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Design to fail? The reasonably foreseeable failure and misuse

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Abstract

This paper examines the critical concept of "reasonably foreseeable failures and misuse" in product design. The psychology of failures and the ethical/legal implications are highlighted. The approach aims to provide a comprehensive understanding of the challenges associated with integrating reasonably foreseeable user failure and misuse into the design process. By taking a proactive approach to failure and misuse, designers can not only increase product safety, but also stimulate innovation that takes into account a wide range of user behaviour, including in unexpected circumstances.

Keywords: human error, human behaviour, human-centred design, socio-technical systems

1. Introduction

In the modern world of product development, progress is rapid and unstoppable. With the advent of new technologies and the integration of advanced concepts into the development process, the landscape of product development has changed significantly. This dynamic brings with it both immense opportunities and considerable challenges. As companies strive to optimise their products and services and adapt to the ever-changing demands of the market, they often encounter hurdles that are often predictable. These predictable failures can be attributed to a variety of factors, from technical and organisational difficulties to human errors and misunderstandings. This paper explores how these errors can be classified, what impact they have on the product development process and how they can be effectively anticipated and avoided. The aim is to provide a comprehensive understanding of the importance of error detection and prevention in product development, while demonstrating how companies can take proactive measures to ensure a more efficient and error-free development process (Design-Society, 2019; Badke-Schaub and Schaub, 2022).

This concept paper uses the insights and findings on human error from the field of psychology and human factors research and relevant guidelines to sensitise designers and engineers involved in the product development process to the predictable human errors in the use of products and processes. The cited literature refers to passages suitable for deepening the conceptual ideas.

2. Classification of foreseeable errors

Foreseeable errors in product development can be divided into different categories based on the underlying causes, the development phases affected and the potential impact (Reason, 1991; Dörner, 1997).

The classification of foreseeable errors plays a crucial role in various fields such as engineering, psychology, and technology. Its main objective is to enhance safety and improve interactions between humans and machines. In your role as a scientist with an interest in human and technology, understanding the significance of this classification can be highly beneficial. One of its primary functions is to increase safety. This is achieved by categorizing errors based on their nature and potential consequences. In doing so, safety experts can develop strategies to prevent or mitigate these errors, contributing to a reduction in accidents and injuries.

Furthermore, the classification of foreseeable errors is integral to user-centred design. It allows designers to create user-friendly interfaces that minimize the occurrence of errors and make it easier for users to use technology effectively and safely.

Additionally, it serves the purpose of risk assessment. Organizations can better assess potential risks associated with their systems or processes and allocate resources to address high-priority error categories.

In education and training, foreseeable errors are valuable teaching tools. Educators can utilize them to highlight common mistakes and their consequences, emphasizing the importance of correct procedures.

In many industries, particularly in healthcare and aviation, error classification is part of a continuous improvement process. Organizations analyse past errors, categorize them, and use these insights to implement changes and prevent similar errors in the future.

For your research interests, the classification of foreseeable errors offers an extensive field of study. You can explore the cognitive and behavioural aspects of errors, contributing to a deeper understanding of the interaction between humans and machines and promoting the development of error-tolerant systems. Overall, the classification of foreseeable errors is of paramount importance in various fields and effectively connects your interests in human and technology.

A deeper look at these categories enables companies to identify potential sources of errors at an early stage and take appropriate countermeasures (Table 1).

Table 1. Classification of foreseeable errors

1. Technical errors: These occur due to deficiencies in the technologies, tools or materials used. Examples are insufficient material quality, faulty software components or non-optimised production processes.
2. Organisational errors: these result from deficiencies in the organisational structure or processes of a company. They can result from unclear communication lines, lack of resource planning or inefficient processes.
3. Human errors: these include errors that result from human weaknesses, such as lack of expertise, overlooking details or wrong decisions.
4. Conceptual errors: these occur in the conceptual phase of a product and concern the basic design or orientation. Such errors could occur due to insufficient market research, misunderstanding of the target group or lack of innovation strategies.
5. External errors: these are the result of influences outside the control of the developing company. Examples are changes in legal regulations, market shifts or unexpected events such as natural disasters.
6. Communicative errors: these arise from misunderstandings or loss of information between different departments, teams or stakeholders. These can be caused by unclear requirements documentation, lack of feedback or inadequate communication channels.
7. Budget-related errors: these result from inadequate financial planning or a misjudgement of costs. They can lead to limitations in product quality, delayed launches or even project abandonment.

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Through a deep understanding of these categories and their respective characteristics, companies can develop targeted strategies to minimise the likelihood of product development errors and increase their overall efficiency.
At this point we want to consider above all the psychological aspects, the human and social errors.

3. Human error in international standards

3.1. Role of human error in the EU Machinery Directive

The EU Machinery Directive (2006/42/EC) sets out the health and safety requirements for machinery placed on the European market or put into service. A central concern of the directive is the protection of persons operating machinery or being in its immediate vicinity. In this context, human error plays a significant role, as it is often a major cause of occupational accidents (European Parliament and of the Council, 2006).
In the EU Machinery Directive, the concept of "reasonably foreseeable human error" is used to encourage manufacturers and operators of machinery to consider both obvious and less obvious risks that may arise from human interaction. The term "reasonably foreseeable" refers to errors that an average user might commit under normal or even abusive conditions.
The safety of machinery and equipment is a central concern of the EU Machinery Directive. An essential aspect of this safety is the consideration of human error. While some errors may be due to obvious design flaws or misunderstandings, there are others that are less obvious but still "reasonably foreseeable".
The term "reasonably foreseeable" in the EU Machinery Directive refers to human errors that can occur during the normal use of a machine or even during improper use. It is not only about errors that occur due to design or instruction deficiencies, but also those that can occur due to distraction, fatigue, routine or lack of understanding on the part of the user accidents (European Parliament and of the Council, 2006).
Manufacturers and operators of machinery are obliged to take such foreseeable human errors into account. This means that they must consider not only the obvious risks, but also the less obvious but still reasonably foreseeable risks.
Some examples of "reasonably foreseeable human errors" could be:

- An operator accidentally pressing the wrong button.
- A user using a machine in extreme weather conditions or in an environment that is not recommended.
- A technician performing maintenance without properly turning off the machine.

Consideration of "reasonably foreseeable human error" is critical to ensure the safety and health of machine operators and others involved. It is the responsibility of manufacturers and operators to consider this aspect at all stages of machinery design, manufacture, installation, and operation.
The EU Machinery Directive emphasises the need for a comprehensive risk assessment that considers all possible sources of error, including those that, although not obvious, are nevertheless reasonably foreseeable. It is vital that machinery manufacturers and operators take this aspect seriously to ensure that their products are as safe as possible accidents (European Parliament and of the Council, 2006).

- Risk assessment: The directive requires manufacturers to carry out a risk assessment for each machine. This must identify and assess potential hazards that could be caused by human error. This includes operating errors, misunderstandings, or incorrect reactions to malfunctions.
- Instructions for use: The Machinery Directive requires that every machine must be supplied with clear and comprehensible instructions for use. These instructions should inform the operator about possible hazards and the correct handling of the machine to avoid human error.
- Ergonomic design: Machinery must be designed to be ergonomic for the user. The design should minimise human error by, for example, arranging controls logically and ensuring that the machine is intuitive to use.
- Emergency measures: The Directive requires that machinery be equipped with emergency stop buttons or other safety devices to enable a rapid response in the event of human error.

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- Education and training: Although the Machinery Directive does not directly prescribe specific training measures, it implies the need for operators to be adequately trained to reduce human error. A well-informed and trained operator is less prone to errors.
- Continuous improvement: The policy recognises that technology and best practices evolve. Therefore, manufacturers should regularly seek feedback from users and analyse human errors to continuously improve their machines.

In summary, the EU Machinery Directive considers human error as a critical factor in ensuring the safety of machinery. The directive sets clear requirements and guidelines to ensure that machinery is designed to minimise the risk of human error while providing a high level of health and safety.

3.2. Role of human error in ISO 9241

ISO 9241 is an international standard that deals with ergonomic requirements for human interaction with interactive systems. The standard consists of several parts that deal with different aspects of human-system interaction. Human error is of particular importance in this standard, as one of the main intentions of ISO 9241 is to design systems so that they can be used effectively, efficiently and satisfactorily by users (Nielsen, 1993; Guastello, 2013; ISO, 2019).

- User-centred design: ISO 9241 emphasises the importance of user-centred design. This means that the design of a system should always consider the users and their needs. One goal is to minimise human error by making systems intuitive and user-friendly (Frankenberger et al., 1998.
- Feedback mechanisms: To identify and correct human errors, the standard emphasises the need for feedback mechanisms. These allow users to recognise when an error has occurred and often provide solutions to correct the error.
- Prevention of errors: The standard provides recommendations for the design of user interfaces to reduce the occurrence of errors. This includes, for example, clear and consistent labelling, logical navigation and the avoidance of superfluous or confusing options.
- Adaptability: ISO 9241 recognises that different users have different abilities and preferences. Therefore, a system should be designed to be adaptable to individual user requirements in order to reduce potential sources of error.
- Evaluation and testing: The standard recommends regular evaluation and user testing to determine how users interact with the system and where potential sources of error might lie. These findings should then be used to continuously improve the system.
- Ergonomic requirements: Various parts of ISO 9241 specify ergonomic requirements to help reduce the physical and mental strain on users. This in turn can help to reduce human error.

Overall, human error takes a central role in ISO 9241. The standard provides a comprehensive framework for the design of user interfaces and systems that anticipate, avoid, and correct human error to ensure an optimal user experience (ISO, 2019).

3.3. Comparison of ISO 9241 and EU Machinery Directive in relation to foreseeable human error

The role of human error in both ISO 9241 and the EU Machinery Directive reflects the desire to make products and machinery safer and more user-friendly. Both documents recognise the need to consider human error to prevent accidents and improper use. However, there are also significant differences in their approach and focus. The following (Table 2) is a comparison between the role of human error in ISO 9241 and the EU Machinery Directive (European Parliament and of the Council, 2006; ISO, 2019).

In summary, both documents recognise the importance of human error in the design and operation of products and machinery. While ISO 9241 focuses more on usability and ergonomics, the EU Machinery Directive focuses on safety and health. However, both approaches are focused on anticipating and mitigating human error to achieve optimal results.

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Table 2. Comparison of human error in ISO 9241 and the EU Machinery Directive

Purpose and scope: • ISO 9241: This international standard focuses on the ergonomic design of human-system interactions, particularly in the context of computer applications and user interfaces. It aims to design systems so that they can be used efficiently, effectively, and satisfactorily. • EU Machinery Directive: This directive focuses on the safety of machinery and equipment sold or operated in the European Union. It sets minimum requirements for the safety and health protection of persons using machinery. Approach to human error: • ISO 9241: Emphasises the importance of user-centred design and ergonomic requirements to minimise human error. It gives recommendations on the design of user interfaces and the implementation of feedback mechanisms. • EU Machinery Directive: Emphasises the need for machinery to be designed in such a way that, when properly installed and maintained and when used correctly, it does not pose any health or safety risks to people. Emphasis is placed on the prediction and prevention of human error. Evaluation and testing: • ISO 9241: Recommends regular evaluation and user testing to determine how users interact with the system and where potential sources of error may lie. • EU Machinery Directive: Places emphasis on conformity assessment procedures and testing to ensure that machinery meets specified safety requirements. Scope: • ISO 9241: While internationally recognised, its application is voluntary unless required by specific national or industry regulations. • EU Machinery Directive: Its application is mandatory for all machinery manufacturers and operators who wish to sell or operate their products in the EU.

4. Human error in product development

Human errors are often difficult to identify and quantify because they are based on individual actions and decisions. However, they can have a significant impact on the entire development process and the final product (Norman, 2002).

4.1. Dirty Dozen

The Dirty Dozen (ICAO Circular, 1993) refers to twelve main factors that promote human error in aviation and other safety-critical industries (Table 3). These twelve factors were identified to better understand human error and develop appropriate training programmes to reduce such errors in the aviation industry (Reason, 1991; Schaub, 2020).
It is important to note that the Dirty Dozen should not be seen as strict causes of human error, but rather as contributing factors that can increase the risk of human error. Training and awareness programmes that address these factors aim to increase awareness of these risks and provide strategies to avoid or minimise errors (Schaub, 2007).

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Table 3. The "Dirty Dozen"

1. Lack of communication: incomplete, missing, or misunderstood communication between stakeholders.
2. Distraction: Any kind of interruption or distraction during a task.
3. Lack of resources: Lack of tools, equipment, information, or time.
4. Stress: Physical or emotional pressure that can affect performance.
5. Lack of teamwork: Lack of cooperation or conflict within a team.
6. Lack of awareness: Failure to recognise hazards or risks in the environment.
7. Lack of knowledge: Insufficient understanding or knowledge of a particular task or procedure.
8. Fatigue: Physical or mental exhaustion that affects performance.
9. Lack of preparation: Insufficient planning or preparation for a task.
10. Pressure: External or internal pressure to complete a task quickly or in a particular way.
11. Lack of persistence: Quickly abandoning or changing plans without careful consideration.
12. Norms: Accepting or following practices that do not conform to official standards or procedures.

4.2. Types of human error

Although the Dirty Dozen are often used in practice, we would like to bring some order into the errors and present a classification of human errors. The following classification (Table 4) provides an overview of different types of human error (Reason, 1991; Dörner and Schaub, 1994).

Table 4. Different types of human error (Dörner and Schaub, 1994)

Cognitive errors:

- Forgetfulness: overlooking tasks or forgetting important information.
- Misjudgement: Incorrectly assessing risks, costs or time.
- Loss of concentration: Errors due to distractions or mental fatigue.

Competence-related errors:

- Insufficient technical knowledge: Errors due to lack of knowledge or skills.
- Misinterpretation: Misunderstanding of instructions, data or feedback.

Communication errors:

- Lack of feedback: Failure to pass on important information to other team members.
- Misunderstanding communication: Providing information in a way that can lead to misinterpretation.

Decision-making errors:

- Bias: Making decisions based on personal preferences rather than objective data.
- Hasty decisions: Making decisions without sufficient analysis or consideration.

Motivation and attitude errors:

- Lack of motivation: errors due to lack of commitment or interest in the task.
- Resistance to change: Hesitating or refusing to adopt new approaches or technologies.

Interpersonal errors:

- Conflicts within the team: differing opinions or interests leading to poor decisions.
- Lack of collaboration: Not working effectively with other team members or departments.

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By recognising and understanding these human errors, companies can take preventative measures and implement training or processes to minimise their frequency and impact (Cross, 2011).

4.3. Man-in-the-loop problems in product development

Automated systems are ubiquitous in modern product development. They offer the possibility to perform tasks faster and more precisely than humans. At the same time, however, there is the challenge of ensuring that these systems can interact effectively and safely with human users. This is where the concept of the man-in-the-loop comes into play (Lindemann, 2003; Vajna, 2020).

Definition: The man-in-the-loop approach means that a human user is actively involved in the decision-making process of an automated system. The human serves as a controller and can intervene in the process at critical moments (Bainbridge, 1983).

- Advantages:
    - Flexibility: humans can adapt to unforeseen situations and find creative solutions.
    - Intuition: Human users can recognise patterns and make decisions based on their experience.
    - Responsibility: In critical applications, humans can act as the last line of control and prevent errors.
- Challenges:
    - Cognitive overload: As system complexity increases, it can become difficult to monitor and understand all aspects of the system.
    - Delayed response: In situations where quick decisions are required, human response times can be too long.
    - Ambiguous responsibilities: It may be unclear when and how humans should intervene and who is responsible in the event of a failure.
- Application examples:
    - Aircraft autonomy: pilots monitor automated systems and intervene only when necessary.
    - Manufacturing automation: technicians monitor production lines and intervene when anomalies occur.
- Future considerations: With advances in AI and machine learning, automated systems are becoming more autonomous. This raises new questions regarding the man-in-the-loop approach, such as the right balance between autonomy and human control. The "man-in-the-loop" problem is a central issue in the discussion about the role of humans in automated systems. A deep understanding of this problem is crucial for the development of safe and efficient products.

4.4. Ethical and legal implications of reasonably foreseeable failure and misuse

The ethical and legal implications of reasonably foreseeable failure and misuse are a wide-ranging and important issue, particularly in areas such as product liability, technology, and medicine. The concepts of foreseeable failure and misuse concern the extent to which a manufacturer or provider can be held liable for harm caused by the use or misuse of a product or technology. Below I will discuss the ethical and legal aspects of this issue in detail (Leech, 2017).

Ethical implications:

- Responsibility for product safety: Manufacturers and suppliers have an ethical duty to develop products that are safe and reliable. If product failure or misuse is foreseeable, reasonable steps should be taken to minimise these risks.
- Duty to inform: It is ethical to inform consumers of potential risks and dangers associated with the use or misuse of a product.
- Prioritising human life: In industries such as medical technology, where product failure can cost lives, there is a high ethical obligation to minimise such risks.

Legal implications:

- Product liability: in many jurisdictions, manufacturers or suppliers can be held liable if their products fail or cause harm in cases of foreseeable misuse.

- Duty to mitigate risk: If a company has knowledge of a potential foreseeable failure or misuse, it may have a legal duty to take steps to mitigate the risk.
- Litigation: Companies may face lawsuits if they fail to respond appropriately to foreseeable risks. This can lead to high costs, reputational damage and possible penalties.

In conclusion, the ethical and legal implications of reasonably foreseeable failure and misuse are important for both companies and consumers. Companies need to be aware of the responsibility to develop safe products and to educate consumers about potential risks. At the same time, consumers have the responsibility to use products according to their intended uses and to inform themselves about potential risks.

5. Solution approaches and prevention in product development

In modern product development, the "human" factor plays a central role. Designers are often confronted with designing products that are both aesthetic and functional. In the process, human errors and weaknesses may be overlooked. To account for such flaws in product development, it is essential that designers are trained in the fundamentals of human psychology and ergonomics (Cross et al., 1997; Badke-Schaub et al., 2011). A deep understanding of human ways of thinking and acting can help develop products that are more intuitive and user-friendly (Dörner and Schaub, 1994; Kahneman, 2011; Gawron, 2019).

- Training and education:
    - Simulation training: By using simulations, users can be trained in a risk-free environment. This allows them to familiarise themselves with the system and identify potential sources of error.
    - Ongoing education: Technologies and systems are constantly evolving. Regular training and education are therefore essential.
- Improved user interfaces:
    - Intuitive designs: User interfaces should be clear, understandable and tailored to users' needs.
    - Feedback mechanisms: Systems should provide continuous feedback to the user to facilitate understanding and anticipation of system behaviour.
- Use of AI and machine learning:
    - Proactive error detection: AI systems can be used to detect errors in real time and warn users.
    - Adaptive systems: Machine learning can help systems adapt to user behaviour and preferences.
- Clear responsibilities:
    - Policies and protocols: it should be clearly defined when and how a human user should intervene in the process.
    - Communication strategies: In team situations, it should be clearly communicated who is responsible for which aspects of the system.
- Redundancy and security mechanisms:
    - Multi-level controls: By using multiple monitoring systems, errors can be detected and corrected before they lead to problems.
    - Emergency protocols: In critical situations, clear protocols should be in place to ensure the safe operation of the system.
- User feedback and continuous improvement:
    - User feedback: Feedback from users should be collected and analysed regularly to identify potential problem areas.
    - Iterative development: Products should be continuously revised and improved based on feedback and identified bugs.

Another approach is user-centred design, which puts the user at the centre of the design process. Through observations, interviews and testing, designers can develop a better understanding of users' needs and behaviours. This leads to products that minimise human error. An iterative development process, in

which the design is repeatedly tested and revised, makes it possible to identify and correct human errors early on (Birkhofer, 2011).
Collaboration in multidisciplinary teams consisting of experts such as psychologists, engineers and designers can lead to a more comprehensive design approach. Such an integrative approach can help to consider human error from different angles. Finally, it is significant that companies cultivate a culture in which errors are analysed. Studying mistakes made in the past can provide valuable insights to avoid future mistakes. Overall, taking human errors into account not only improves the safety and usability of products, but can also help products be more successful in the marketplace. It is an investment in the future of the product and the company.
By combining technical and human problem-solving approaches, predictable errors in product development can be minimised. It is crucial that companies and developers are proactive and strive to continuously develop and train both technology and human users.

6. Conclusion

The analysis of foreseeable errors in product development has shown that a variety of factors - both human and technical - can influence the final product. Human errors, technical shortcomings and the "man-in-the-loop" problem are just some of the challenges developers face.
The solutions presented offer a range of ways to address these challenges. From improved training and education to the integration of AI and machine learning, to clear accountability and feedback mechanisms, all these strategies have the potential to streamline product development and minimise the risk of errors.
However, it is important to emphasise that no single approach is sufficient to address all potential sources of error. A holistic approach that considers both the technical aspects and the human dimension is essential. The integration of technology and humanity, coupled with constant reflection and evolution, will pave the way to products that are both powerful and reliable.
In conclusion, product development is a dynamic process that is shaped by both advances in technology and our understanding of human capabilities and limitations. By balancing both aspects and constantly seeking improvements, we can pave the way for innovative and safe products of the future.

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