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DEVELOPING A MISTAKEPROOFING MINDSET TO INCREASE SAFETY CAPACITY

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ABSTRACT

Safety capacity is the ability to increase the likelihood that work will go right under variable- and uncertain conditions. In construction projects, safety has traditionally been managed using lagging indicators, but these offer limited insights to develop safety capacity. Whereas safety management practices can be reactive and compliance-driven, they can also be proactive and anticipation-driven. Specific mistakeproofing (poka yoke) practices can be either one. In this paper, we argue that mistakeproofing practiced with a proactive mindset helps to build safety capacity. We present an approach for developing and sustaining a mistakeproofing mindset by drawing on concepts from uncertainty management (including risk management), Safety-I, Safety-II, and resilience engineering. To demonstrate this mindset, the Work Operation Framework was applied to analyze two construction examples of mistakeproofing related to safety management. Developing this mindset may narrow the gap between work-as-imagined and work-as-done. It recognizes that making adaptations is a part of doing work and reflects the intelligence of a (group of) worker(s). The reason for developing a mistakeproofing mindset is to support organizations with continuous improvement to increase their safety capacity.

KEYWORDS

Mistakeproofing, Poka Yoke, health, safety, Safety-I, Safety-II, safety capacity, mindset, resilience engineering.

INTRODUCTION

Safety capacity is the ability to increase the likelihood that work will go right under variable- and uncertain conditions (Dekker & Tooma 2022). It is a relatively new concept, especially in the construction industry where instead the focus has been on reacting to incidents and figuring out what went wrong. Variable conditions can impact quality, health, and safety, and enhancing these remains a goal in both academic research and industry.

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To manage safety under such conditions, organizations rely on performance measurement systems. When things have gone wrong, people collect data from their operations and use lagging performance indicators, such as incident-, injury-, or fatality rates. In contrast, Johnsen (2024) and others argue that both lagging and leading indicators should be integrated to proactively improve safety performance, but they also acknowledge integration challenges. Similarly, OSHA (2019) suggests bridging the gap between reliance on historical data and anticipation of future performance by identifying leading indicators to increase safety capacity.

One way to bridge this gap is to implement lean principles and practices from the Toyota Production System (TPS) and promote a lean mindset (Toyota n.d.), e.g., by using mistakeproofing (poka yoke in Japanese) (Note: For consistency, we spell mistakeproofing as a single word throughout our paper). The premise of this paper is that the practice of mistakeproofing will be enhanced by the cultivation of a mistakeproofing mindset, which in turn will help to increase practitioners' safety capacity.

The following section presents the literature review related to lean thinking including mistakeproofing, mindsets, risk- and uncertainty management, Safety-I and Safety-II, and resilience engineering. We then describe our research methodology and present a framework for helping people see opportunities to be proactive rather than reactive in managing safety. Using this framework and mistakeproofing examples, we discuss how a mistakeproofing mindset can be developed and sustained. The conclusion section offers directions for future research.

LITERATURE REVIEW

This literature review starts by introducing terminology. Mistake is defined as "an inadvertent human action that may lead to a defect in a process or product, or harm to a person" (e.g., Tommelein & Demirkesen 2018 p. 18). Although "mistake" and "error" are sometimes used interchangeably, the former is more commonly referred to as a person not doing or not understanding something correctly, whereas the latter more generally refers to a deviation from an expected outcome, whether resulting from a human or machine action. As we focus here on developing a mistakeproofing mindset, which pertains to human behavior, we use the term "mistake" consistently throughout the paper to denote both.

Mistakeproofing is defined as using a device or practice to either prevent or detect abnormalities that might be detrimental either to product or process quality or to a person's health and safety (after Saurin et al. 2012). Its application in quality- and safety management is quite broad, although the expertise in these areas may reside in different people (Stewart & Grout 2001).

One way to practice mistakeproofing is using the Work Operation Framework, formalized in the construction context by Tommelein and Demirkesen (2018). This Framework includes four principles upstream of a mistake to "make the occurrence of a mistake less likely" (namely eliminate, prevent, replace, and facilitate) and two principles downstream of a mistake to "alleviate the impact after the mistake occurred" (detect and mitigate) (Tommelein 2019). Figure 1 shows a simplified version.

The Framework can be used to describe concerns and countermeasures. A "concern describes something that might go wrong," and a "countermeasure describes a mistakeproofing practice either to reduce the likelihood of the mistake being made or to alleviate the impact of the mistake after it has been made (Tommelein 2024)." When a concern is identified, one or several countermeasures may be proposed to address it. The identification of concerns and countermeasures is iterative and aligns with the PDCA cycle for continuous improvement, concepts well known in lean management.

Figure 1: Simplified Work Operation Framework (Source: Modified from Tommelein (2019))

The Framework can be tied to the use of leading and lagging indicators. Lagging indicators refer to historical events (alleviate impact after occurrence), e.g., they may quantify a fatality rate. In contrast, leading indicators refer to proactive measures (making occurrence less likely), e.g., they may quantify the effectiveness of an organization's safety performance (Toellner 2001, OSHA 2019). The ability to anticipate and address concerns serves as a leading indicator of safety capacity.

This ability may be nurtured by developing a mistakeproofing mindset. Dweck (2006) defines a mindset as a set of beliefs that guides how a person interacts with the world. A fixed mindset is the belief that skills and knowledge come naturally to a person with little motivation to challenge the current way of thinking. In contrast, a growth mindset is the belief that skills and knowledge are not fixed, but traits that can be acquired or improved through effort over time. In the context of mistakeproofing, a growth mindset is essential because it encourages the questioning of existing practices and actively seeks opportunities for continuous improvement.

The ability to anticipate concerns aligns with a risk management mindset, at least to some degree. Pym (1987) defines a risk management mindset as "identifying, analyzing, and responding to risk factors throughout the life of a project and in the best interests of its objectives." Whereas project risk management may consider both threats and opportunities, it is all-too-commonly operationalized through the adoption of a downside view of uncertainty (i.e., identifying what might go wrong and taking for granted what is going right). In general, uncertainty refers to the "lack of certainty" that may lead to positive or negative outcomes, but in practice, risk management tends to focus more on threats, adverse events, and their mitigation (Ward & Chapman 2003). Even when the aim is to improve performance and create opportunities, the analytical starting point is typically potential failure rather than existing successful performance.

Advocating for a more balanced mindset, Grote (2003) distinguishes two approaches to uncertainty management. One approach seeks to minimize uncertainty through central planning, continuous monitoring, and minimizing degrees of freedom at the point of execution. The other emphasizes coping with uncertainty when conditions are variable. The first approach may be appropriate in predictable environments, whereas the second becomes increasingly important in more complex settings. As an uncertainty management approach, mistakeproofing may help to reduce sources of uncertainty from the system, however, it does not eliminate the need for adaptability when uncertainty cannot be designed out.

To distinguish mindsets for understanding safety management, Hollnagel et al. (2013) talk about Safety-I and Safety-II. Safety-I defines safety in terms of adverse outcomes and tends to include blaming people after-the-fact for what went wrong. It follows a "find and fix" approach, looking for failures and tracing back their causes, and then eliminating these causes to prevent reoccurrence. Safety-I simply assumes things will go right when preventing them from going wrong, without any motivation to examine what was done correctly. This type of mindset stems from outcome and hindsight biases, known as shortcut thinking (Scanlon & Jacobson 2025). Outcome bias is the judgment of the quality of a decision made based on the result of an event. Hindsight bias is the belief that the outcome of an event would have been predicted before it occurred, even if the information was not available beforehand (Hollnagel et al. 2015). Acknowledging both cognitive biases, Hollnagel et al. (2015) suggest that Safety-I is a causality credo, based on the "belief that adverse outcomes happen because something goes wrong."

In contrast, Safety-II focuses on increasing the likelihood that tasks will be performed correctly in order to improve safety performance. It includes the study of what usually goes right. Contrary to Safety-I, this mindset assumes that a system's performance involves many interrelated components and multiple variations. For mistakeproofing, this implies that preventing mistakes requires not only eliminating potential failures but also understanding how successful adaptations emerge during the normal execution of operations. In this sense, conventional risk-management aligns with Safety-I, whereas mistakeproofing builds on the foundation and extends it through Safety-II.

A gap exists between work-as-imagined (theoretical) and work-as-done (reality) (e.g., Shorrock 2016). Work-as-imagined refers to the idealized work procedures designed by management based on assumptions and predictions. Work-as-done reflects the reality of work performance with adaptations. A mistakeproofing mindset needs to acknowledge the reality of work-as-done rather than rely solely on the fantasy of work-as-imagined. It involves designing systems that tolerate human variability and celebrate human creativity, that lead to emergent adaptations and facilitate recovery when variability manifests itself.

Recognizing the value of emergent adaptations on the performance of complex systems, Hollnagel (2012) defines resilience engineering as a system having the four abilities to "adjust its functioning prior to, during, or following changes and disturbances, so that it can sustain required operations under both expected and unexpected conditions." These four abilities refer to "sustain," "respond," "monitor," and "learn." Resilience engineering requires a mindset that involves learning proactively how things usually go well and developing methods to enhance a system's capabilities. This focus on adaptation aligns with Safety-II thinking.

However, in practice, safety management may emphasize regulatory compliance, treating work variations as mistakes rather than potential improvements. When safety management focuses solely on compliance with work-as-imagined, it creates a "brittle" system in which the gap between procedure and reality widens, increasing the risk of unpredicted failure (Woods 2015).

The development of a resilient mindset – including a mistakeproofing mindset – that proactively monitors the gap between work-as-imagined and work-as-done is a leading indicator of safety capacity. It identifies where workers are forced to adapt or violate procedures to get the job done. By treating these adaptations not as violations but as signals of system design flaws, organizations can implement "upstream" mistakeproofing measures before an incident occurs. As Hollnagel (2018) suggests, the ability to anticipate and monitor these operational gaps is the hallmark of a safe system. Consequently, fostering a mindset that embraces the complexities of work-as-done is the ultimate form of cognitive mistakeproofing, transforming the workforce from a source of mistakes into a source of system resilience.

METHODOLOGY

We propose and formulate an approach for developing and sustaining a mistakeproofing mindset and apply it to construction safety management, aiming to help people develop safety capacity. To do so, we leverage principles and methods from lean construction, safety management paradigms including Safety-I and Safety-II, and resilience engineering. This formulation is to support the transition from a compliance-based to a lean philosophy-based safety education approach.

To illustrate what drives a mistakeproofing mindset, we present the Work Operation Framework and use it to analyze two construction examples. These examples were selected because they address common safety concerns in construction. The purpose is to show how the mindset can be applied to narrow the gap between work-as-imagined and work-as-done. The methodology follows the PDCA cycle to illustrate that practicing mistakeproofing is iterative. Each example was analyzed through multiple iterations to show that implementing

countermeasures creates a new state that reveals new concerns. The premise of our presentation is that the ability to proactively identify concerns should be established as a leading indicator to increase safety capacity.

MISTAKEPROOFING MINDSET

To position a mistakeproofing mindset as a means to increase safety capacity, a distinction must be made between observable practices and the mindset that precedes and governs them. Drawing on Dweck's (2006) concept of a fixed versus a growth mindset, a mistakeproofing mindset can be a leading indicator for safety capacity. In practice, a person with this mindset does not just follow a safety rule but actively seeks ways to make the mistake impossible even in novel situations where a specific "rule" or "practice" has not yet been established (Grout 2007).

A mindset is dynamic and must be developed and sustained. To develop a mistakeproofing mindset, a person needs to recognize their current way of thinking. However, because a person's mindset largely operates outside of conscious awareness, this self-recognition may be obstructed by biases to be overcome. Therefore, the development of the mindset must be structured methodologically. From an educational perspective, as suggested in Bloom's Taxonomy, a person's capability to mistakeproof may be built sequentially. Bloom's Taxonomy is "designed to be a classification of the student behaviors which represent the intended outcomes of the educational process" that is "organized from simple to complex [...] behavior" (Bloom et al. 1956). Applying this logic, one cannot expect a person to outright be able to create new countermeasures, given that 'create' reflects the highest level of Bloom's Taxonomy. A person's ability to create something new will be aided by first understanding, e.g., the principles presented in the Work Operation Framework.

The development of a mistakeproofing mindset focuses on shifting from a compliance-based to a lean philosophy-based safety education. Traditional safety education provides a baseline of knowledge, whereas education for a mistakeproofing mindset goes deeper by introducing principles from TPS. Specifically, once the principles are taught, hands-on training may be provided to help the person practice. Training may make use of the Work Operation Framework to analyze mistakeproofing examples, where participants learn to question current state concerns before they become mistakes. In addition, to bridge the gap between work-as-imagined and work-as-done, pedagogical simulations such as the "Mistakeproofing! It's in the Cards" game by Tommelein (2024) allow a person to practice lean thinking in a risk-free environment.

Sustainability is achieved when, through continuous practice, mistakeproofing becomes a habit. It is the continuous improvement mindset itself that contributes to ensuring that things go right, and this builds safety capacity. Importantly, sustaining a mistakeproofing mindset also requires preserving a sense of situational awareness. When a countermeasure becomes part of the 'normal' environment, the original concern and rationale for it may no longer be obvious: mistakeproofing applications must be documented. In practice, one countermeasure can introduce many new concerns to be addressed. If not duly documented, a concern may be addressed by a countermeasure, but the implementation of that countermeasure itself may already have been the source of concerns. The progression is not linear but manifold. The following two examples illustrate progressions of concerns and countermeasures.

EXAMPLE 1: MOBILE ELEVATED WORK PLATFORMS (MEWPS)

Falls are the leading cause of death in construction, with 370 fatal falls recorded in 2024 out of 1,032 total construction fatalities (Bureau of Labor Statistics 2026). Fall protection ranked as OSHA's most frequently cited violation in fiscal year 2024 (OSHA 2025). A mistakeproofing mindset can help to address safety concerns related to falls when working at height.

When constructing a structural-steel building, field-welded connections will require working at height. In this context, equipment such as mobile elevated work platforms (MEWPs) can play a critical role in reducing the likelihood of falls.

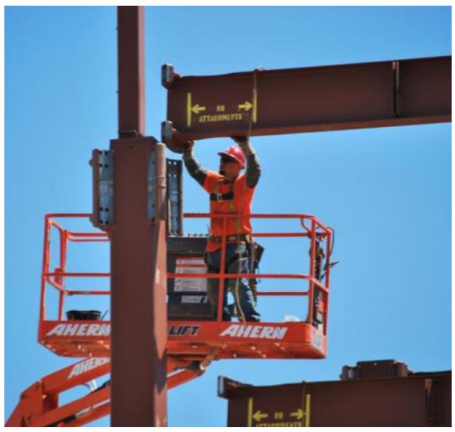

Figure 2: Bolted steel moment resisting frame (Source: ConXtech (n.d.) visited 11 February 2017)

Concern: Completing a field-welded beam-to-column connection requires workers working at height to wear a harness and tie themselves off as they position themselves to weld around the joint. This work exposes them for an extended period of time to fall hazards.

Countermeasure: A steel moment-resisting frame with welded connections is replaced by bolted connections. A 'shoe' is shop-welded onto the column. On site, steel beams slide into it (Figure 2) to form a secure connection, and are then bolted in place. This work can be done by a worker standing on a MEWP and in a shorter amount of time, and is therefore safer.

Figure 3: MEWP (Source: WSM Training (n.d.) visited 29 January 2026)

Concern: Workers need to perform tasks at height. Accessing high or hard-to-reach areas using traditional tools like ladders or scaffolding can be challenging and risky. When climbing, workers risk losing balance and falling from height.

Countermeasure: A MEWP provides a safer way for workers to reach elevated work areas (Figure 3). It reduces the risk of falling and allows workers to work more conveniently at height. Workers can perform tasks in an optimal work posture, reducing bending and stretching.

Figure 4: Wireless anti-overhead protection sensor device (Source: CITAC (n.d.) visited 31 December 2025)

Concern: MEWPs are controlled manually and based on sight by authorized operators. Despite OSHA requiring all MEWP operators to receive training, mistakes may occur during MEWP operation. An operator may raise the MEWP too high and collide with an overhead obstruction.

Countermeasure: A wireless overhead protection sensor device can be installed on MEWPs (Figure 4). It provides visual and audible alerts to operators. The ability of the operator to hear and respond to alerts reduces the likelihood of entrapment and crush hazards, thereby enhancing the safety of MEWP use.

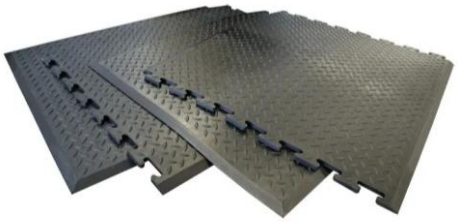

Figure 5: Anti-fatigue mats (Source: Rubber Cal (n.d.) visited 31 December 2025)

Concern: Prolonged work on MEWPs may expose workers to the risk of developing musculoskeletal disorders, such as "lifting heavy items, bending, reaching overhead, [...] working in awkward body postures" (OSHA n.d.-a). This exposure increases the risk of injury or longer-term health issues.

Countermeasure: Anti-fatigue mats on MEWPs reduce stress on workers' feet and legs (Figure 5). Their cushioning provides comfort during long working hours. Although no specific regulation prohibits the placement of anti-fatigue mats on MEWPs, users must follow safety requirements when installing them (Plessis 2025).

EXAMPLE 2: SAFETY SHOES

Foot injuries represent a significant and preventable workplace risk. OSHA's mandate of protective footwear under standard 29 CFR 1910.136 requires employers to ensure employees wear safety shoes in areas where there is danger of foot injuries due to falling or rolling objects, or electrical hazards (OSHA n.d.-b).

This example illustrates how personal protective equipment addresses impact-related risks while simultaneously introducing secondary concerns related to ergonomics and, in sensor-enabled applications, data privacy. It highlights how mistakeproofing extends beyond initial protection toward ongoing risk awareness.

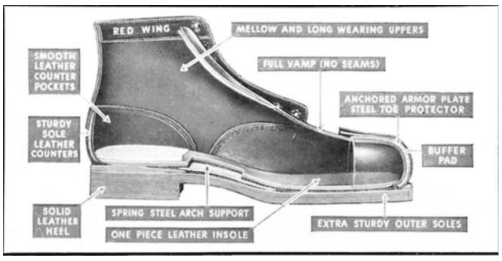

Figure 6: Traditional steel-toe boot (Source: Walker Art Center (2017) visited 1 November 2017)

Concern: Workers on construction sites may incur foot injuries from falling or rolling objects, or from stomping against obstacles.

Countermeasure: A steel cap is built into the toe box to protect against impact and compression (Figure 6). Steel-toe boots do not prevent objects from falling or obstacles from being in the way, however. Even though they must be worn at all times, their benefit occurs only after a mistake has been made.

Figure 7: Smart construction safety shoe (Source: Båstadgruppen (n.d.) visited 31 December 2025)

Concern 1: Added weight of steel-toe boots may increase strain on the kinetic chain (feet, ankles, and legs). **Concern 2:** Traditional steel-toe boots are passive and do not prevent mistakes.

Countermeasure: Weight reduction thanks to modern materials reduces the strain (Figure 7). The shoe "monitors movement patterns to detect falls or abnormal incidents." It "automatically sends an alert to [...] emergency contacts, including the user's status and real-time location" and it "enables integration with emergency services, sharing critical data to help ensure the fastest and most appropriate response." [T]he user can store their medical ID and other essential information directly within the shoe" (Båstadgruppen 2025)

The examples illustrated by figures 2 to 7 show how addressing one concern may raise multiple new concerns. This highlights that practicing mistakeproofing may require endless iteration.

DISCUSSION

The contribution of this study is to position the mistakeproofing mindset as a leading indicator of improved safety performance and safety capacity. The notion of safety capacity is relatively new, and it must be understood as the ability to ensure that work goes right even under variable conditions. In this context, it is vital to distinguish between capacity, which is what you are capable of and can do, and performance, which is what you actually do. For example, a site may have safe lifting equipment and trained workers but still experience accidents when time pressure leads people to skip procedures. Consequently, the absence of mistakes does not necessarily equal the presence of safety. Therefore, developing a mistakeproofing mindset

requires a person to question the extent to which something goes right to overcome biases and adopt Safety-II thinking.

A mistakeproofing mindset contrasts with the Safety-I mindset and its causality credo. Any countermeasure addressing a concern should be viewed as temporary rather than permanent. New concerns will arise from a current countermeasure. This reinforces the need for continuous improvement and requiring mistakeproofing to be practiced iteratively in line with the Kaizen philosophy. In this way, the mistakeproofing mindset encourages questioning "what goes right" rather than just "what goes wrong" in risk management. The safety shoe example illustrates this: whereas traditional steel-toe boots address impact risks, they also introduce concerns such as ergonomic fatigue. Thus, in practice, the leading indicator is neither the wearing of the boot nor the use of the sensor, but the ability to recognize that the current state countermeasure is likely the source of a future-state concern.

Variations are central to understanding the development of a mistakeproofing mindset. This is because variations reflect workers' ability to adapt to circumstances in their work. Even though Hollnagel (2012) suggests differentiating between work-as-imagined and work-as-done in managing safety, this paper proposes that developing a mistakeproofing mindset helps reduce the brittleness described by Woods (2015) by making gaps visible. In this sense, narrowing the gap reflects the presence of a mistakeproofing mindset.

A person's adaptations should be viewed as an expression of intelligence rather than a violation of a standard, as suggested in resilience engineering. For example, when a person intuitively modifies a workspace, they are practicing mistakeproofing. One such example is adding an anti-fatigue mat to a MEWP. At the organizational level, if people capture concerns that drive adaptation, they gain access to leading indicators. This access to operational insight encourages organizations to investigate how work goes right during normal operations, overcoming hindsight bias and outcome bias. Consequently, the ability to recognize work variations with this mindset entails anticipating both expected and unexpected outcomes, which gradually strengthen organizational resilience.

Once a mistakeproofing mindset is present, sustaining it can improve safety capacity. Rather than focusing on the number of iterations, the quality of learning across iterations reflects an organization's safety capacity. For this learning to occur, organizational support is required to educate, train, and encourage people to practice using, for example, the Work Operation Framework in real-life situations. Through such support, frequent practice helps a person to turn the mistakeproofing mindset into a habit. Over time, the person can influence others to adopt the same mindset and achieve continuous improvement collectively. Arguably, the mindset is not limited to safety and health concerns but also includes design and quality.

CONCLUSIONS

This paper positioned mistakeproofing not only as the practice of identifying concerns and addressing them by countermeasures, but as a mindset. We hypothesized that mistakeproofing and a mistakeproofing mindset can serve as leading indicators of improved safety performance and safety capacity. In this context, the notion of safety capacity is relatively new, and it must be understood as the ability to ensure that work goes right even under variable conditions. It is presumed that improving safety capacity suggests that safety performance may improve over time. This focus on the development of safety capacity moves safety management beyond compliance and towards continuous improvement.

Furthermore, this paper demonstrated that mistakeproofing is not a linear process but an iterative process drawing on the PDCA cycle of continuous improvement. The leading indicator is the ability to recognize these cycles of improvement. This ability represents a state of mindfulness, of constant alertness, in which current countermeasures introduce multiple future state concerns.

In practice, although the gap between work-as-imagined and work-as-done may not be entirely closed by applying a mistakeproofing mindset, this mindset allows organizations to recognize and value that people's ability to adapt to circumstances is part of their work. At the organizational level, by capturing the concerns that drive adaptations, a company gains access to leading indicators. To enable this, developing and sustaining a mistakeproofing mindset requires education and hands-on practice, which can be supported, for example, by applying the Work Operation Framework. Beyond this example, organizations must foster a culture in which situational awareness of previous examples is not lost when people encounter existing countermeasures. Over time, this mindset can become habitual, strengthening a person's safety capacity.

A limitation of our research is the lack of empirical data to test our hypothesis. Future research should test our proposed approach in developing and sustaining a mistakeproofing mindset with real-world projects.

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