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Human Error Reduction through Prevention in Design (PtD)

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Abstract

Human error remains one of the most persistent contributors to accidents, quality failures, and inefficiencies across industrial systems. Traditional safety approaches often rely on training, procedures, and post-incident corrective actions, which may not adequately address the root causes of human error. Prevention in Design (PtD) offers a proactive approach by integrating safety, usability, and error prevention strategies directly into the design phase of products, processes, and systems. This review paper examines the role of PtD in reducing human error by focusing on design-based prevention rather than behavioral correction. The paper discusses theoretical foundations of human error, classifications of error types, and the evolution of PtD principles. Key design strategies such as error-proofing, ergonomics, human-centered design, and system simplification are analyzed. Industrial case examples from manufacturing, healthcare, construction, and transportation sectors are reviewed to demonstrate practical implementation. Challenges, limitations, and future research directions related to digital design tools and Industry 4.0 integration are also discussed. The study concludes that human error reduction through PtD is not only feasible but essential for achieving sustainable safety and quality performance in complex socio-technical systems.

Keywords: *Human error, Prevention in Design, PtD, error-proofing, human-centered design, safety engineering*

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INTRODUCTION

Human error has been widely recognized as a major cause of accidents, system failures, and quality defects in both industrial and service sectors. Studies across domains such as aviation, healthcare, construction, and manufacturing consistently show that human-related factors contribute to a significant percentage of adverse events. Despite advancements in automation and digital technologies, human interaction with systems remains unavoidable, making error prevention a critical design concern.

Conventional approaches to managing human error often emphasize training, supervision, and procedural compliance. While these measures are important, they assume that humans can consistently perform error-free actions under varying conditions. In reality, fatigue, cognitive overload, time pressure, and poorly designed interfaces frequently undermine human performance. As a result, safety interventions implemented after system deployment tend to be reactive rather than preventive.

Prevention in Design (PtD) represents a paradigm shift toward proactively addressing hazards and human error during the earliest stages of system design. PtD promotes the elimination or reduction of risks by embedding safety and usability directly into products, equipment, work environments, and processes. Instead of asking workers to adapt to unsafe designs, PtD emphasizes adapting the design to human capabilities and limitations.

This paper provides a comprehensive review of human error reduction through PtD. It explores theoretical perspectives on human error, outlines core PtD principles, reviews design strategies for error prevention, and examines industrial applications. The objective is to highlight how thoughtful design decisions can significantly reduce reliance on human vigilance and thereby improve overall system safety and performance.

UNDERSTANDING HUMAN ERROR

Understanding human error is essential for developing effective Prevention in Design (PtD) strategies. Rather than viewing errors as isolated mistakes made by individuals, modern safety and design research emphasizes that errors often emerge from the interaction between humans, technology, and organizational systems. This perspective allows designers to focus on improving system conditions that shape human behavior, rather than assigning blame to users.

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Definition and Nature of Human Error

Human error is generally defined as any deviation from intended actions, planned procedures, or expected system outcomes that results in an undesired or unsafe condition. Importantly, human error does not necessarily indicate carelessness, lack of skill, or negligence on the part of the user. Even experienced and well-trained individuals are prone to errors when operating within poorly designed systems or under challenging conditions.

In many cases, human errors arise due to a mismatch between system demands and human capabilities. Systems may require users to process excessive information, perform tasks under time pressure, or operate controls that are unintuitive or physically demanding. When the cognitive or physical load exceeds human limits, the probability of error increases significantly. This mismatch highlights the importance of aligning system design with realistic human abilities and limitations.

Human performance is influenced by a combination of cognitive, physical, and organizational factors. Cognitive factors include attention, memory, perception, and decision-making. Physical factors involve posture, reach, strength, and sensory capabilities such as vision and hearing. Organizational factors, such as work schedules, production targets, communication practices, and safety culture, also play a major role in shaping human behavior. For example, long working hours and unclear responsibilities can contribute to fatigue and confusion, increasing the likelihood of mistakes.

Poorly designed interfaces are a frequent source of human error. Complex control layouts, similar-looking buttons, unclear symbols, and lack of feedback can confuse users and lead to incorrect actions. Ambiguous instructions or inconsistent procedures further add to uncertainty, forcing users to rely on assumptions or memory. Excessive system complexity, especially in highly automated environments, can also reduce situational awareness and make it difficult for users to detect and recover from errors.

From a Prevention in Design perspective, human error should be understood as a property of the system rather than a failure of the individual. Errors are often symptoms of deeper design flaws, such as inadequate information flow, poor ergonomics, or unrealistic task requirements. By recognizing this systemic nature of human error, designers and engineers can shift their

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focus toward eliminating error-prone conditions during the design phase, instead of relying solely on training and supervision after implementation.

CLASSIFICATION OF HUMAN ERRORS

Human errors are commonly classified based on the underlying cognitive processes involved in task execution and decision-making. These classifications help designers understand why errors occur and guide the selection of appropriate prevention strategies. One widely used framework categorizes errors into slips, lapses, mistakes, and violations.

Slips occur when an individual has the correct intention but executes the action incorrectly. These errors are often associated with attention failures and are common in routine or repetitive tasks. For example, pressing the wrong button on a control panel due to similar shape or placement is a typical slip. Design-based interventions such as better spacing, distinct shapes, or tactile feedback can effectively reduce slips.

Lapses are memory-related errors that involve forgetting to perform an action or losing track of task progress. These errors frequently occur in complex tasks that require multiple steps or interruptions. For instance, forgetting to tighten a fastener or skipping a checklist item may result from lapses. Design solutions such as visual reminders, checklists, and automated prompts are effective in minimizing such errors.

Mistakes differ from slips and lapses in that they involve incorrect intentions or decisions. In this case, the action is performed as planned, but the plan itself is flawed. Mistakes often arise from inadequate knowledge, incorrect assumptions, or misleading information. For example, selecting the wrong operating mode due to unclear labeling reflects a mistake rather than a slip. Addressing mistakes typically requires improved information presentation, decision support, and user training integrated into the design.

Violations are deliberate deviations from established procedures or rules. Unlike other error types, violations are intentional, though they may not be malicious. Workers may bypass safety guards or ignore procedures due to time pressure, perceived inefficiency, or poor usability of the system. From a PtD standpoint, frequent violations may indicate that procedures are impractical or that the system design encourages unsafe shortcuts. Redesigning tasks to align

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with real-world working conditions can significantly reduce such behavior.

By classifying human errors in this manner, designers gain insights into the root causes of failures and can apply targeted design strategies. Rather than applying generic safety measures, PtD encourages solutions that directly address the specific error mechanisms present in a system.

Table 1: Common Classification of Human Errors

Error Type	Description	Example
Slips	Incorrect execution of a correct intention	Pressing wrong button
Lapses	Memory-related failures	Forgetting a step
Mistakes	Incorrect decision or plan	Choosing wrong procedure
Violations	Deliberate deviation from rules	Bypassing safety guards

Understanding these error types is essential for designing effective prevention strategies. For instance, slips may be reduced through better interface design, while mistakes may require improved information presentation.

PREVENTION IN DESIGN (PTD): CONCEPT AND EVOLUTION

Prevention in Design (PtD) represents a proactive philosophy that seeks to address safety, health, and human error concerns at the earliest possible stage of system development. Rather than treating safety as an additional requirement or a corrective action after incidents occur, PtD integrates prevention directly into the design process. This approach acknowledges that many hazards and error-prone conditions are “designed in” long before a system is operated, maintained, or modified.

Concept of Prevention in Design

Prevention in Design refers to the systematic consideration of occupational safety, health, and human factors during the conceptualization, design, and development of products, processes, equipment, and work environments. The fundamental principle of PtD is that early design decisions have long-term and often irreversible effects on how safely and effectively a system can be used. Once a system is built and deployed, opportunities to eliminate hazards become

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limited, costly, or impractical.

The central idea of PtD is to anticipate potential hazards, human errors, and misuse scenarios before they occur and to design them out of the system wherever possible. This may involve eliminating dangerous materials, simplifying task sequences, improving accessibility, or redesigning interfaces to better match human capabilities. By embedding prevention into design, PtD reduces the need for later interventions such as warnings, training, and personal protective equipment.

PtD closely aligns with the hierarchy of controls, a widely accepted framework in safety engineering. The hierarchy prioritizes hazard elimination and substitution as the most effective control measures, followed by engineering controls, administrative controls, and finally personal protective equipment. PtD strongly emphasizes the upper levels of this hierarchy, particularly elimination and engineering controls, as these approaches do not rely heavily on human compliance or continuous attention.

By eliminating hazards at the source, PtD significantly reduces dependence on human behavior for maintaining safety. This is particularly important in complex or high-risk systems where expecting flawless human performance is unrealistic. For example, designing machinery with built-in guards or interlocks is more reliable than relying solely on workers to follow safety procedures. In this way, PtD shifts the responsibility for safety from the user to the design itself. Another important aspect of PtD is its interdisciplinary nature. Effective implementation requires collaboration among designers, engineers, ergonomists, safety professionals, and end users. Incorporating diverse perspectives during design helps identify hidden risks and ensures that safety solutions do not compromise usability or productivity.

Evolution of PtD Approaches

The concept of Prevention in Design originally emerged within the field of occupational safety and health, particularly in high-risk industries such as construction, manufacturing, and mining. Early PtD efforts focused on reducing physical hazards associated with machinery, tools, and work environments. Typical examples included guarding moving parts, improving ventilation, and designing safer access points for maintenance activities.

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As understanding of human factors and ergonomics advanced, PtD began to expand beyond purely physical hazards. Researchers and practitioners recognized that cognitive workload, poor interface design, and organizational pressures also contribute significantly to accidents and errors. This realization led to the integration of ergonomic principles into PtD, emphasizing the need to design systems that support human physical and cognitive capabilities.

Over time, PtD approaches increasingly incorporated usability engineering and human-centered design methodologies. Designers started to involve users more actively in the design process through task analysis, user testing, and iterative prototyping. This shift helped identify error-prone interactions and usability issues early, when changes were easier and less expensive to implement.

The development of digital design tools further accelerated the adoption of PtD. Computer-aided design (CAD), digital human modeling, and simulation software allow designers to visualize workspaces, test reachability, and evaluate task sequences before physical systems are built. Virtual reality and digital twins enable realistic simulations of human-system interactions, making it possible to identify safety and error risks that might otherwise go unnoticed.

In recent years, PtD has also aligned with broader concepts such as Safety by Design, Inclusive Design, and Design for Reliability. The rise of Industry 4.0 and smart systems has expanded the scope of PtD to include human interaction with automated and cyber-physical systems. As systems become more interconnected and autonomous, PtD continues to evolve as a critical framework for ensuring that technological progress does not introduce new forms of human error or risk.

DESIGN STRATEGIES FOR HUMAN ERROR REDUCTION

Design plays a critical role in shaping human behavior and performance within systems. Effective design strategies can significantly reduce the likelihood of human error by minimizing reliance on memory, attention, and continuous vigilance. Prevention in Design emphasizes the use of systematic, design-based interventions that make correct actions easier and incorrect actions difficult or impossible. This section discusses key design strategies commonly used to reduce human error across various domains.

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Error-Proofing (Poka-Yoke)

Error-proofing, commonly referred to as *Poka-Yoke*, is a design strategy that aims to prevent errors from occurring or to ensure that errors are immediately detected before they lead to serious consequences. Originally developed within manufacturing systems, error-proofing techniques are particularly effective in repetitive tasks, assembly operations, and routine processes where small mistakes can accumulate into major quality or safety issues.

The primary objective of error-proofing is to reduce dependence on worker attention, experience, and memory. Instead of expecting operators to remember correct procedures at all times, the design itself guides correct action. One common approach involves the use of physical constraints that prevent incorrect assembly or operation. For example, parts may be designed so that they can only be assembled in the correct orientation, eliminating the possibility of reversal or misalignment.

Sensors and automated checks are another widely used error-proofing method. These systems detect missing components, incorrect sequences, or abnormal conditions and provide immediate feedback or stop the process altogether. In many production environments, such mechanisms prevent defective products from moving to the next stage, thereby reducing rework and safety risks.

Color coding and visual differentiation are simple yet effective techniques for error-proofing. By using distinct colors, shapes, or labels to differentiate parts, tools, or controls, designers help users quickly identify correct components and avoid confusion. These visual cues are especially useful in fast-paced environments where decisions must be made quickly.
Overall, error-proofing strategies shift the burden of error prevention from the individual to the system. By embedding safeguards directly into the design, organizations can achieve consistent performance even in the presence of human variability.

Ergonomic Design

Ergonomic design focuses on optimizing the interaction between humans and systems by considering physical, cognitive, and sensory capabilities. Poor ergonomic design is a well-known contributor to fatigue, discomfort, musculoskeletal disorders, and increased error rates. When workers are required to operate in awkward postures, exert excessive force, or strain to

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see and reach controls, their ability to perform tasks accurately is compromised.

One of the core principles of ergonomic design is maintaining neutral postures. Designing workstations, tools, and interfaces that allow users to keep joints in natural positions reduces physical strain and improves endurance. This is particularly important in tasks that are performed repeatedly or for extended periods.

Adequate reach and visibility are also essential ergonomic considerations. Controls, displays, and materials should be placed within comfortable reach zones and clearly visible without excessive bending or twisting. Poor visibility can lead to misreading information or missing critical cues, increasing the likelihood of operational errors.

Reducing physical effort is another key ergonomic objective. Tools and equipment should be designed to minimize force requirements, for example through mechanical assistance, counterbalancing, or improved grip design. Lower physical demands help reduce fatigue, which in turn supports sustained attention and accuracy.

By accommodating human physical limitations, ergonomic design not only reduces immediate errors but also lowers long-term health risks. This dual benefit makes ergonomics a fundamental component of Prevention in Design strategies.

Human-Centered Design (HCD)

Human-centered design (HCD) places users at the core of the design process and recognizes that systems should be shaped around human needs rather than forcing users to adapt to technology. HCD emphasizes a deep understanding of user tasks, environments, and constraints through methods such as observation, interviews, and usability testing.

A central goal of HCD is to reduce cognitive load, which refers to the mental effort required to perform a task. Complex interfaces, unclear information, and inconsistent interactions increase cognitive demands and raise the probability of mistakes. Simplified interfaces that present only relevant information help users focus on critical tasks and make accurate decisions.

Clear feedback and affordances are also important elements of human-centered design. Users

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should receive immediate and understandable feedback indicating whether an action has been successful or if corrective steps are needed. Affordances, such as the shape or placement of controls, should naturally suggest their intended use, reducing the need for instructions or trial-and-error learning.

Consistency in layouts, symbols, and interaction patterns further supports error reduction. When users encounter familiar designs across different systems or tasks, they can apply prior knowledge more effectively. Inconsistent designs, on the other hand, increase confusion and the risk of incorrect actions.

Through iterative testing and refinement, HCD enables designers to identify error-prone interactions early and make adjustments before systems are fully implemented. This proactive approach aligns closely with the principles of Prevention in Design.

Standardization and Simplification

Complexity is a major driver of human error in modern systems. As the number of components, procedures, and options increases, so does the likelihood of confusion and incorrect decisions. Standardization and simplification are powerful design strategies that aim to reduce unnecessary variability and complexity.

Standardization involves the use of common components, interfaces, procedures, and symbols across systems and tasks. When elements are standardized, users can transfer knowledge and skills from one context to another, reducing the need for retraining and lowering error rates. Standardized control layouts and operating procedures are especially beneficial in safety-critical environments.

Simplification focuses on reducing the number of steps, choices, and decisions required to complete a task. By eliminating redundant actions and streamlining workflows, designers reduce opportunities for mistakes. Simplified systems are easier to learn, operate, and maintain, which directly supports safer and more reliable performance.

Together, standardization and simplification help create systems that are more tolerant of human limitations. By making tasks clearer and more predictable, these strategies play a crucial

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role in reducing human error through Prevention in Design.

INDUSTRIAL APPLICATIONS OF PTD

Manufacturing Systems

In manufacturing, PtD is widely applied to reduce assembly errors and equipment-related accidents. Digital mock-ups allow designers to evaluate accessibility, visibility, and sequence of operations before physical installation.

Virtual simulations help identify potential error-prone steps and enable design modifications early in development.

Healthcare Systems

Healthcare environments are highly complex and time-sensitive. PtD has been used to redesign medication packaging, medical devices, and information systems.

For example, standardized connectors and color-coded labels reduce the risk of administering incorrect medications or fluids.

Construction Industry

Construction sites are dynamic and hazardous. PtD approaches include designing prefabricated components, integrated fall protection systems, and safer access points.
Designing safety features into structures reduces dependence on temporary protective measures.

Transportation and Mobility

In transportation, PtD principles are applied to vehicle interfaces, signaling systems, and infrastructure layout. Improved dashboard design, automation, and fail-safe mechanisms reduce driver workload and error probability.

INTEGRATION OF PTD WITH DIGITAL TECHNOLOGIES

Digital tools such as CAD, digital twins, and virtual reality enable designers to evaluate human interaction scenarios early. Human-in-the-loop simulations help predict error likelihood and test alternative designs.

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Industry 4.0 technologies further support PtD by enabling real-time feedback, adaptive systems, and predictive analytics.

CHALLENGES AND LIMITATIONS

Despite its benefits, PtD faces several challenges:

- Higher initial design effort and cost
- Limited awareness among designers
- Difficulty in predicting all user behaviors
- Organizational resistance to design changes

However, long-term benefits often outweigh initial investments, particularly in safety-critical systems.

FUTURE RESEARCH DIRECTIONS

Future research should focus on:

- Quantitative models for predicting human error during design
- Integration of AI-driven usability analysis
- PtD frameworks for autonomous systems
- Cross-disciplinary collaboration between designers and safety engineers

CONCLUSION

Human error cannot be completely eliminated, but its consequences can be significantly reduced through thoughtful design. Prevention in Design provides a proactive and systematic approach to minimizing error by addressing hazards at their source. By integrating error-proofing, ergonomics, and human-centered principles early in the design process, organizations can create safer, more reliable systems. As systems become more complex, the importance of PtD in supporting human performance will continue to grow. Ultimately, designing for humans rather than expecting humans to adapt to flawed designs is essential for sustainable safety and quality improvement.

REFERENCES

1. Reason, J. (1990). *Human Error*. Cambridge University Press.
2. Dekker, S. (2014). *The Field Guide to Understanding Human Error*. Ashgate Publishing.
3. Gawande, A. (2009). *The Checklist Manifesto*. Metropolitan Books.

Page 22-34 © MANTECH PUBLICATIONS 2025. All Rights Reserved

4. Salvendy, G. (2012). *Handbook of Human Factors and Ergonomics*. Wiley.
5. National Institute for Occupational Safety and Health (NIOSH). (2013). *Prevention through Design Guidelines*.
6. Norman, D. A. (2013). *The Design of Everyday Things*. Basic Books.
7. Dul, J., & Weerdmeester, B. (2008). *Ergonomics for Beginners*. CRC Press.
8. Hollnagel, E. (2014). *Safety-I and Safety-II*. Ashgate.
9. Wogalter, M. S. (2006). *Handbook of Warnings*. Lawrence Erlbaum Associates.
10. Wilson, J. R. (2014). *Fundamentals of Systems Ergonomics*. CRC Press.

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