IEC matrix, critical points are identified where interaction causes unacceptable consequences. Conclusions are drawn as to the required design modifications to eliminate the possibility of negative interaction or to reduce its effect.

3. CASE STUDY: SAFETY ANALYSIS OF A HOTEL SHOWER MIXER

In this chapter, the IEC method will be applied to a real example of a sanitary device that has been identified as the cause of safety incidents and user dissatisfaction. The aim of the analysis is to systematically map all possible forms of user interaction with the device, including individual and simultaneous actions, in order to detect hidden risks arising from the design of the interface.

The subject of analysis is a modern cylindrical thermostatic shower mixer, installed in the bathrooms of a high-category (4-star) hotel. This shower mixer is shown in Figure 1. Based on visual inspection of the device, the following technical and design characteristics relevant to the ergonomic safety assessment have been identified:

- Control is performed via two symmetrically positioned rotary handles at the ends of the cylindrical body.
- The left handle is intended for water flow control and source selection (switching between the upper “rising” shower and the lower hand shower).
- The right handle is intended for thermostatic regulation of water temperature.

- Control buttons. Both handles feature integrated gray rectangular buttons with rounded edges. Their function is the mechanical unlocking of safety limiters (a block at 50% flow on the left side and a block at 38°C on the right side).

Figure 1. Shower mixer with interface elements subject to assessment using the IEC method.

The initiative for conducting this analysis arose from a series of reported incidents and negative user experiences among hotel guests. The problems manifest across a wide spectrum, ranging from the inability to adjust the desired water flow to serious safety risks such as exposure to hot water or thermal shock due to sudden inflow of cold water.

For the controls on the left side of the shower mixer, 12 possible interactions were identified, relating to different handle positions depending on the direction of rotation and the activation mode of the left button. In a similar way, 12 possible interactions were identified for the right handle, resulting from adjustments of the temperature regulator and activation of the right button.

IEC matrices were formed for all four mentioned interface elements. Then, an IEC matrix was created for the paired interface elements, containing a total of 144 possible interaction modalities (12 possible activations of the left side of the shower mixer × 12 possible activations of the right side of the shower mixer).

3.1. Results

By analyzing the total state space (144 system combinations + 4 individual analyses), a clear polarization of risk is observed. The system shows a tendency toward extremes – it is either completely safe (when used as intended) or enters the high-risk zone due to small deviations in use.

The distribution of risk across zones in the case of combined interactions shows the following:

- Zone I (negligible risk, $R \leq 8$): ~55% of cases. Refers to idle situations or proper use of the hand shower.

- Zone II (low risk, R = 9–18): ~20% of cases. Mostly related to minor handling errors without thermal consequences (button lock).
- Zone III (moderate risk, R = 19–45): ~15% of cases. Situations of frustration, hand slipping, and mild thermal discomfort.
- Zones IV and V (high and critical, R ≥ 46): ~10% of cases. This is an alarming percentage. The fact that every tenth interaction can lead to a serious incident indicates a fundamentally unsafe design.

Based on the calculated values of the risk level R, three of the most dangerous scenarios have been singled out that require urgent engineering intervention. Table 6 shows the ranking in descending order. Note: The critical threshold of unacceptability is R > 45.

Rank	ID	Left handle action	Left button action	Right handle action	Right button action	Resulting effect (Ecomb)	R
1.	5-1	Rotation upwards (passing the Eco position)	Pressed inward (intentional activation)	In cold position	Not pressed	Severe cold shock Maximum strike of icy water from above (100% flow).	80
2.	3-1	Rotation upwards (to Eco position)	Not pressed	In cold position	Not pressed	Cold shock. Activation of the overhead shower with cold water.	60
3.	7-1	Zero position overshoot	Not pressed	In cold position	Not pressed	Unintentional cold shock. User intends shutdown, receives icy water from above.	60

Table 6. Three combined interactions with shower mixer interface elements that produce the highest level of risk.

The analysis clearly demonstrates that the risks are not accidental in nature, but are a systemic result of poor design. A high risk ranking (R ≥ 60) in several scenarios confirms the hypothesis that human-object interaction in this case is not guided by the principles of Poka-Yoke (error prevention). On the contrary, the design makes it difficult to react correctly in critical moments. Particularly dangerous is the "invisible" nature of the hazard: the user has neither visual information (labels) nor tactile confirmation (clicks) which forces them to operate the system "blindly", relying on assumptions that are often wrong.

4. CONCLUSION

Development and application of the Interaction - Effect - Consequence (IEC) method in this study demonstrated the necessity of a paradigm shift in product safety assessment. While the traditional methodologies for analysis, such as FMEA or FTA, mainly focus on the reliability of the components and technological failures, the IEC method presents an innovative approach, in which the human-object interface is the focus of the analysis.

The most important scientific and practical value of the IEC method is that it provides a way of quantifying risks that are not the result of mechanical failure, but rather design-induced errors. Unlike linear methods that often treat human error as a stochastic (random) event, through the probability of interaction factor (V_i), the IEC method recognizes that error is often determined by poor affordance and ergonomics.

The method is distinguished particularly by the introduction of the combined interaction matrix, which makes it possible to analyze actions at several control elements. This enables the detection of "hidden" or emergent risks - situations in which the individual components are safe, but their combined use (e.g. in a state of panic) has catastrophic results. In this way, the IEC method bridges the gap between the disciplines of reliability engineering and ergonomics and provides a tool for predicting the system behavior in real, unforeseen or chaotic operating conditions.

Application of the IEC method to a sample thermostatic shower mixer confirmed the hypothesis that a "technically correct" product can be highly risky for the user. Analysis of 144 state combinations showed that the greatest danger does not necessarily come from the worst injuries, but from design flaws that are manifested through frequent use of interface elements.

The conducted case study shows that safety cannot be achieved by installing safety valves only (hardware protection), but must be designed through an intuitive interface that "guides" the user towards correct use. Implementation of fairly simple solutions based on this analysis, such as clear visual markings and easy to perceive tactile limiters, would drastically reduce the calculated risk. This validates the usefulness of the IEC method in the product development process.

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