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February 2018

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CPWR Small Study Final Report
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MISTAKEPROOFING THE DESIGN OF CONSTRUCTION PROCESSES USING INVENTIVE PROBLEM SOLVING (TRIZ)

Final Report for CPWR Small Study No. 16-3-PS

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EXECUTIVE SUMMARY

This study set out to investigate and document how the principles and practices of so-called ***mistakeproofing*** may be applied to improve safety and health performance—aspects of product- and process quality—specifically in the construction industry.

Mistakeproofing (translated from the Japanese word ***poka yoke***, a concept integral to the Toyota Production System, defined as ***Lean***) has been successfully used in numerous other industry sectors. It can be used likewise in the construction industry.

A strength of Lean is its conceptual clarity on principles and the associated ***systems thinking*** it promotes. In addition, supporting the principles are numerous tools and methods (such as mistakeproofing), to be applied judiciously in any given system's context and, when used in combination, leveraging one-another.

The research defined the Lean principles of mistakeproofing, and also the principles of TRIZ (Theory of Inventive Problem Solving) used for concept generation. Thirty examples, collected by reading the literature and interviewing industry practitioners, were catalogued based on the mistakeproofing and TRIZ principles they illustrate.

The need to mistakeproof everyday products and processes (tasks and work methods) may seem obvious (or hopefully will appear obvious in hindsight), but mistakeproofing is by no means a common practice. By defining the principles and offering examples, this report aims to encourage broader awareness and use of it. Knowledgeable and purposeful use of mistakeproofing principles and their practical application will lead to improved industry performance in construction, as it has in other industries.

TABLE OF CONTENTS

LIST OF FIGURES

1. INTRODUCTION

1.1. Background on Lean Thinking in Construction

This study set out to investigate and document how the principles and practices of so-called ***mistakeproofing*** may be applied to improve safety and health performance—aspects of product- and process quality—specifically in the construction industry. The thought process of mistakeproofing is in numerous ways aligned with the safety-mindedness that OSHA is promoting to achieve higher standards of performance in the construction industry, i.e., lowering fatality-, illness-, and injury rates. However, their origins and focus of practice appear to differ. For example, mistakeproofing is concerned with preventing mistakes of any kind, while safety-mindedness tends to focus on hazardous situations and incidents. This notwithstanding, mistakeproofing and OSHA's pursuits are aligned in that OSHA (2016) states "The recommended practices emphasize a proactive approach to managing occupational safety and health. Traditional approaches are often reactive—that is, actions are taken only after a worker is injured or becomes sick, a new standard or regulation is published, or an outside inspection finds a problem that must be fixed. Finding and fixing hazards before they cause injury or illness is a far more effective approach. Doing so avoids the direct and indirect costs of worker injuries and illnesses, and promotes a positive work environment."

Mistakeproofing (or fail-safing) is the English translation of the Japanese term ***poka yoke***. Poka yoke has been used for many years at Toyota and is integral to the Toyota Production System (TPS). Toyota's Production System was singled out and gained notoriety in the 1980s for its superior performance compared to other companies (American as well as Japanese). John Krafcik, who served on the MIT-Harvard team in the 1980s that studied Japanese practices in automobile manufacturing (Womack et al. 1989), therefore coined the term "Lean Production" to refer to its systemic approach, while also differentiating it from mass- and from craft production. With "Lean" he highlighted that Toyota uses less of everything by comparison with US producers: fewer materials, fewer human resources, fewer machines, less money, less time, and less space, to engineer and manufacture products of high quality for their customers. The Lean Enterprise Institute (LEI 2016) thus defines the term Lean as "Creating more value for customers with fewer resources." Lean Thinking is fundamentally rooted in (1) respect for people and (2) continuous improvement.

Numerous books that have since been written to describe the TPS principles and methods (e.g., Ohno 1988, Liker 2004, Liker and Meier 2005). A strength of the TPS is its conceptual clarity on principles and the associated holistic "systems thinking" it promotes. In addition, supporting the principles are numerous tools and methods (such as mistakeproofing), to be applied judiciously in any given system's context and, when used in combination, leveraging one-another.

Many researchers and practitioners have applied Lean Thinking very successfully in a variety of domains other than automobile manufacturing (e.g., service sectors including healthcare). The application of Lean Thinking to construction, so-called ***Lean Construction***, has been pursued by researchers and practitioners since the early 1990s (e.g., Koskela 1992, Ballard et al. 2002, Koskela et al. 2002). They formed a community of practice called the International Group for Lean Construction (IGLC) that has been active since 1993 (www.iglc.net).

Gambatese and Pestan (2014) described how Lean Design and Construction relates to construction worker safety. Their report mentions once (on p. 12) the practice of mistakeproofing but offered no further detail on this Lean method. Research by others has shown correlation between the adoption of Lean Thinking, for example using the Last Planner® System (Ballard 2000), and improved safety performance on construction sites, and an agenda on Lean safety is being pursued (e.g., Howell et al. 2002). Mistakeproofing fits into that agenda.

All too many aspects of the construction industry today are still based on craft production, and inefficiencies and incidents abound. On a day-to-day basis, workers face the numerous challenges and characteristics of one-off production but lack individual training and team-wide systemic thinking to help improve performance overall.

Recognizing the means Lean Thinking offers, this report will introduce mistakeproofing principles and examples in the architecture-engineering-construction (AEC) industry. In doing so, it aims to drive industry innovation in developing products and processes of greater quality and thereby contribute to construction industry performance improvement.

1.2. Background on Mistakeproofing

While the concept of mistakeproofing has been around at least since the 1980s, mentioned in the early work by Suzaki (1985) and Shingo (1986) who wrote the book *Zero Quality Control*, it does not appear to be commonly understood and applied in the construction industry. Where it has been used in other industry sectors (manufacturing, healthcare, and many more) it has yielded significant benefits. Reasonably one may therefore expect that the construction industry will benefit from its use as well.

Many online glossaries with lean production terms include mistakeproofing or poka yoke, and at least one web site has been dedicated to this topic (www.mistakeproofing.com). However, while the use of mistakeproofing has been mentioned in the construction literature (e.g., dos Santos and

Powell 1999, Tommelein 2008a, 2008b), it does not appear to be have been systematically researched nor is it practiced as widely as it can be. Owners, designers, contractors, engineers, and others involved in the architecture-engineering-construction (AEC) industry need to know what and where opportunities exist for mistakeproofing, to gauge what value may stem from it, and to sharpen everyone's thinking about opportunities to mistakeproof AEC products and processes. Mistakeproofing is relevant and applies to tasks, operations, and projects small and large, simple and complex, and all sectors of the construction industry (e.g., Wood 1986, McDonald 1998).

Mistakeproofing is particularly well suited for the AEC industry with its low-volume and mixed production systems, where other improvement methods such as Statistical Process Control (SPC) and Six Sigma have not gained much traction. Construction practitioners who tried using SPC found they could not implement it widely due to lack of a statistically significant amount of data and un-timeliness of findings that result from after-the-fact data processing. The applicability of Lean methods to events that occur only once or occasionally is relevant especially in construction project settings. Construction activities get performed once, or possibly repeated a few times, but then finish and get followed by a follow-on activities well before statistics can be used.

Mistakeproofing can be thought of as a practice akin to constructability, that is, changing a design so that it can be built "better"—more safely, easily, cost effectively, so it will last longer, etc. However, it differs from constructability in two regards. First, the goal of mistakeproofing is to improve system performance by eliminating waste—avoiding product and process defects (e.g., creation of hazardous situations), reducing variation, and not tolerating poor quality. Second, efforts at mistakeproofing do not necessarily coincide with the timing of constructability review in a project's delivery process. Simply put, pursuing constructability sometimes means cutting costs after a design already has been substantially developed but exceeds budget. In contrast, mistakeproofing is a practice for all project participants—designers, manufacturers, fabricators, builders, owner-operators, and others—to pursue in their day-to-day work and throughout project delivery. Mistakeproofing is a method for Prevention through Design (PtD), a practice that has been advanced in recent years in the AEC industry, but has yet a long way to go before it will be part of everyday thinking in practice (Duffy 2004, Shulte et al. 2008, NIOSH 2014).

In many regards, mistakeproofing complements SPC (e.g., Baudin 2001, Stewart and Grout 2001). It is a method for so-called error management (Tommelein 2017). Indeed, the systems view that Lean thinkers adopts, recognizes that each individual person works in a larger, complex whole where—despite best efforts—errors will never be 100% preventable.

Mistakeproofing requires a different way of thinking about production processes and its constituent operations, and it can be applied fittingly in construction (for a sneak preview, see the example in Appendix IV). It offers an alternative to the all-too-prevalent “regulate, enforce, and punish” approaches used in construction safety management.

Stewart and Grout (2001) also mention that mistakeproofing may not be taken seriously enough, especially by academics, because of its lack of theoretical grounding and its apparent simplicity of solutions. They state that this lack of grounding of mistakeproofing is due to its boundary-spanning nature: it lies, not in “operations management, management science, operations research, industrial engineering, and statistics” but in “qualitative subject of human psychology…” and “…cognitive science.” The same can be said, at least to a degree, about theoretical grounding for safety management. That literature includes work on human error and cognitive systems engineering (e.g., Dekker2004, 2006, 2012, 2014, Rasmussen 1982, Rasmussen et al. 1994, and Reason 1990) as well as on project production system design (e.g., Mitropoulos 2014, Memarian and Mitropoulos 2013, 2015).

Without a doubt, mistakeproofing has been and is being applied in the AEC industry. However, it appears that barriers to its widespread implementation may exist. Barriers such a lack of knowledge and understanding of its principles can be overcome by increasing industry awareness by means of dissemination of reports such as this one. Once practitioners will have learned to recognize mistakeproofing devices, their new mind-set will enable them to spot numerous opportunities available to mistakeproof their workplace. Though some mistakeproofing practices do require investment in new product development, they will find that many can be implemented at a minimal cost.

1.3. Overview of Report

Section 2 of this report summarizes the research objectives, goal, and approach. Section 3 defines mistakeproofing, expands on its 6 principles, and illustrates them with a few examples (Appendix IV presents a richer set of 30 detailed examples that use these principles). Section 3 also ties-in several related concepts. Subsequently, the report ventures into describing a rational way of coming up with (new) mistakeproofing practices. To this end, Section 4 defines the concept generation method called TRIZ (the Theory of Inventive Problem Solving) and expands on its 40 principles. Section 5 and examples in Appendix IV illustrate the application of TRIZ to create new means for mistakeproofing. Section 6 offers key findings with recommendations on the further use of mistakeproofing in the construction industry, and concludes the report.

Appendix I provides a glossary of terms related to mistakeproofing. Appendix II lists the references cited in this report as well as a selected bibliography. Appendix III enumerates the 40 TRIZ principles. Last but not least, Appendix IV includes 30 examples of mistakeproofing practices categorized first by mistakeproofing principle exemplified, and then by the TRIZ principles exemplified.

2. RESEARCH OBJECTIVES, GOAL, AND APPROACH

The objectives of this research study were to shine the limelight on the concept of mistakeproofing and its application specifically to improve safety performance in the construction industry, to explain its underlying principles, and to provide examples to illustrate how it is used in practice.

The goal of the research is to inspire workers so that they will think routinely of new ways to use the method in order to mistakeproof their everyday environment.

The researchers conducted descriptive research of theory and practice. They approached this study by reviewing the academic and professional literature, as well as numerous online postings, for references on the principles and examples of mistakeproofing. They contacted industry professionals in construction and manufacturing companies, spoke with them over the phone, and visited their facilities to learn about mistakeproofing practices and to identify specific examples. The researchers assembled a set of mistakeproofing examples and then classified these examples based on the mistakeproofing principle(s) applied. They also classified them based on the TRIZ principles applied. Finally, the researchers detailed a rich selection of examples (provided in Appendix IV) and wrote this report.

3. MISTAKEPROOFING

3.1. Definition of Mistakeproofing

Mistakeproofing (also called errorproofing, as the terms mistake and error are used interchangeably) “is the use of any automatic device or method that either makes it impossible for an error to occur or makes the error immediately obvious once it has occurred (ASQ.org).” The objective of mistakeproofing is to prevent errors from turning into defect, in order to reduce (at best: eliminate altogether) quality defects in construction products and processes. Unquestionably, safety is a metric of quality, so mistakes and defects include those that are safety-related and might lead to hazards, incidents, or chronic pain.

In the strict sense of this definition, mistakeproofing is about managing mistakes being made by people, recognizing that to err is human. It is a Lean method for error management as noted in

Tommelein (2017). However, when working back from the objective stated, to reduce defects, one recognizes that defects may also be caused by machines or processes that cannot consistently produce quality output. While considering performance improvement opportunities in the construction industry, it may make sense to broaden the notion of mistakeproofing, by including concern for ascertaining so-called process capability (more on this in Section 3.3.1).

Mistakeproofing is rooted in the concept ***zero quality control*** developed in Shingo's (1986) so-named book *Zero Quality Control: Source Inspection and the Poka-yoke System.* The back cover reads, "Defects = 0 is absolutely possible!" Shingo critiqued the use of SPC and was set on eliminating ad-hoc quality control (QC). Translated to the construction industry, such ad-hoc QC includes the punch-list process and corresponding rework that everyone appears to take for granted. He advised that ***source inspection*** and ***successive inspection*** be implemented in order to ascertain that only quality products would be passed along the assembly line, recognizing that errors would occur.

Shingo (op. cit., p. 82) stated, "I claim that it is impossible to eliminate all errors from any task performed by humans. Indeed, inadvertent errors are both possible and inevitable. Indeed, the systems view that Lean thinkers adopts, recognizes that each individual person works in a larger, complex whole where—despite best efforts—errors will never be 100% preventable. Certainly there is no reason why the same error should occur more than once; recurrence is especially bad. "Yet errors will not turn into defects if feedback and action take place at the error stage. In this way, I am advocating the elimination of defects by clearly distinguishing between errors and defects, i.e., between causes and effects." Shingo advocated the use of mistakeproofing to reduce the possibility of errors occurring, to make errors—should they occur—easily detectable, and to mitigate their effects so they would not turn into defects. As a result, mistakeproofing reduces the need for inspection.

Defined by principles, mistakeproofing is a mindset; it requires Lean Thinking. Mistakeproofing shuns the blame mentality. Instead it aims to develop a mind-set in individuals and teams and equip them with principles to manage mistakes using prevention combined with increased awareness to respond judiciously to unforeseen conditions when mistakes cannot a priori be prevented but their detrimental impact can possibly be alleviated. In other words, mistakeproofing is about seeing (or learning to see) where something may go awry, figuring out the reasons why a defect may occur and how the causes may be prevented, and then taking action to prevent these anticipated occurrences. The range of action that any one individual can take to mistakeproof a product or process will vary depending on their responsibility and authority within their organization. In Lean organizations, everyone is expected to be involved.

3.2. Principles of Mistakeproofing

Mistakeproofing is based on 6 principles (e.g., Shingo 1986, Shimbun 1988, McMahon 2016). In the remainder of this report and in Appendix IV where examples are detailed, the authors classify them using the color coding shown in Figure 1.

Figure 1: Color Code for Each of Six Mistakeproofing Principles

Quite a few examples have different aspects to them, each of which can illustrate a different principle. Of note is that the principles are not as crisply defined as they could be. People may argue about an example exemplifying one principle or another. Practically speaking, the goal of showing examples is not to get into such arguments but rather to help readers practice their ability to see and recognize mistakeproofing practices in their everyday environment, and then leverage that ability to create their own mistakeproofing applications.

The 6 mistakeproofing principles are:

1. **Elimination** (paraphrased as “don’t do it anymore”) is to remove the possibility of an error occurring in a task of a process by redesigning the product or process so that the task (or associated product part) is no longer necessary. For example:
   - Several hazards stemming from the use of electrical extension cords to power tools (e.g., tripping over them) are eliminated by replacing corded tools with battery-powered ones (see Example 1 in Appendix IV).
   - Several hazards to which ironworkers are exposed while welding structural steel, are eliminated by redesigning the structural system to use, not welded connections, but bolted connections instead (a new process and new parts).
2. **Prevention** (“make sure it can never be done wrong”) is to design and engineer the product or process so that it is impossible to make a mistake at all. For example:
   - A vehicle’s engine will not start unless the driver has a foot on the brakes (limit switch).
   - A three-pronged electrical plug can be inserted into a power outlet in only one way (part asymmetry).

3. **Replacement** (“use something better”) is to substitute one process with a more reliable process to improve consistency. For example:
    - Instead of using ladders on site, use scissor lifts.
    - Instead of surveying using a theodolite, use an electronic total station instead (automation).
    - An existing planning system for on-site trade coordination may be replaced by the Last Planner System (Ballard 2000) to promote work flow reliability and enhance safety performance.
    - Rather than use a tape measure to measure the spacing between parts repeatedly, one part at a time, use a jig to space parts evenly.
4. **Facilitation** (“catch people’s attention, help them make fewer mistakes”) is to use various means (e.g., sensory input) to make tasks easier to perform. For example:
    - Construction equipment has a backup signal (auditory input) to alert people nearby that it is moving and the driver’s view going backward is restricted.
    - The trigger on a nail gun works only when the nail gun is contact with a surface so it cannot be used to shoot in the air (Figure 2), though note that the surface can be skin (Figure 3).

Figure 2: Pneumatic Nail Gun in Use (en.wikipedia.org/wiki/Nail_gun)

Figure 3: Nail in Hand (Hellerhoff (2012) upload.wikimedia.org/ vikipedia/commons/f/f8/Nagel_von_Scl ussapparat_in_Hand_-_Roe_ap.jpg)

- Create a visual workplace by using color coding: screws of different color are easy to tell apart (Figure 4).

Figure 4: Color-coded Screws (and Corresponding Bin Labels) are Easy to Match/Tell Apart (facilitate recognition) (Source: Iris Tommelein)

5. **Detection** ("notice what is going wrong and stop it") is to identify a mistake promptly so that a person can quickly correct it and thereby avoid that the error may turn into a defect (Shingo 1986). Examples are:
    - Rumble strips on highways alert drivers when they are crossing lanes and may run off the road (sensory feedback)
6. **Mitigation** ("don't let the situation get too bad") is to minimize the effects of errors. Grout (2003) calls this "designing benign failures." Examples are:
    - Electrical fuses prevent overloading circuits resulting from shorts (McMahon 2016).
    - Personal Protection Equipment (PPE) to various degrees protects a person by reducing the effect of any impact (e.g., a hard hat cushions the blow on the head from the impact of a falling object).
    - Fall protection systems protect workers from falls and, related, to prevent damage caused by falling objects (Figure 5). As recorded by the Bureau of Labor Statistics (BLS 2016), fatalities caused by falls are the main cause of death for construction workers. In 2014, 337 of the 874 construction fatalities stemmed from falls from elevation. Hence, there is a great demand for such systems.

Figure 5: Fall Protection System (butlermfg.com/en/products_systems/roof_systems/skyweb_ii_skyweb)

Figure 6 lays out these 6 principles based on when they apply in the course of executing work (work operations). Elimination, Prevention, Replacement, and Facilitation are means to **avoid the occurrence** of mistakes. Detection and Mitigation are means to **minimize the effects** of mistakes once they occur. In any one of these cases, mistakeproofing devices and processes should be designed so that they meet three criteria: (1) be simple, (2) be infallible, (3) be used effortlessly (e.g., McMurray and Garcia 2016).

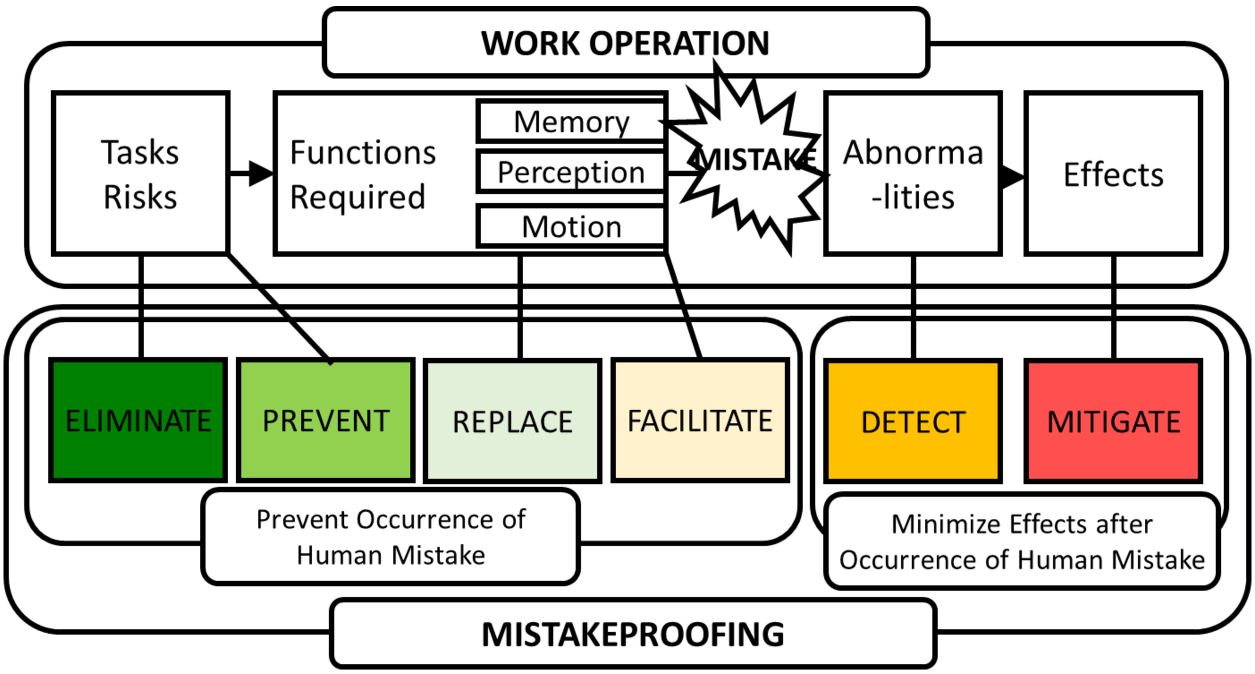


Figure 6: Applicability of Mistakeproofing Principles to Work Operations (adapted from Godfrey et al. 2005)

The 6 mistakeproofing principles were color-coded in order of decreasing preference for their application. On one end of the range is Elimination (dark green in Figure 1 and 4), the most desired of all as it makes not only the hazard associated with a task, but the entire task go away. Mistakeproof processes are intolerant of defects. At best they are designed so that no mistakes can be made; at least they reduce the chance of mistakes being made. On the other end of the range is Mitigation (reddish in Figures 1 and 4), as it should be the last principle considered to mistakeproof a product or process, when other ones cannot be made to work in the current situation. NPD-solutions (n.d.) among others note, “[i]deally, mistakeproofing should be considered during the development of a new product to maximize opportunities to mistake-proof through design of the product and the process (elimination, prevention, replacement, and facilitation). Once the product is designed and the process is selected, mistakeproofing opportunities are more limited ([…] detection and mitigation).”

Among the numerous examples of mistakeproofing documented in the course of this research project, and singling out safety-related devices and practices, the authors found that many are Mitigation related (e.g., PPE). Mitigation (and Detection) are after-the-fact (reactive, before the mistake occur has occurred) mistakeproofing approaches and therefore not the best. The before-the-fact (proactive, before the mistake occurs) mistakeproofing approaches have been gaining prominence in the construction safety community through efforts such as Prevention through Design (PtD) (NIOSH 2014, Schulte et al. 2008), Our industry can do a lot more in this regard to make its products and processes safer.

These 6 principles all focus on the worker in their environment. The aim is to mistakeproof the tasks workers perform in the process of delivering a product or service. To be of quality, the delivery process must also consider the recipient of that product/service, namely the customer. Some mistakeproofing practitioners (e.g., in healthcare, Gregory and Kaprielian 2016) add another principle, namely "Patient Involvement" as the patient is the customer of the healthcare provider. That principle is addressed by Shingo's concept of successive inspection and applies in construction as well. To deliver a quality product to a customer, one must know what the customer wants and allow the customer to express their concerns and have a say in making an assessment of the quality of the product or service received.

3.3. Concepts Related to Mistakeproofing

A number of concepts from quality management and other schools of thought also pertain to creating defect-free products and processes, as is the case for mistakeproofing.

3.3.1. Mistakes vs Process Capability

Although the term process capability is not commonly used in the construction industry, it helps make a crucial distinction between it and the occurrence of mistakes, that is important in the pursuit of continuous improvement. Process capability has been established (at a certain level of performance) if anyone (at some level of skill, as per the process specifications) doing the job will consistently meet the expected quality standard.

Process capability affects all workers (e.g., exposure to silica fumes from grinding or drilling into stone or concrete) and must therefore be established with worker safety and health in mind. The same is true for design of operations by means of which one can, for example, shift the kinds of hazards workers are exposed to (installing duct work at ground level to fit under a raised floor system is less hazard-prone that working overhead on duct installation, but it is hard on the knees).

By definition, ***process capability*** describes the variation in a property of the output of a process (e.g., the geometry of the material produced) that is achieved under normal operating conditions. This definition pertaining to geometry equally applies to any material, resource, or process property such as duration, temperature, impact strength, etc. (P2SL Glossary 2017).

The term "normal operating conditions" presumes that the workers involved are qualified to do the work and make no mistakes. By definition, a ***mistake*** is an inadvertent human action that may lead to a defect in a process or product, or harm to a person. This brings us back to mistakeproofing, which is to design products or processes to eliminate (or at least to reduce) the probability or impact of mistakes and defects in use or execution. When people are not successful (mistakes occur or the outcome produced is defective) in executing a certain process or constructing a certain product to the desired quality standard, a number of causes may be in play:

1. The process they are to follow is not capable—irrespectively of the person involved—of consistently achieving the desired outcome, in which case process capability must be improved. For example:
    - When using a panelized concrete formwork system there will be joints through which concrete or grout can seep. Excessive formwork leakage may be considered a defect. As long as the workers have erected the formwork "the correct way," such leakage is not to be attributed to human mistake. How much the forms will leak is matter of process capability: it will vary by formwork system selected, methods used to put it in place, as well as precautions taken to prevent leakage from occurring.

      Such precautionary measures do not fall under the realm of mistakeproofing (in the strict sense, because they do not pertain to human error), nevertheless, why not consider them if mistakeproofing principles can address them?

      Following the same argument, the authors see no reason to single out opportunities to improve safety in performing a task from opportunities to improve quality in general, and therefore use the term "integrated task planning" to denote that all aspects of a task, separately, together with others, and holistically, are to be considered for improvement (by mistakeproofing or other means).
2. The quality standard (for construction) may not have been articulated or made clear to them, that is, they may not know what is expected and need to learn it.
3. Perhaps they knew but forgot (an opportunity for mistakeproofing).
4. Not all requirements for executing the selected, capable process are in place. E.g., some inputs provided may be of inferior quality.

5. The process is capable, people know the process and its quality standard, and all requirements are satisfied, and yet they may still make mistakes in the course of executing the process (a clear need for mistakeproofing). For example:
    - Building on the earlier example of formwork erection, if a worker leaves off a clamp to hold panels together (and that causes leakage), that would be a mistake.

Both process capability and human error affect product and process quality. In construction projects, it is often taken for granted that process capability is established, processes are in place, and workers will consistently follow them. From the author's experience and direct observation of how work gets done on site and off site, however, it is clear that specific work methods and quality expectations are not necessarily spelled out nor systematically followed; enforcement is often lax. When worker preferences govern over how they go about their work, significant differences may exist between what one worker accomplishes vs. another one. This makes it difficult to establish a standard for performance relative to which improvements may be assessed.

One way forward is to stepwise establish a quality processes to deliver quality products or services to customers. Baudin (2001) suggests that the first step is to establish process capability. In the case of repeatable processes, this may be done by setting expectations (e.g., setting upper and lower bounds on acceptable performance and applying Six Sigma methods), identifying recurring defects, and remediating them.

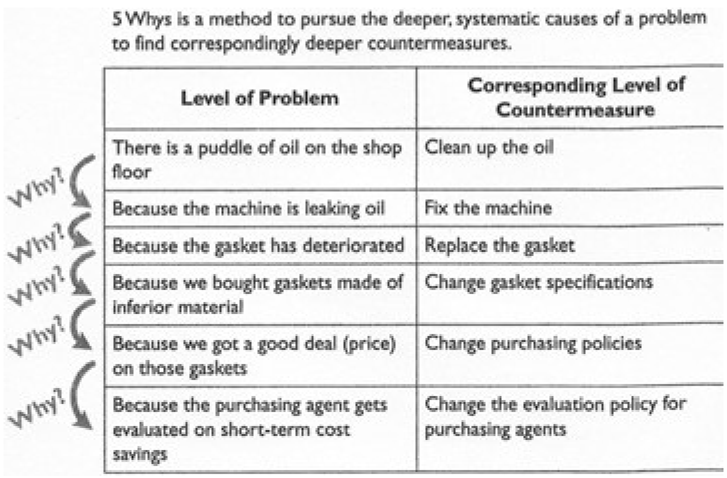
Once process capability has been established, however, people involved in the process may still make occasional mistakes. Ideally, systems will be designed so that no mistakes *can* be made, however, to err is human. Given that mistakes *will* occur, the subsequent steps are therefore to make it quick and easy to detect them so that remedial action can be taken and mistakes will not become defects. Here is where Lean methods such as one-piece flow, first-in first-out, cellular manufacturing, 5 WHYs, and small wins come in. The latter two are explained next.

3.3.2. 5 WHYs, Failure Modes and Effects Analysis (FMEA), and Small Wins

When a situation is unsatisfactory to someone for some reason, people should express a ***concern***. A concern is precautionary in nature: the situation may not be deemed problematic (yet) and no incident has as of yet occurred, but it is important to express it, because that is the start to identify causes and potential countermeasures (e.g., use mistakeproofing), and implement them before the problem arises or incident occurs.

A ***countermeasure*** is a corrective action taken in response to the identification of a deviation from a desired expected condition (a standard condition) in an attempt to prevent that deviation from reoccurring. Whether or not that attempt is successful in the short- or long term will have to bear out. Recognizing that further improvements, even better than the current corrective action, may exist and be identified at a later time, Lean practitioners therefore opt to use the term countermeasure rather than say “a problem is solved.” It indicates their ongoing and never-ending pursuit of continuous improvement.

The Lean method called ***5 WHYs*** is one of several methods to identify root causes of product- or process failures. Ohno (1988) defines this concept in greater detail. The essence is that one must ask *Why?* successively—at least 5 times—in order to get beyond the symptoms of a problem that can be addressed with a local countermeasure, to uncover one or several of the problem’s root causes so that they may be addressed by using more systemic, longer-lasting countermeasures (Figure 7).



5 Whys is a method to pursue the deeper, systematic causes of a problem to find correspondingly deeper countermeasures.

Level of Problem	Corresponding Level of Countermeasure
There is a puddle of oil on the shop floor	Clean up the oil
Because the machine is leaking oil	Fix the machine
Because the gasket has deteriorated	Replace the gasket
Because we bought gaskets made of inferior material	Change gasket specifications
Because we got a good deal (price) on those gaskets	Change purchasing policies
Because the purchasing agent gets evaluated on short-term cost savings	Change the evaluation policy for purchasing agents

Figure 7: “5 Why” Investigation Questions (Source: Scholtes, P.R. (1998). *The Leader’s Handbook.* McGraw-Hill, Figure 20-1)

The **Failure Modes and Effects *Analysis (FMEA)*** method offers a systematic way to describe failures and pursue remedial action. The FMEA analyst must identify all possible ways in which a product or process can fail (so-called ***failure modes***) and then assign a likelihood of occurrence and severity to each one. Based on these, the analyst can compute a relative ***Risk Priority Number (RPN)*** and use that, in combination with other considerations, to prioritize which failure mode to address first.

From the perspective of a Lean thinker, note that any improvement opportunity (including potential or occurring problems), big or small, is worth addressing. Lean thinkers at all levels in their organization are encouraged to pursue not only high risk challenges (presumably with big wins) but also ***small wins*** (Amabile and Kramer 2011). Any improvement is a win and many small ones accumulate over time. More importantly, Lean organizations want everyone trained and involved in pursuing improvement opportunities in a systematic way. Alertness to small wins sharpens people's skills at finding improvement opportunities in general (e.g., Akers 2011).

The next task is to explore each of the 6 mistakeproofing principles and identify means by which they may be achieved. This requires a concept generation method such as TRIZ (expanded on in Section 4). A means can then be selected and implemented as a countermeasure. Further observation of the implementation may lead to yet new insights into how yet further means for mistakeproofing may be deployed.

Before proceeding with TRIZ, however, the next section briefly describes how mistakeproofing relates to OSHA's well-known Hierarchy of Hazard Controls.

3.3.3. Hierarchy of Hazard Controls

The 6 mistakeproofing principles as described align to some degree with OSHA's Hierarchy of Hazard Controls. OSHA's hierarchy includes five levels. Figure 8 depicts it by an upside-down triangle to stress that the top level (elimination) is deemed most effective and the bottom one (PPE) least effective.

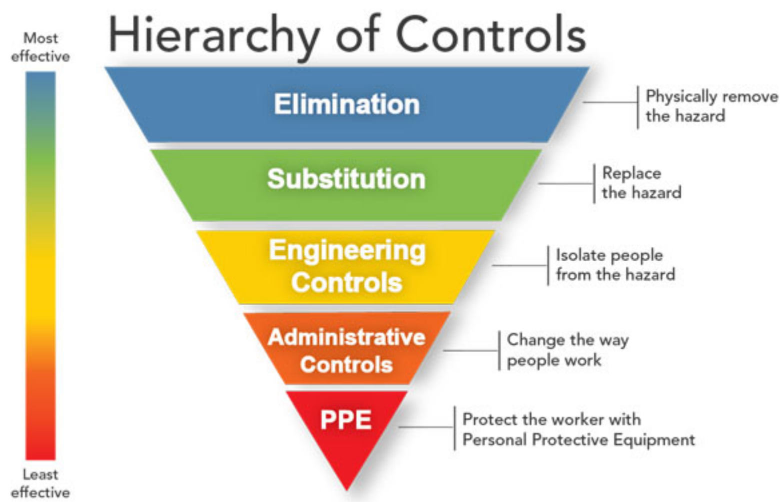


Figure 8: Hierarchy of Hazard Controls (Source: www.osha.gov/shpguidelines/hazard-prevention.html after Peterson 1973)

The 5 levels in the Hierarchy of Hazard Controls are:

1. **Elimination** is about preventatively, on paper and physically removing any hazard so it will no longer be part of the design.
2. **Substitution** is about preventatively replacing a product or process with another one that is deemed less hazardous or risky.

3. **Engineering Controls** is about isolating people from the hazard and guarding them.
4. **Administrative Controls** is about changing the way people work, by providing training and scheduling work with safety in mind
5. **Personal Protective Equipment (PPE)** is about shielding the worker from hazards should incidents occur.

Particularly the first two match their namesake principles of mistakeproofing, though OSHA is of course safety and health focused. Both Elimination and Substitution are about "designing it out." The other three in the Hierarchy appear more narrowly focused than the principles of mistakeproofing are.

4. THEORY OF INVENTIVE PROBLEM SOLVING (TRIZ)

Knowing the principles of mistakeproofing will help people recognize what practices have been implemented. This in turn will help them do their own mistakeproofing by simply copying examples from one application to another, or perhaps extrapolating. But when these do not work, a method is needed to generate new concepts to mistakeproof an existing product or process, or generate altogether new mistakeproofed-ones. The design methodology called the "Theory Inventive Problem Solving" or TRIZ may serve as a means to this end (Cerit et al. 2014).

4.1. Definition of TRIZ

TRIZ is the Russian acronym that is translated in English as the ***Theory of Inventive Problem Solving*** (TIPS). It was developed by Genrich Altshuller in 1946 and evolved over the course of about 50 years (Altshuller 1997, 1999, Souchkov 2008 rev. 2015). Altshuller had been working in a patent office and studied what defined an innovation. Over this period of time, Altshuller and colleagues developed not only principles but also Algorithms for Inventive Problem Solving (ARIZ) (e.g., Altshuller 1999, Marconi 1998) and related methods to foster innovative thinking. The focus in this report in on using the 40 TRIZ Principles and use them to generate mistakeproofing concepts. The notion of using TRIZ as a Lean Thinking tool is not new (e.g., Ikovenko 2005).

4.2. 40 Principles of TRIZ

The challenge stems from the fact that, when designing something new, designers face requirements and constraints that may be contradictory. They must then must negotiate tradeoffs. In the TRIZ context, these are called contradictions. To offer an example from Toyota, engineer Suzuki who spearheaded the Lexus program, became known for his uncompromising stance on seemingly conflicting design requirements (e.g., develop a car that can reach high top speeds, yet have low fuel consumption) , Suzuki's YETs (Liker 2004 p. 43-50).

Altshuller (1999 pp. 287-289) identified a set of 40 TRIZ Principles that can be used as a toolbox to resolve contradictions and thereby spur innovative thinking. With minor adjustments in wording, the TRIZ40 (n.d.) website replicates these 40 TRIZ Principles and they are included in this report in Appendix III. Appendix IV includes examples of mistakeproofing practices and the description of each practice also mentions which TRIZ Principle appears to have been applied. For more detail, however, please refer to Altshuller (1999) and the TRIZ40 (n.d.) website.

Innovation using the 40 TRIZ Principles (Figure 9) is a four-step process. It requires (1) an expression of concern (earlier in the report, a distinction was made between concern and problem), (2) abstraction to a more conceptual level, (3) followed by the application of a Principle, and (4) then specialization to formulate a countermeasure (solution).

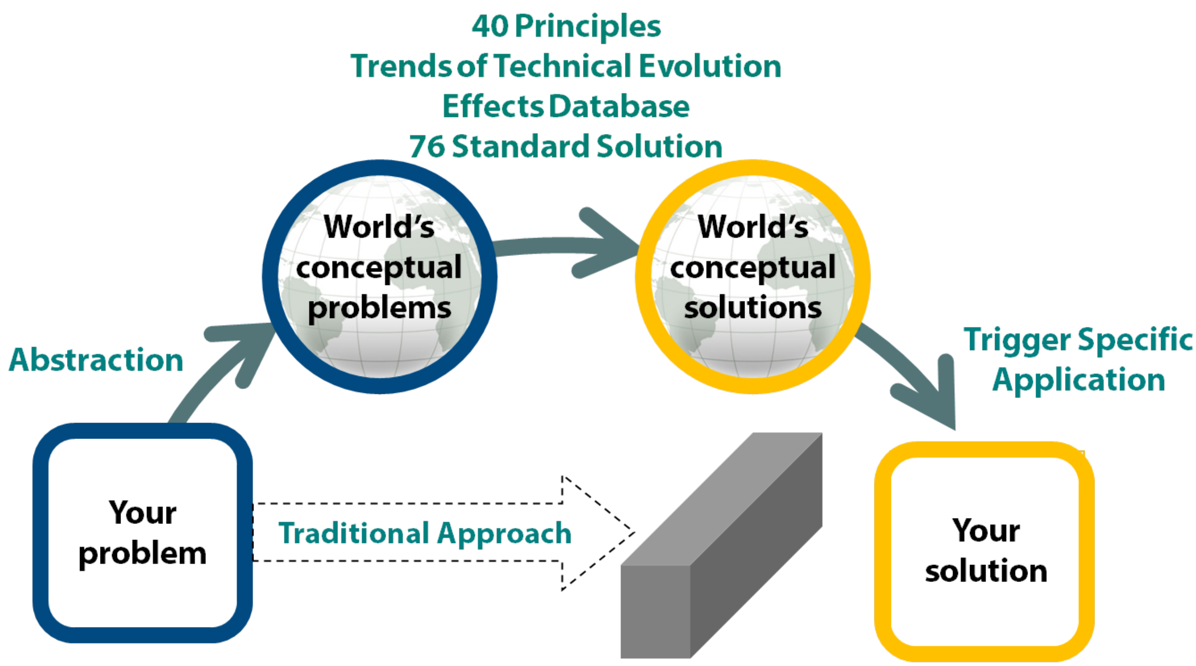


Figure 9: Prism of TRIZ Problem Solving Solutions (Oxford Creativity, (upload.wikimedia.org/wikipedia/commons/thumb/a/a2/Prism_of_TRIZ_Oxford_Creativity.png/ 640px-Prism_of_TRIZ_Oxford_Creativity.png)

To expand on the 40 TRIZ Principles, consider items 9 and 11 on the list in Appendix III:

9. Preliminary anti-action
    9.1. If it will be necessary to do an action with both harmful and useful effects, this action should be replaced with anti-actions to control harmful effects.
    9.2. Create beforehand stresses in an object that will oppose known undesirable working stresses later on.

and

11. Beforehand cushioning
    11.1Prepare emergency means beforehand to compensate for the relatively low reliability of an object.

These principles are commonly used when designing PPE such as steel-toed boots (steel to cushion the blow of impact) and hard hats.

5. EXAMPLE APPLICATIONS OF PRINCIPLES OF MISTAKEPROOFING AND TRIZ

With the 6 mistakeproofing principles presented in Section 3 and the mistakeproofing mind-set explained, and 40 TRIZ Principles (Appendix III) available to rationalize innovations (in this case, means for mistakeproofing), the best way to learn to apply it, is to study examples. Appendix IV includes 30 examples of mistakeproofing practices in the architecture-engineering-construction industry, selected to illustrate variety in application opportunities in design and construction. They are labeled consecutively by the number shown in the lower-right corner.

The examples are ordered first by mistakeproofing principle, then by TRIZ principle. The box in the upper-left of each illustration designates, based on the color codes shown in Figure 1, which of 6 mistakeproofing principles the example is to illustrate. The box next to it, with blue text designates which of 40 TRIZ principles (all listed in Appendix III) the example is to illustrate.

One can also create a new means for mistakeproofing by combining the principles implemented in different examples. One can imagine designing a nail gun with a contact sensor that also, like SawStop (Example 30) gauges the conductivity of the surface it touches. The nail gun should fail to engage upon contact with a person.

In fact, many examples may be used to illustrate multiple principles. We leave it to the reader to expand on them further. The examples are intended to help readers practice their ability to see and recognize mistakeproofing practices in their everyday environment and then leverage that ability to create their own mistakeproofing applications.

6. RESEARCH FINDINGS AND CONCLUSIONS

The research led to the following findings:

1. The principles of mistakeproofing offer practical and useful application in the construction industry. Their systematic pursuit is bound to help improve quality performance (including safety and health performance by prevent hazards, incidents, and chronic pain altogether) in the short- and long-term as it has across the board in other industries.

2. While perhaps not so obvious to the untrained eye, quite a few applications of mistakeproofing already exist in the construction industry. The practice of mistakeproofing construction needs to be made more visible. Documentation of existing practices will inspire greater adoption of mistakeproofing.

3. While some mistakeproofing opportunities require investment in new product development, many can be implemented at a minimal- if any cost.

4. The generation of new ideas on how to mistakeproof certain designs, tasks, or processes can be supported by drawing on the principles of TRIZ (Theory of Inventive Problem Solving). TRIZ takes a scientific approach to foster innovative thinking and offers methods that can be taught. It should be considered for inclusion in a mistakeproofing curriculum.

5. The need to mistakeproof the design of everyday construction products (materials, tools, assemblies, etc.) and processes (work methods) may seem obvious (or, upon reading this report, hopefully will appear obvious in hindsight), but mistakeproofing is by no means a common practice in the construction industry. Developing a mistakeproofing mindset starts by raising awareness and empowering people to systematically experiment with making changes in how work gets done on their projects, big or small, in pursuit of continuous improvement. Training will be needed to foster a mistakeproofing mindset.

6. The six principles of mistakeproofing align to some degree with the five levels in OSHA's Hierarchy of Hazard Controls. They appear to be broader in their focus of application, however, not so focused on safety and health, but rather addressing quality (which includes concern for safety and health) at a more holistic level questions of production system design and overall performance.

7. Further advancement of the use of mistakeproofing in construction will contribute to the initiatives unfolding around Prevention through Design (PtD), Safety by Design (SbD), and others that focus on improving the industry's health and safety performance.

By explaining the goal to be achieved, defining the principles, and offering examples, this report aimed to encourage broader awareness and use of this Lean Thinking method. Intentional and purposeful use of mistakeproofing principles through their practical application will lead to improved industry performance in construction, as it has in other industries.

7. ACKNOWLEDGMENTS

The authors of this report owe many thanks to everyone they spoke with and who hosted their visits, for their time and willingness to contribute to this research by sharing ideas and examples of mistakeproofing (only some of which made it into this report).

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APPENDIX I: GLOSSARY

This glossary of terms includes a number of definitions provided in Tommelein and Ballard (2017), referred to as the “P2SL Glossary 2017.” In certain places, adjustments were made so that those terms would be compatible with definitions used by OSHA (e.g., OSHA 2016).

5 WHYs, 5 Why analysis: Problem solving method based on asking Why? successively—at least 5 times—in order to get beyond the symptoms of a problem that can be addressed with a local countermeasure, to uncover the root cause of a problem that can be addressed by a systemic, more lasting countermeasure. (P2SL Glossary 2017)

Reference: also see → Ohno (1988 p. 17)

5 Whys is a method to pursue the deeper, systematic causes of a problem to find correspondingly deeper countermeasures.

Level of Problem	Corresponding Level of Countermeasure
There is a puddle of oil on the shop floor	Clean up the oil
Because the machine is leaking oil	Fix the machine
Because the gasket has deteriorated	Replace the gasket
Because we bought gaskets made of inferior material	Change gasket specifications
Because we got a good deal (price) on those gaskets	Change purchasing policies
Because the purchasing agent gets evaluated on short-term cost savings	Change the evaluation policy for purchasing agents

Figure 20-1. “5-Why” investigation questions

Source: Peter R. Scholtes, *The Leader's Handbook*, McGraw-Hill, 1998.

40 TRIZ Principles: see → Appendix III.

ARIZ: Algorithm for Inventive Problem Solving, part of TRIZ developed by Altshuller (1984, 1997)

breakdown: Deviation from standard process or target outcome(s). Types of breakdowns:

- Incidents and close calls (near misses)
- Errors, defects, rework
- Broken promises, plan failures

A breakdown provides a learning opportunity because either (1) we did not properly perform process A and need to learn how to, or (2) our knowledge regarding causality “IF A THEN B” is inadequate. (P2SL Glossary 2017)

close call, near miss: Incident that could have—if circumstances had been slightly different—resulted in human harm, but did not.

Condition of Satisfaction (COS): Directive (proactive: for steering) and criterion (reactive: for judging), imposed by the entity initiating a process (usually the customer) that specify (to the performer of that process) how success of the outcome will be gauged.

What will make a customer satisfied with the service or product received. (P2SL Glossary 2017)

COS → see *Condition of Satisfaction* (COS)

defect: An output that does not conform to a *Condition of Satisfaction* (COS) or specification; not to *standard*; not of *quality*.

detection [mistakeproofing]: principle of mistakeproofing aimed at helping people recognize that a mistake has occurred, e.g., by providing sensory feedback, so that they can promptly correct the situation.

DfS: see → *Safety by Design (SbD)*

elimination[1] [hierarchy of controls]: Change in process or workplace condition that removes the hazard or ensures that no person can be exposed to a hazard under any foreseeable circumstances (after OSHA 2016).

elimination[2] [mistakeproofing]: principle of mistakeproofing aimed at redesigning the product or process so that the task where people may make mistakes or incidents may occur is no longer needed.

error: see → *mistake*

errorproofing: see → mistakeproofing

facilitation [mistakeproofing]: principle of mistakeproofing that aims at making tasks easier to perform and helping people make distinctions in a situation or artifact that are relevant to the proper execution of their task, by providing sensory input.

fail safing: see → mistakeproofing

Failure Modes and Effects Analysis (FMEA): "Failure modes and effects analysis (FMEA) is a step-by-step approach for identifying all possible failures in a design, a manufacturing or assembly process, or a product or service. (ASQ 2017)."

FMEA → see *Failure Modes and Effects Analysis*

hazard: Situation where an event may occur that causes human harm.

hazard analysis: Technique that focuses on tasks as a way to identify hazards before they occur. It focuses on the relationships among the worker, the task, the tools, and the work environment (after OSHA 2016).

Hierarchy of Hazard Controls: System for selecting and implementing the most effective control solutions for workplace hazards that includes:

1. Elimination
2. Substitution
3. Engineering controls
4. Administrative controls
5. Personal protective equipment

This is referred to as a hierarchy because they should be considered in the order presented. Controls at the top of the hierarchy are potentially more effective and more protective than those lower in the hierarchy (OSHA 2016).

Reference: Peterson (1973)

human harm: Death, injury, or illness.

illness: Human harm caused by, e.g., skin diseases or disorders, respiratory conditions, poisoning, and hearing loss (OSHA categories in Zaidman 2006)

Reference: Zaidman (2006)

In contrast to → *injury*

incident: Occurrence of an event that results in a fatality, injury, illness, or close call (sometimes called "near misses"), in which a person might have been hurt if the circumstances had been slightly different.

injury: Wound or damage to the body resulting from an event in the (work) environment. Examples are a cut, abrasion, fracture, or burn. Sprain and strain injuries to muscles, joints, and connective tissues are classified as injuries when they result from a slip, trip, fall, or other similar incidents (after Zaidman 2006).

job hazard analysis: see → *hazard analysis*.

mistake, error: Inadvertent human action that may lead to a defect in a process or product, or harm to a person.

mistakeproofing, poka yoke, errorproofing, fail-safing (P2SL Glossary 2017): Designing products or processes to eliminate (or at least to reduce) the probability or impact of mistakes and defects in use or execution. Mistakeproofing is based on six principles:

1. Elimination (akin to elimination as defined in *Hierarchy of Controls*)
2. Prevention
3. Replacement or substitution (akin to substitution as defined in *Hierarchy of Controls*)
4. Facilitation
5. Detection
6. Mitigation

Reference: Shingo (1986)

mitigation [mistakeproofing]: principle of mistakeproofing aimed at alleviating or minimizing the impact of a mistake or incident that has occurred.

near miss: see → *close call*.

poka yoke: see → *mistakeproofing*

PPE: personal protection equipment

Prevention through Design (PtD): Anticipating and "designing out" (preventing the occurrence of) potential occupational safety and health hazards that may arise as a result of people engaging in processes to make products (e.g., organizing work using work structuring or operation design) or using products-as-designed (e.g., materials, assemblies, equipment, tools) (P2SL Glossary 2017)

References: NIOSH (2014), Schulte et al. (2008), designforconstructionsafety.org

Related see → *mistakeproofing* and *Safety by Design* (SbD)

process capability: Probability distribution describing the variation in a property of the output of a process (e.g., the geometry of the material produced) under normal operating conditions. This definition pertaining to geometry equally applies to any material, resource, or process property such as duration, temperature, impact strength, etc. (P2SL Glossary 2017)

PtD → see *Prevention through Design*

quality: Meeting requirements. "Consistently producing a product (outcome) that meets customers' expectations and that is fit for the purpose intended. (Lichtig 2011)" (P2SL Glossary 2017)

root cause analysis: A collective term that describes a wide range of approaches, tools, and techniques used to uncover causes of problems (OSHA 2016).

safe, safety: Not harmful. (P2SL Glossary 2017)

Safety by Design (SbD): Practice that encourages product and process designers to "design out" during design development what may be health and safety risks to makers and users of their design. It supports the view that design affects, not only quality, scope, and cost, but also safety (after Wikipedia 2016). (after P2SL Glossary 2017)

In the context of mistakeproofing, SbD follows two principles, elimination and substitution.

Reference: Wikipedia (2016-05-14) https://en.wikipedia.org/wiki/Safety_by_design (17 JAN 2017)

Related → see *Prevention through Design* (PtD)

SbD → see *Safety by Design*

self-inspection: Process whereby the performer of a task confirms that the hand-off produced conforms to requirements and all known purposes including the purpose expressed in the Conditions of Satisfaction (COS) of the immediate and ultimate customers. This eliminates the defects against known requirements and it eliminates the defects that are relevant to the next customers, though possibly not all defects that may affect customers further downstream. (P2SL Glossary 2017)

In contrast to → *successive inspection*

Ref.: Shingo, S. (1986). Zero Quality Control: Source Inspection and the Poka-Yoke System. Taylor&Francis.

small win: Related to continuous improvement, recognition that any gain (win) is a gain (win) and therefore worth pursuing. More importantly, alertness to small wins sharpens people's skills at finding improvement opportunities in general. (P2SL Glossary 2017)

References: Akers (2011), Amabile and Kramer (2011)

source inspection → see *self-inspection*

standard: An agreed-upon reference or baseline from which deviation is observed and measured. Any standard is implied to be a current-best standard that can be improved upon and replaced by a better standard.

standard(ized) work: Agreed-upon process for performing work, used repeatedly, and serving as the baseline from which to measure improvements.

substitution [hierarchy of controls]: The replacement of a toxic or hazardous material (or the equipment or processes used with them) with one that is less harmful. (OSHA 2016)

substitution^2 [mistakeproofing]: principle of mistakeproofing aimed at identifying tasks where people make mistakes or incidents occur, and then replacing them with tasks that are less error- and incident-prone (e.g., a less hazardous one).

successive inspection: Inspection performed by the immediate customer of a process, principally focused on the inspector's own *Conditions of Satisfaction* (COS). This may include technical inspectors who take into account all quality conditions. (P2SL Glossary 2017)

In contrast to → *self-inspection*

Reference: Shingo (1986).

TRIZ: Theory of Inventive Problem Solving, developed by Altshuller (1984, 1997, 1999)

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APPENDIX III: 40 TRIZ PRINCIPLES

Altshuller (1999 pp. 287-289) identified a set of 40 TRIZ Principles that can be applied to resolve contradictions and thereby spur innovative thinking. With minor adjustments in wording, the TRIZ40 (n.d.) website replicates these 40 TRIZ Principles. The site furthermore offers examples from various domains for each principle and mentions which contradictions may be solved by which principle(s) by relating them in matrices akin to Altshuller's (1999 pp. 281-285) Contradictions Matrix.

As Appendix IV includes examples of mistakeproofing practices and the description of each practice also mentions which TRIZ principle appears to have been applied, those 40 TRIZ principles are listed next. For more detail, however, please refer to Altshuller (1999) and the TRIZ40 (n.d.) website.

1. Segmentation
   - 1.1. Divide an object into independent parts.
   - 1.2. Make an object easy to disassemble.
   - 1.3. Increase the degree of fragmentation or segmentation.
2. Taking out
   - 2.1. Separate an interfering part or property from an object, or single out the only necessary part (or property) of an object.
3. Local quality
   - 3.1. Change an object's structure from uniform to non-uniform, change an external environment (or external influence) from uniform to non-uniform.
   - 3.2. Make each part of an object function in conditions most suitable for its operation.
   - 3.3. Make each part of an object fulfill a different and useful function.
4. Asymmetry
   - 4.1. Change the shape of an object from symmetrical to asymmetrical.
   - 4.2. If an object is asymmetrical, increase its degree of asymmetry.
5. Merging
   - 5.1. Bring closer together (or merge) identical or similar objects, assemble identical or similar parts to perform parallel operations.
   - 5.2. Make operations contiguous or parallel; bring them together in time.
6. Universality
   - 6.1. Make a part or object perform multiple functions; eliminate the need for other parts.
7. Nested doll
   - 7.1. Place one object inside another; place each object, in turn, inside the other.
   - 7.2. Make one part pass through a cavity in the other.

8. Anti-weight
    8.1. To compensate for the weight of an object, merge it with other objects that provide lift.
    8.2. To compensate for the weight of an object, make it interact with the environment (e.g. use aerodynamic, hydrodynamic, buoyancy and other forces).
9. Preliminary anti-action
    9.1. If it will be necessary to do an action with both harmful and useful effects, this action should be replaced with anti-actions to control harmful effects.
    9.2. Create beforehand stresses in an object that will oppose known undesirable working stresses later on.
10. Preliminary action
    10.1. Perform, before it is needed, the required change of an object (either fully or partially).
    10.2. Pre-arrange objects such that they can come into action from the most convenient place and without losing time for their delivery.
11. Beforehand cushioning
    11.1. Prepare emergency means beforehand to compensate for the relatively low reliability of an object.
12. Equipotentiality
    12.1. Change the condition of the work in such a way that it will not require lifting or lowering an object (Altshuler 1999 p.287)
13. Do it in reverse (Altshuler 1999 p.287), the other way around
    13.1. Invert the action(s) used to solve the problem (e.g. instead of cooling an object, heat it).
    13.2. Make movable parts (or the external environment) fixed, and fixed parts movable.
    13.3. Turn the object (or process) 'upside down'.
14. Spheroidality – Curvature
    14.1. Instead of using rectilinear parts, surfaces, or forms, use curvilinear ones; move from flat surfaces to spherical ones; from parts shaped as a cube (parallelepiped) to ball-shaped structures.
    14.2. Use rollers, balls, spirals, domes.
    14.3. Go from linear to rotary motion, use centrifugal forces.
15. Dynamicity / Dynamics
    15.1. Allow (or design) the characteristics of an object, external environment, or process to change to be optimal or to find an optimal operating condition.
    15.2. Divide an object into parts capable of movement relative to each other.
    15.3. If an object (or process) is rigid or inflexible, make it movable or adaptive.
16. Partial or excessive actions
    16.1. If 100 percent of an object is hard to achieve using a given solution method then, by using 'slightly less' or 'slightly more' of the same method, the problem may be considerably easier to solve.

17. Another dimension
    17.1. To move an object in two- or three-dimensional space.
    17.2. Use a multi-story arrangement of objects instead of a single-story arrangement.
    17.3. Tilt or re-orient the object, lay it on its side.
    17.4. Use 'another side' of a given area.
18. Mechanical vibration
    18.1. Cause an object to oscillate or vibrate.
    18.2. Increase its frequency (even up to the ultrasonic).
    18.3. Use an object's resonant frequency.
    18.4. Use piezoelectric vibrators instead of mechanical ones.
    18.5. Use combined ultrasonic and electromagnetic field oscillations.
19. Periodic action
    19.1. Instead of continuous action, use periodic or pulsating actions.
    19.2. If an action is already periodic, change the periodic magnitude or frequency.
    19.3. Use pauses between impulses to perform a different action.
20. Continuity of useful action
    20.1. Carry on work continuously; make all parts of an object work at full load, all the time.
    20.2. Eliminate all idle or intermittent actions or work.
21. Skipping
    21.1. Conduct a process, or certain stages (e.g. destructible, harmful or hazardous operations) at high speed.
22. *Blessing in disguise* or *Turn Lemons into Lemonade*
    22.1. Use harmful factors (particularly, harmful effects of the environment or surroundings) to achieve a positive effect.
    22.2. Eliminate the primary harmful action by adding it to another harmful action to resolve the problem.
    22.3. Amplify a harmful factor to such a degree that it is no longer harmful.
23. Feedback
    23.1. Introduce feedback (referring back, cross-checking) to improve a process or action.
    23.2. If feedback is already used, change its magnitude or influence.
24. Intermediary
    24.1. Use an intermediary carrier article or intermediary process.
    24.2. Merge one object temporarily with another (which can be easily removed).
25. Self-service
    25.1. Make an object serve itself by performing auxiliary helpful functions.
    25.2. Use waste resources, energy, or substances.
26. Copying
    26.1. Instead of an unavailable, expensive, fragile object, use simpler and inexpensive copies.
    26.2. Replace an object, or process with optical copies.
    26.3. If visible optical copies are already used, move to infrared or ultraviolet copies.

27. Cheap short-living objects
    27.1. Replace an inexpensive object with a multiple of inexpensive objects, comprising certain qualities (such as service life, for instance).
28. Mechanics substitution
    28.1. Replace a mechanical means with a sensory (optical, acoustic, taste, or smell) means.
    28.2. Use electric, magnetic and electromagnetic fields to interact with the object.
    28.3. Change from static to movable fields, from unstructured fields to those having structure.
    28.4. Use fields in conjunction with field-activated (e.g., ferromagnetic) particles.
29. Pneumatics and hydraulics
    29.1. Use gas and liquid parts of an object instead of solid parts (e.g., inflatable, filled with liquids, air cushion, hydrostatic, hydro-reactive).
30. Flexible shells and thin films
    30.1. Use flexible shells and thin films instead of three dimensional structures
    30.2. Isolate the object from the external environment using flexible shells and thin films.
31. Porous materials
    31.1. Make an object porous or add porous elements (inserts, coatings, etc.).
    31.2. If an object is already porous, use the pores to introduce a useful substance or function.
32. Color changes
    32.1. Change the color of an object or its external environment.
    32.2. Change the transparency of an object or its external environment.
33. Homogeneity
    33.1. Make objects interacting with a given object of the same material (or material with identical properties).
34. Discarding and recovering
    34.1. Make portions of an object that have fulfilled their functions go away (discard by dissolving, evaporating, etc.) or modify these directly during operation.
    34.2. Conversely, restore consumable parts of an object directly in operation.
35. Parameter changes
    35.1. Change an object's physical state (e.g., to a gas, liquid, or solid.)
    35.2. Change the concentration or consistency.
    35.3. Change the degree of flexibility.
    35.4. Change the temperature.
36. Phase transitions
    36.1. Use phenomena occurring during phase transitions (e.g., volume changes, loss or absorption of heat, etc.).
37. Thermal expansion
    37.1. Use thermal expansion (or contraction) of materials.
    37.2. If thermal expansion is being used, use multiple materials with different coefficients of thermal expansion.

38. Strong oxidants
    38.1. Replace common air with oxygen-enriched air.
    38.2. Replace enriched air with pure oxygen.
    38.3. Expose air or oxygen to ionizing radiation.
    38.4. Use ionized oxygen.
    38.5. Replace ozonized (or ionized) oxygen with ozone.
39. Inert environment atmosphere
    39.1. Replace a normal environment with an inert one.
    39.2. Add neutral parts, or inert additives to an object.
40. Composite materials
    40.1. Change from uniform to composite (multiple) materials.

APPENDIX IV: CATALOG WITH MISTAKEPROOFING EXAMPLES

The following pages present 30 examples of mistakeproofing practices in the architecture-engineering-construction industry, selected to illustrate variety in application opportunities of mistakeproofing in design and construction. The examples are ordered first by mistakeproofing principle, then by TRIZ principle. The box in the upper-left of each slide designates, based on the color codes shown in Figure 1 (this figure appeared earlier in the report but is copied below), which of 6 mistakeproofing principles the example is to illustrate. The box next to it, with blue text designates which of 40 TRIZ principles (all listed in Appendix III) the example is to illustrate.

In fact, many examples may be used to illustrate multiple principles. We leave it to the reader to expand on them further. The examples are intended to help readers practice their ability to see and recognize mistakeproofing practices in their everyday environment and then leverage that ability to create their own mistakeproofing applications.

Figure 1: Color Code for Each of Six Mistakeproofing Principles

ELIMINATE
PREVENT
REPLACE
FACILITATE
DETECT
MITIGATE

TRIZ Principle 2 Taking Out: Separate an interfering part or property from an object, or single out the only necessary part (or property) of an object.

Cordless Power Tool

CONCERN:

1. The electrical cord on a power tool limits the worker's working range.
2. The cord attached to the tool and any extension cords may get tangled or damaged in use, and create a tripping hazard.

COUNTERMEASURE: Eliminate cord and tripping hazard by using batteries to supply electricity to power tools.

LIMITATION: Battery-powered tools tend to have less power and limited in capacity.

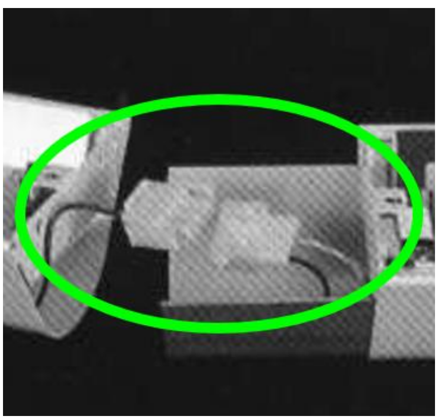
Two nearly identical circular saws.
Photo Credit: Tim Carter - www.askthebuilder.com/which-circular-saw-should-i-buy/

1

ELIMINATE
PREVENT
REPLACE
FACILITATE
DETECT
MITIGATE

TRIZ Principle 4 Asymmetry:
4.1 Change the shape of an object from symmetrical to asymmetrical.

Connection Plug



CONCERN:

1. Electrical wires may get connected wrongly.
2. Electricians must work at elevation to wire linear light fixtures.

COUNTERMEASURE:

In a shop environment, install clips to end the wiring on each fixture. Put on correctly, these clips can snap together in only one way (asymmetry) so that the wires will always be connected correctly.

The electrician's installation work at elevation takes less time.

Connect plug and wiring of linear light fixtures (Source: Finelite (2008). Estimator and Contractor Guide. Available online at http://www.finelite.com/contractor/ContractorGd_m.pdf visited 22 April.

2

ELIMINATE
PREVENT
REPLACE
FACILITATE
DETECT
MITIGATE

TRIZ Principle 14 Spheroidality (Curvature):
Instead of using rectilinear parts, surfaces, or forms, use curvilinear ones…

Manhole Cover

CONCERN: The cover for an opening that is rectangular (e.g., a ground excavation), can be turned sideways and fall into the opening. People working underneath inside the opening would be in harm's way.

COUNTERMEASURE: A manhole cover is round because a round cover cannot fall through a circular opening of at least the same diameter, no matter how it is positioned.

Manhole cover (McCarthy (2015-01-07) "Why Are Manhole Covers Round?" mentalfloss.com/article/60929/why-are-manhole-covers-round 19 OCT 2016).

3

ELIMINATE
PREVENT
REPLACE
FACILITATE
DETECT
MITIGATE

TRIZ Principle 6 Universality:
6.1 Make a part or object perform multiple functions; eliminate the need for other parts.

Lock with Electronic Key

CONCERN: losing a key

COUNTERMEASURE: an electronic lock unlocks by inputting a (memorized) code using a keypad, by reading a person's iris, or by reading their fingerprint.

Lock with keypad or sensor
(www.wired.com/2013/06/smart-locks/ visited by AlChaer on 10/30/2017)

4

ELIMINATE
PREVENT
REPLACE
FACILITATE
DETECT
MITIGATE

TRIZ Principle 6 Universality:
6.1 Make a part or object perform multiple functions; eliminate the need for other parts.

Perimeter Guard

CONCERN: Workers may fall off the edge of the roof.

COUNTERMEASURE: A barrier along the perimeter will hold back anyone coming too close.

A parapet (part of the permanent structure) that can function as a perimeter guard eliminates the need to provide temporary fall protection for construction and maintenance activities on the roof thus reducing total costs over the building life cycle.

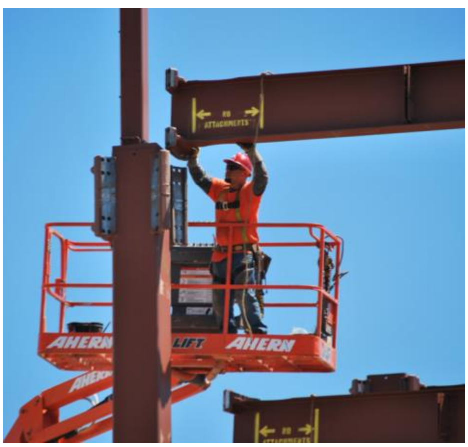
Parapet - Figure from slide 52 in OSHA (2015). *Design for Construction Safety.* Powerpoint slides online at https://designforconstructionsafety.files.wordpress.com/2017/10/dfcs_short-course-06_2015.pptx

5

ELIMINATE
PREVENT
REPLACE
FACILITATE
DETECT
MITIGATE

TRIZ Principle 7 Nested Doll:
7.2 Make one part pass through a cavity in the other.

Bolted Steel Moment Resisting Frame



CONCERN: Workers must work at elevation to weld connections during structural steel erection.

COUNTERMEASURE: Welded connections are replaced by hoist-in-place beams that are then bolted together.

Worker can work while standing in basket.

Time to complete connections is reduced, so that the time the worker has to work at elevation is reduced as well.

Hoist-in-place, bolted, moment-resisting frame
www.conxtech.com/conx-system/on-site-construction-services/ visited 11 FEB 2017

6

ELIMINATE
PREVENT
REPLACE
FACILITATE
DETECT
MITIGATE

TRIZ Principle 9 Preliminary Anti-action:
9.1 If it will be necessary to do an action with both harmful and useful effects, this action should be replaced with anti-actions to control harmful effects.

Lockout-Tagout (LOTO)

CONCERN: Working with electricity can be dangerous: it can harm a person (e.g., electrocution when touching a live circuit) or ignite a fire. A worker can turn off the breaker before starting any work, but then someone else might turn it back on. The fact that anyone passing by has access to the electrical breaker panel increases the risk of electrocution.

COUNTERMEASURE: OSHA 1926.417 requires lockout-tagout (LOTO) of circuits while any employee may be exposed to contact with parts of fixed electric equipment or circuits (US Department of Labor, n.d.).

A lock is placed on the door of the entire breaker panel to prevent anyone other than the worker doing the work from accessing the panel and accidently switching on breakers that should not be switched on. By locking the door, access to the breakers is prevented, and the safety of the workers is enhanced.

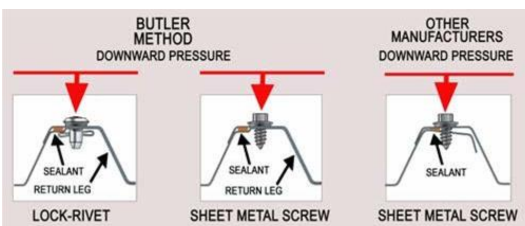
Parts for Lockout (left) and Installed Panel Lockout (right) (Electrical Panel Lockout (2017) OSHA Compliant Lockout Tagout Devices. http://www.panellockout.com/ visited by Bardaweel on 1 NOV 2017)

7

ELIMINATE
PREVENT
REPLACE
FACILITATE
DETECT
MITIGATE

TRIZ Principle 40 Composite Materials:
Change from uniform to composite (multiple) materials.

Weather-tight Roof



Sealant and return leg guarantee roof performance (Source: Butler manufacturing product literature; http://www.butlermfg.com/images/level3_pages/returnleglink-large.jpg visited 5/23/06).

CONCERN: Metal roofs covering a large area will expand and shrink significantly due to temperature changes. The panels that make up the roof must allow for movement while also guaranteeing weather-tightness.

Securing overlapping roof panels using a sheet metal screw may cause a gap on one side (right-hand figure) , while squeezing out the sealant on the other side. Over time, this may cause the roof to leak.

COUNTERMEASURE: (left and center figure) The sheet metal was indented to accommodate a certain amount of sealant, and embeds in the sealant were added (making the composite) to guarantee a minimum thickness, ensuring that enough sealant will be present to guarantee performance.

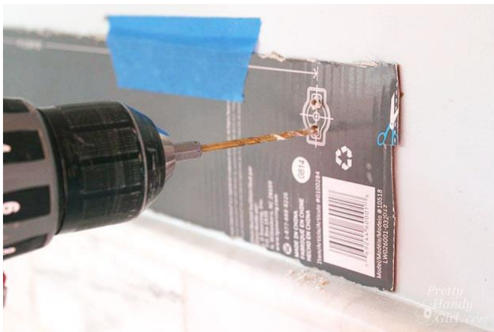
A longer return leg eliminates the possibility of movement (no gap) when the screw is screwed in.

8

ELIMINATE
PREVENT
REPLACE
FACILITATE
DETECT
MITIGATE

TRIZ Principle 6 Universality:
6.1 Make a part or object perform multiple functions; eliminate the need for other parts.

Towel Bar Installation Template



Towel Bar Installation Template (Brittany (2015). How to Install a Towel Bar Securely. www.prettyhandygirl.com/how-to-install-towel-bar-securely/ visited by Bardaweel on 1 NOV 2017)

CONCERN: Mounting a towel bar on a wall requires accurate measurement of the spacing between screws.

COUNTERMEASURE: The towel bar packaging can act as a template to facilitate installation by identifying the location of the drill holes, thereby eliminating the need to measure the distance between screws and then marking the location before drilling holes.

The template is held level and then taped to the wall. The location of the 4 drill holes needed are illustrated on the template without any additional work being necessary.

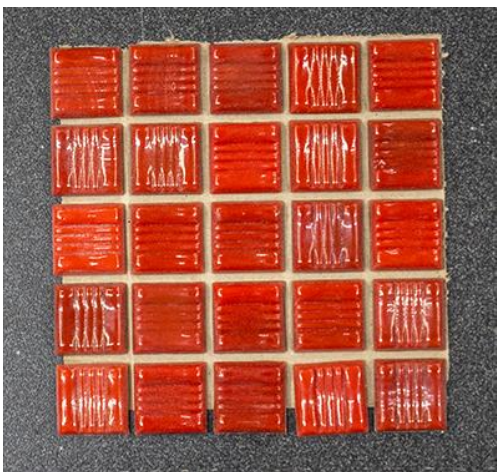
Use of templates makes it significantly easier and faster to complete the work.

9

ELIMINATE
PREVENT
REPLACE
FACILITATE
DETECT
MITIGATE

TRIZ Principle 10 Preliminary Action:
Perform, before it is needed, the required change of an object (either fully or partially).

Face-Mounted Tile



mosaicartsupply.com/paper-mesh-mosaic/ visited 10 March 2017

CONCERN:
- Achieve even spacing when mounting tile on a wall.
- Protect face of tile during transportation and handling.

COUNTERMEASURE:
- Secure spacing before installation.
- Cover tile.

Glass mosaic tile comes glued face down on paper with their back side exposed. They have ridges on the back to allow adhesive to bond securely to an otherwise slick glass surface.

First, tile adhesive is applied to the wall. Then the sheet is pressed into the adhesive paper-side out. After the adhesive and time have had time to bond securely, the paper is sprayed with water until it slides from the face of the tiles. Paper removed, the tiles can be grouted.

10

ELIMINATE
PREVENT
REPLACE
FACILITATE
DETECT
MITIGATE

TRIZ Principle 12 Equipotentiality:
Change the condition of the work in such a way that it will not require lifting or lowering an object

Clamps to Rotate Welded Steel Components

CONCERN:

- Welders must bend over and twist their bodies to access connections to be welded.
- Weld material may run down due to gravity.

COUNTERMEASURE: "ConXtech is the first manufacturing facility in the world to weld, in a production environment, Hollow Structural Steel (HSS) columns entirely in the horizontal position."

- Welder works at comfortable height and can turn by hand the column to the right position.
- Weld material is deposited horizontally.

ConXTech fabrication shop with rotating clamps
www.prweb.com/releases/conxtech/ladbs-approved/prweb10762433.htm

11

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TRIZ Principle 15 Dynamicity:
15.3 If an object (or process) is rigid or inflexible, make it movable or adaptive.

Flexible Pipe

CONCERN: Neither the location where the plumbing pipe comes out of the wall nor the location of the fixture on the floor are very precise (installed within some tolerance.

COUNTERMEASURE: Use a flexible pipe that bends to suit site conditions.

Flexible water supply connector, Flex Pipe, or Flexi Hose
(Source: Picture by Iris D. Tommelein, Boston, MA, 2007)

12

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TRIZ Principle16 Partial or Excessive Actions: If 100% of an object is hard to achieve using a given solution method then, by using 'slightly less' or 'slightly more' of the same method, the problem may be considerably easier to solve.

Paint Stencil

CONCERN: It is difficult to paint exactly what is needed (e.g., a number) with sharp edges especially when using spray paint.

COUNTERMEASURE: Stencils, painters' tape, etc. capture the overspray of paint, and get removed after painting.

www.uline.com/Product/Detail/S-1963/Stencils/Brass-Stencils-Letters-and-Numbers-2?pricode=WB2005&gadtype=pla&id=S-1963&gclid=EAIaIQobChMI9M-8-Yug2QIV27XACh1QrAizEAQYAyABEgJj7PD_BwE&gclsrc=aw.ds

13

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TRIZ Principle 24 Intermediary: 24.1 Use an intermediary carrier article or intermediary process.

Jig for Anchor Bolts

CONCERN: Light poles are secured to their concrete foundation using four anchor bolts. The rods on which they will be threaded must be aligned exactly or the metal base of the pole will not fit onto them.

The rods must be lined up beforehand but may accidentally move when concrete gets placed and vibrated.

COUNTERMEASURE: Secure spacing before installation.

The jig secures the four rods in place relative to each other.

"AJ Speedset is an adjustable jig that creates a simplified, time saving way to install ¾", 1" or 1¼" anchor bolts in concrete for area lighting." www.rndproducts.com/products_aj.htm

14

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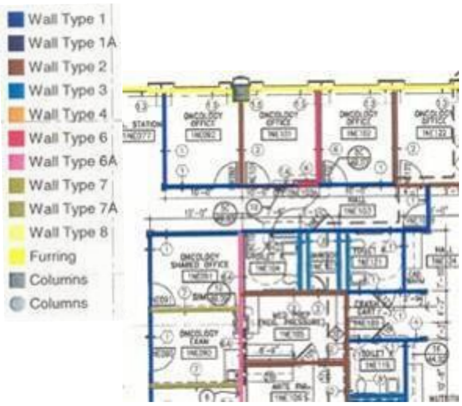
TRIZ Principle 32 Color changes:
32.1 Change the color of an object or its external environment.

Drawings and BIM Elements



CONCERN: On a black-and-white drawings, many wall types may look alike. Symbols that denote each type require a table lookup.

COUNTERMEASURE: Different colors designate different wall types in design drawings to assist estimators, plan reviewers, and builders with looking up and “seeing” the differences.

Source: DPR Inc., Camino Medical Center Project

15

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DETECT
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TRIZ Principle 32 Color changes:
32.1 Change the color of an object or its external environment.

Nail Heads

CONCERN: Using a nail that is too short will not result in the required performance, and one that is too long may protrude (become visible or penetrate another object).

COUNTERMEASURE: The heads of these pneumatic nails have different colors to correspond to different lengths and diameters. This makes it easy for workers to grab the right nails (less likely they will confuse sizes), and reorder the color they need.

It also makes it possible for workers and inspectors to see and verify whether or not nails were installed according to the design requirements.

Hawks, J. “Tool Review: Color-Coded Pneumatic Nails.” *Fine Homebuilding Magazine* reprinted on http://www.taunton.com/finehomebuilding/pages/h00090.asp visited 5/23/06.

16

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TRIZ Principle 32 Color changes:
32.1 Change the color of an object or its external environment.

Pipe Markers

Pipe identified by color (blue: potable cold water, green: hot water, and red: fire water)
www.safetysign.com/blog/brimar-is-coming-to-the-ahr-expo/ visited by Briones on 11/02/2017

CONCERN: Buildings include many piping systems, for hot- and cold water supply, fire sprinklers, etc. The proper pipe sections must be connected during construction. The right valves must be opened and closed while the facility is in use.

COUNTERMEASURE: Each pipe is identified by color and with labels to indicate the system it supports (e.g., per the ANSI/ASME 13.1 standard for identification of pipe).

These colors help workers recognize the function of each pipe, so they can clearly identify which one(s) to work on, what valves to shut off, etc.

17

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DETECT
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TRIZ Principle 32 Color changes:
32.1 Change the color of an object or its external environment.

Color-Changing Paint

CONCERN: when using white paint to paint over a white ceiling, it is hard to see which areas have already been painted, so application may be uneven.

COUNTERMEASURE: Additives to the paint make the white paint look pink for as long as it is wet. When it dries, it gradually turns white.

Glidden® EZ Track Ceiling Paint - kk.org/cooltools/glidden-ceiling/

18

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TRIZ Principle 39 Inert Environment Atmosphere:
39.1 Replace a normal environment with an inert one.

"Sterilize" an Area

CONCERN: When work is done overhead, objects may fall down; they may strike people underneath or cause damage when they hit something.

COUNTERMEASURE: Block off the area ("sterilize it") to show that no one is allowed to be underneath.

https://www.mprnews.org/story/2014/06/19/as-pipeline-production-soars-in-minnesota-critics-urge-focus-on-safety#gallery Kraker, D. (19 JUN 2014). "As pipeline production soars in Minnesota, critics urge focus on safety."

19

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TRIZ Principle 40 Composite Materials: 40.1 Change from uniform to composite (multiple) materials.

Mark Drill Hole Locations

Source: Simpson Strongtie

CONCERN: Trades that follow the placement of a floor slab with post-tensioned (PT) concrete may have to drill into the slab to secure their work. It is hard to know the exact location of the PT cable (depth and x-y position in slab) but drilling into it is dangerous: it could cause the cable to snap and jeopardize the structure's performance.

COUNTERMEASURE: Blue Bangers are inserts positioned in-between PT cables and then nailed to the slab formwork prior to placing concrete. They are visible from underneath the slab when the formwork has been stripped and mark spots where it is OK to drill.

20

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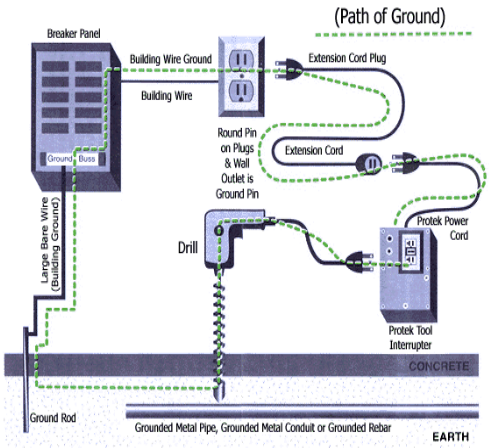
TRIZ Principle 11 Beforehand Cushioning: Prepare emergency means beforehand to compensate for the relatively low reliability of an object.

Power Interrupter for Drill



CONCERN: When drilling into a reinforced concrete element, one can hit rebar, conduit, or other metal embeds. Drilling into these may cause damage to the element as well as the drill.

COUNTERMEASURE: A device called the PROTEK drill interrupter helps detect metal in the concrete. As soon as the drill bit makes contact with grounded metal piping, conduit, reinforcement steel, etc. the control loop is completed (closed) and the device stops the electricity supply to the drill so that the operator cannot continue to drill through the metal object.

Drill Interrupter System (www.geotechsupply.com/protekiidrillinterrupter.aspx visited 18 OCT 2016)

21

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TRIZ Principle 18 Mechanical Vibration: Cause an object to oscillate or vibrate.

Rumble Strips

CONCERN: Distracted or sleepy drivers may veer off the road or cross the centerline into the opposing traffic lane.

COUNTERMEASURE: Rumble strips cause the vehicle to make a loud noise (auditory feedback) that alerts the driver, so that they can avoid running off the road or colliding with other vehicles or obstacles.

www.rumblestrips.com/resources/research-and-publications/cyclists-and-rumble-strips/
visited by Briones on 11/02/2017

22

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TRIZ Principle 23 Feedback:
23.1 Introduce feedback (referring back, cross-checking) to improve a process or action.

Crane Overload Switch

CONCERN: The load a hoist or crane can carry depends on its rigging as well as the lift radius and thus boom length. The crane capacity is lower when the lever arm is greater.

COUNTERMEASURE: An overload switch indicates the load carried by a hoisting device or crane.

Mechanical Overload Switch (vetec.dk/products/mechanical-overload-switch-crane-limit-switch-hoist-limit-switch/ and vetec.dk/wp-content/uploads/2015/10/MECHANICAL-OVERLOAD-SWITCH.pdf visited 20 OCT 2017).

23

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TRIZ Principle 23 Feedback:
23.1 Introduce feedback (referring back, cross-checking) to improve a process or action.

Tension Bolt

CONCERN: Structural bolts must have the proper pretension in order to be functional. This tension is achieved by torqueing the bolt however torque is not a reliable indicator of tension.

COUNTERMEASURE: Squirter DTIs are compressible washers that show when a bolt reaches its target tension, independent of torque, by expressing orange-colored material.

Myhrum, B. (2010). "Simple QA for Wind Turbine Bolts." Windpower, online at www.windpowerengineering.com/construction/simple-qa-for-wind-turbine-bolts/

24

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TRIZ Principle 3 Local Quality:
3.1 Change an object's structure from uniform to non-uniform.

Electrical Fuse

CONCERN: *When a load on a system exceeds its capacity, the system will fail.* When too much current flows through a circuit, it can overheat and cause a fire.

COUNTERMEASURE: *Intentionally create a weak spot in the system so it will fail when the loads exceeds a threshold.*

The weak spot– the fuse– will overheat and melt ("blow") when too much current (exceeding amperage of the fuse) flows through the circuit. This interrupts the current before more damage can occur.

By locating the fuse judiciously in the circuit, it will be easy to locate the system failure and replace the fuse. One must determine why the fuse blows and remedy the cause before replacing the fuse with a new one, or it will also blow.

The illustration shows that the fuse gives a visual indication of its demise (text after Chris 2015).

Fuse before (top) and after it has blown (bottom); this fuse shown is for single use. Other kinds of fuses may be reset and reused. Source: Chris (2015). "Electrical Fuses | The Home Depot Community." *The Home Depot*, 24 Nov., community.homedepot.com/howto/DiscussionDetail/Fuses-90650000000CeU9)

25

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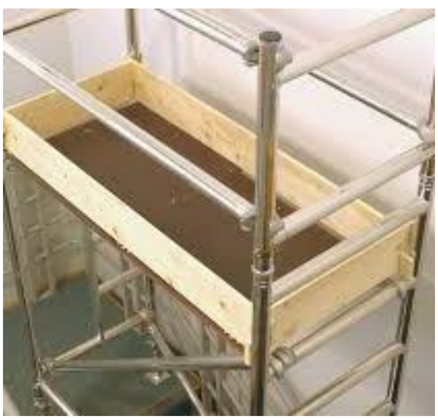
TRIZ Principle 3 Local Quality:
3.3 Make each part of an object fulfill a different and useful function.

Toeboard on Scaffold



CONCERN: A worker on a scaffold may accidentally push over an object staged on the platform (e.g., a bucket) and strike a worker passing underneath or cause damage.

COUNTERMEASURE: OSHA (2010) requires workers on a scaffold 10 feet or higher to place toe boards at the platform edges to mitigate the chance of kicking over objects.

This reduces the chance of an object falling down; it does not fully prevent it from happening.

Toeboard on Scaffold
www.contractors-solutions.net/Toe-Board-Bracket-for-Utility-Scaffolding.aspx visited by AlChaer on 10/30/2017
OSHA (2010) https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=INTERPRETATIONS&p_id=27335 visited on 10/30/2017.

26

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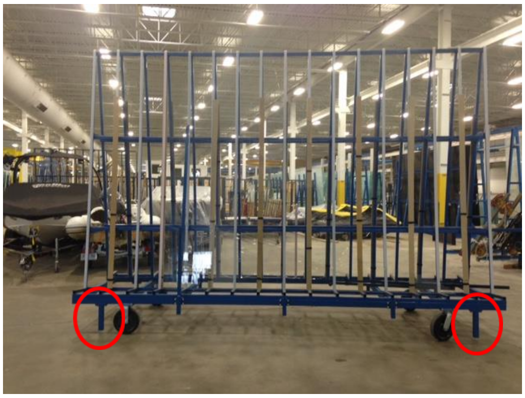
TRIZ Principle 3 Local Quality: 3.3 Make each part of an object fulfill a different and useful function.

"Dead Man" Cart Leg



CONCERN: Cart (as shown, loaded with 3,500 pounds of glass) may tilt over or collapse due to wheel/caster failure, and crush or kill a worker.

COUNTERMEASURE: Added a Dead man concept to the 4 corners of the fabricated cart to protect against wheel/caster failure.

Wheeled cart with dead man legs

Stoker, I. and Stearns, L. (2017). "Harmon Glass Handling Kaizen-Report Out (Event Dates: 1/12 to 1/14)." Harmon, Inc. Manufacturing Facility, Cincinnati, OH, 30 November 2017; Powerpoint slides provided by Chad Hoffmann, 23 pp.

27

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TRIZ Principle 11 Beforehand Cushioning: Prepare emergency means beforehand to compensate for the relatively low reliability of an object.

Worker Fall Protection

CONCERN: Workers can fall from heights.

COUNTERMEASURE: The g-link dual retractable system allows 100% tie-off where one can move from one anchor point to the next without disconnecting the retractable. The bulk of the unit is attached to the back of person's harness and the system is constructed of lightweight aluminum components, which reduces worker fatigue.

Guardian G-Link Dual Retractable System (www.fallprotectionpros.com/amfilerating/file/download/file_id/1317/ and www.fallprotectionpros.com/guardian-g-link-dual-retractable-system-aluminum-rebar-11ft.html visited 18 OCT 2016)

28

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REPLACE
FACILITATE
DETECT
MITIGATE

TRIZ Principle 11 Beforehand Cushioning: Prepare emergency means beforehand to compensate for the relatively low reliability of an object.

Lanyard for Tools

CONCERN: “Dropping a tool while working at height can have devastating consequences.”

COUNTERMEASURE: “Lanyards, which can be attached to the operator's wrist, belt, harness or other suitable tether site location,” prevent objects falling a great distance.

www.utilityproducts.com/articles/print/volume-16/issue-2/readers-choice-awards/tools-supplies/utilities-can-improve-productivity-and-safety-through-adoption-of-dedicated-tools-at-height-products.html

29

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FACILITATE
DETECT
MITIGATE

TRIZ Principle 11 Beforehand Cushioning: Prepare emergency means beforehand to compensate for the relatively low reliability of an object.

Table Saw Stop

www.sawstop.com

CONCERN: People use their hands to push material and cut it with the table saw. Their hand may get caught by the blade.

Table saws have blade guards to reduce the likelihood of a hand getting caught, but workers may remove these guards as they find them to be impractical.

COUNTERMEASURE: “The SawStop saw detects contact with skin. The blade carries a small electrical signal, which the safety system continually monitors. When skin contacts the blade, the signal changes because the human body is conductive. The change to the signal activates the safety system.”

30