'POKA YOKE' OR QUALITY BY MISTAKE PROOFING DESIGN AND CONSTRUCTION SYSTEMS

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ABSTRACT

The Japanese concept 'poka yoke', translated into English as 'mistake proofing,' has been mentioned at previous IGLC conferences. This notwithstanding, mistake proofing appears to not have been (nor be) systematically researched or practiced in the lean construction community. To raise awareness of opportunities provided by thinking with mistake proofing in mind as a means to build quality into project delivery, this paper summarizes the philosophy that underlies mistake proofing. Examples illustrate how mistake proofing applies to the work done within one specialty trade, how manufacturers and fabricators can design their products so they cannot be constructed defectively, and how architects and engineers may conceive of system designs that are less likely to fail during construction or in a product's life cycle. Reader contributions to an online repository of mistake proofing applications in the architecture-engineering-construction (AEC) industry, posted at http://p2sl.berkeley.edu/pokayoke/, will be gratefully acknowledged.

KEY WORDS

poka yoke, mistake proofing, jidoka, autonomation, design, engineering, system, specification, construction, safety, quality, constructability, tolerance management, life-cycle performance, lean construction

INTRODUCTION AND DEFINITION

Shingo (1986), a master mind of the Toyota Production System, introduced the concept of 'poka yoke' in Japanese, translated as 'mistake proofing' in English, in his book titled *Zero Quality Control: Source Inspection and the Poka-yoke System.* This concept goes hand-in-hand with the concept of 'jidoka' in Japanese, translated as 'autonomation' in English, as together they form a pillar of the Toyota Production System.

Autonomation refers to machines built to detect problems and stop by themselves, so as to "relieve the burden of constantly supervising a machine, and allow [people] to use their talents for more beneficial things (like adding value)" (Liker and Meier 2006 p. 177) "The purpose of autonomation is the rapid or immediate address, identification and correction

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of mistakes that occur in a process… Once the line is stopped, a supervisor or person designated to help correct problems give immediate attention to the problem the worker or machine has discovered. To complete jidoka, not only is the defect corrected in the product where discovered, but the process is evaluated and changed to remove the possibility of making the same mistake again. This 'mistake-proofing' of the production line is called poka yoke." (Superfactory 2008).

Many online glossaries with lean production terms include 'poka yoke' (e.g., http://www.nummi.com/tps.php) and at least one website has been dedicated to this topic (http://www.mistakeproofing.com/). Books have been written on the application of mistake proofing in specific industries (e.g., Grout 2007 is on health care processes). Lean construction researchers have mentioned the concept for many years at previous IGLC conferences and elsewhere (e.g., Koskela 1992, dos Santos et al. 1998, 1999, dos Santos and Powell 1999, Moser and dos Santos 2003, Adbelhamid and Salem 2005). This notwithstanding, the practice of mistake proofing still appears to not be systematically pursued by researchers and practitioners in the lean construction community. To raise awareness of opportunities provided by thinking with mistake proofing in mind as a means to build quality into project delivery, this paper summarizes the philosophy underlying mistake proofing, illustrates opportunities for application of this concept in practice by means of examples, and solicits contributions from readers who may wish to volunteer other mistake proofing examples. The aim of this effort is to develop a community knowledge base and to spur discussion around mistake proofing opportunities in the architecture-engineering-construction (AEC) industry.

APPLICABILITY OF MISTAKE PROOFING IN THE AEC INDUSTRY

Shingo's premise of 'zero quality control' is to 'do it right the first time.' Bodek stressed this idea in his preface to Shingo's book (1986 p. vii) by stating that we should "drop the idea that defects are a normal part of manufacturing." In the AEC industry, this thinking is contrary to the reliance of practitioners on inspection and punch lists as means to work towards an acceptable end product, hopefully one that is satisfactory and of quality! To eliminate the need for quality control, the practice of mistake proofing sets out to prevent errors or defects from occurring in the first place.

Mistake proofing is particularly well suited for the AEC industry with its low-volume and mixed production systems where statistical quality control methods cannot be implemented due to lack of data and un-timeliness of findings that result from after-the-fact data processing. Mistake proofing requires a different way of thinking about production processes and its constituent operations, but once practitioners have learned to recognize mistake proofing devices, their new mind-set will enable them to spot numerous opportunities available to mistake proof their workplace. They will find that many mistake proofing practices can be implemented at a minimal cost, though some do require investment in new product development.

Mistake proofing could be thought of as a practice that is part of pursuing constructability, that is, changing a design so that it could be built 'better' (e.g., more easily, cost effectively, safely, so it will last longer, etc.), but it differs from constructability in two regards. First, the goal of mistake proofing is to improve production system performance by eliminating waste, e.g., avoiding product and process defects, reducing variation, and not tolerating poor quality. Second, efforts at mistake proofing 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, examples in this paper illustrate that mistake proofing is a practice for all project participants (designers, manufacturers, fabricators, builders, and others) to pursue in their day-to-day work and throughout project delivery.

The purpose of this paper is to raise awareness of how mistake proofing practices support lean implementation, specifically on products and processes in the AEC industry. Mistake proofing practices contribute to improving a system's performance, for example, by reducing the time it takes to perform a task while also narrowing the variation of that task's duration, by making sure hand-offs from one task to the next are sound (not defective), and by reducing variation in products and process outcomes. Though the focus in this paper is on mistake proofing and though application of this concept in-and-by itself yields advantages, practitioners will reap the greatest benefits from mistake proofing when applying it in concert with other lean practices.

Shingo (1986 p. 135) "thought that explaining poka-yoke methods by means of examples would be extremely effective when it came to actually adopting the poka-yoke system" and he goes on to present numerous examples (ibid pp. 139-261). Likewise, this paper includes a selection from nearly hundred AEC examples I have collected to date, to show the broad applicability of mistake proofing in various phases of project delivery. Tommelein and Grout (2008) describe and analyse many more examples and offer more detail than is presented here. Examples in this work are not intended to be endorsements of the products they refer to.

MISTAKE PROOFING IN DESIGN, CONSTRUCTION, OR MAINTENANCE

Mistake proofing applies to work done by a single specialist or by several specialists. In example 1 (Figures 1 and 2), specialists in design and in construction have color coded distinctions that matter for their specific work and phase of a project so as to avoid mix-ups. In examples 2, 3, and 4 (Figures 3, 4, 5,and 6), work has been 'productized.' Manufacturers have made devices to address a specific need and thereby reduced the amount of work, and simplified the nature of the work required of field personnel. In example 4 (Figures 5 and 6), a component is added to the system in order to fail safe maintenance work. These devices literally or figuratively turn work into 'plug-and-play.'

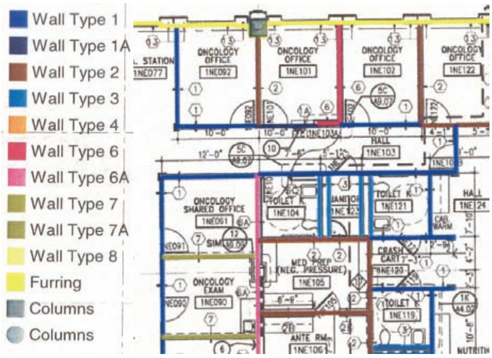

Figure 1: Color coding of design drawing shows different wall types for drywall cost estimate

(Source: DPR, Inc., Camino Medical Project)

Figure 2: Color coding shows locations for sheet metal straps and pipe hangers on metal decking

(Source: John Mack, Southland Industries, Inc., presentation at 2007 Annual Conference of the Lean Construction Institute, San Francisco, CA)

Example 1: Colour Coding to Improve Identification

Figure 1 shows colour codes a construction estimator has assigned to distinguish various wall types. This helps in clarifying and categorizing the design requirements specified by the architects, in performing a quantity take off and preparing a cost estimate, and in planning the work. Figure 2 shows colour codes being used on site, to highlight which metal-decking inserts belong to which trade. This helps, among other things, in making it easy to assess whether or not all inserts are in place prior to casting the concrete slab on this decking. These two examples illustrate mistake proofing approaches that help reduce the likelihood of occurrence—though not 100% prevention—of mistakes.

Example 2: Flexible Connection to Accommodate Dimensional Variation

Figure 3 shows plumbing where the mistake proofing device is a flexible hose that solves a typical fit-up problem. At one end, the toilet bowl (commode) is seated on waste-water pipe located in the floor, and the water tank rests on and connects to that base of the fixture. At the other end, the water supply pipe runs in the wall and stubs out of it, ending with a valve. The challenge is to connect the pipe at this valve to the entry into the water tank, recognizing that all construction work that precedes this connection step is subject to dimensional variation (tolerances), that is, things do not get physically located exactly where drawings or computer models showed them to be. Rather than requiring bending of more rigid tubing or pipe and cutting it to size, a flexible hose of approximate (standard) size suits this purpose without requiring accurate measurement.

Mistake proofing devices to accommodate the manifestation of uncertainty in physical geometry (dimensions and location), and accumulation of that uncertainty as work progresses, similarly exist in other specialties. Another example is that mechanical contractors who build HVAC systems rely on flexible duct to connect rigid sheet-metal duct in plenum spaces to diffusers in modular ceiling-tile grids.

Figure 3: Flexible hose (Source: Picture by Iris D. Tommelein, Boston, MA, 2007)

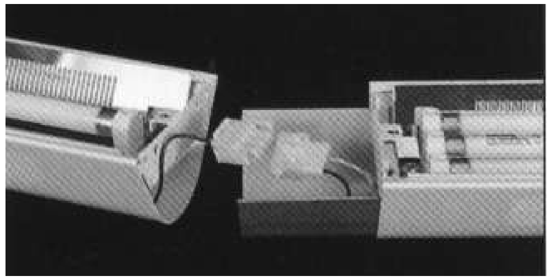

Figure 4: Connect plug and wiring of light fixtures (Source: Finelite (2001) product literature)

EXAMPLE 3: PLUGS TO ENSURE CORRECT CONNECTIONS DURING ASSEMBLY

Figure 4 shows a connect plug that ensures the correct wiring of electrical light fixtures and that, furthermore, greatly simplifies the work otherwise required of a skilled field electrician (Finelite 2001, 2008, Tsao and Tommelein 2001). The challenge is that custom-wiring of light fixtures on site requires meticulous attention (avoid cross-wiring) and work overhead. The plugs for each fixture are wired off-site in a shop environment, leaving only final assembly to be done on site. The plug allows for only one way in which to connect adjacent fixtures together. A minimal investment in plugs and shop assembly thus result in a safer, less error-prone, and faster process overall.

EXAMPLE 4: PLUGS TO ENSURE CORRECT MAINTENANCE

Figure 5 shows a connect plug installed in the power supply to a ballast, which is a component in a light fixture used to stabilize the current flow. All wires related to the ballast fits into the fixture and wiring can be done off site. Until recently, all this wiring was continuous; new code requires the use of the plug as described. The challenge is that maintenance personnel, who must disconnect the ballast from the electrical circuit prior to working on it, at times would not disconnect all wiring properly and thus risk electrocuting themselves. The mistake proofing device is a brightly colored plug that is easy to unplug and plug back in (Figure 5). A sticker (Figure 6) on the outside of the light fixture but out of sight for people occupying the room informs maintenance personnel that this feature is present in that fixture. A minimal investment in plugs wired during off-site assembly of the fixture thus results in a safer, less error-prone fixture maintenance process.

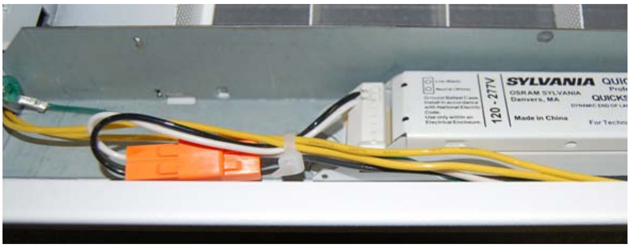

Figure 5: Wiring plug for ballast inside light fixture (Source: Picture by Iris D. Tommelein taken at Finelite, Union City, CA, 2008)

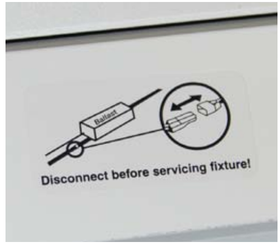

Figure 6: Instruction label on outside of fixture (Source: Picture by Iris D. Tommelein taken at Finelite, Union City, CA, 2008)

MISTAKE PROOFING A PRODUCT DESIGN FOR CONSTRUCTABILITY AND LIFE-CYCLE PERFORMANCE

Mistake proofing can be done in design. The following examples illustrate how a product was designed and engineered for constructability while targeting life-cycle performance.

EXAMPLE 5: SEALANT TO ALLOW LIMITED COMPRESSION

Figure 7 shows the cross-section of a metal roof, where two roof panels are joined. The challenge is to make a seam that is watertight. This is particularly important to the manufacturer of these roofing products who guarantees long-term performance (e.g., 20 years if not more) of their installed products and wants to maintain their brand-name reputation. This manufacturer studied the performance of installed roofs and found that the sealant between panels was not always of consistent and adequate thickness. Either the panels had not been tightened sufficiently (uneven thickness), so the sealant left gaps through which water could penetrate, or the panels had been tightened too much (minimum thickness not met), so the sealant had been squeezed out, leaving too little material to be effective. This sealant is a mistake proofing device that curbs variation in the system.

To mistake proof the tightening process, the manufacturer co-developed with their supplier a new sealant product, in which tiny but hard cubes are embedded and more-or-less evenly distributed. The dimension of these cubes is commensurate with the optimal thickness of the sealant application. As a result, contractors need no longer worry about overly tightening their fasteners: the minimum thickness of the sealant is guaranteed.

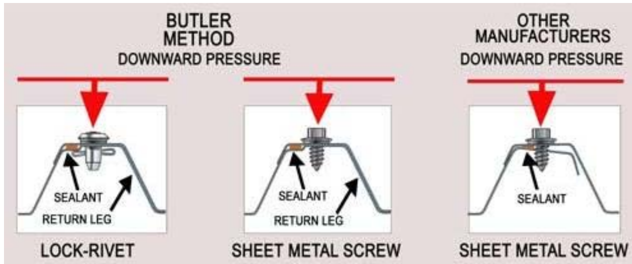

Figure 7: Sealant and return leg to guarantee roof performance (Source: Butler manufacturing product literature)

EXAMPLE 6: OVERLAPPING MATERIAL TO ACCOMMODATE DIMENSIONAL VARIATION

Figure 7 also shows a 'sealant pocket' and a return leg on each overlapping panel made by this manufacturer to further ensure that the joined roof panels would be water tight.

MISTAKE PROOFING THE DESIGN OF A SYSTEM

The last example illustrates how designers may use mistake proofing as a means to accommodate a variety of competing requirements from users while recognizing that dimensional variation will occur during construction, and mistakes could occur as well. Consider designing and constructing a restroom facility with sinks (wash basins). The challenge with such facilities is that (in no specific order of value): (1) the plumbing must be functional (i.e., the sink drains into a pipe with a water lock); (2) designers and users may want sinks to be aesthetically pleasing; (3) the sink height must be convenient for hand washing; (4) in the United States, public restroom facilities must meet American with Disabilities Act (ADA) requirements (this act basically states that people with disabilities just like everyone else must be able to use such public facilities); and (5) the floor must slope slightly to allow water to run to a drain for ease of cleaning the floor.

To complicate the situation, design drawings showing the layout plan view of a restroom may not accurately reflect the slope of the floor towards the drain (Figure 8). A builder may have to pull information together from different drawings and sections in the specifications in order to develop a clearer 3-dimensional picture of the situation (Figure 9). Because of this slope, when the designer selects sinks with an apron to hide plumbing behind it, the clearance between the bottom of it and the floor will vary in the room. As a result, some clearances as shown in the design may meet the ADA requirements whereas others in the same room will not. Add to that the effect of tolerances that will manifest themselves during construction and it becomes less likely that clearances will suffice (Figure 10). It is no wonder then that quite a few facilities get built but fail to meet ADA requirements, and following inspection thus require rework prior to commissioning.

Practitioners are aware of these challenges (conflicting values) and have developed various solutions in response. Figure 11 shows a 'bare' sink with 'ugly' plumbing underneath of it. Figure 12 shows an architecturally more pleasing solution, however, this one would not meet ADA requirements.

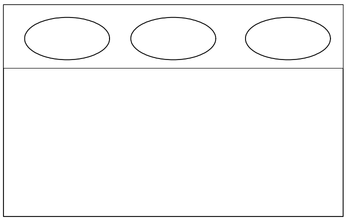

Figure 8: Sketch with Plan View of Sink Layout

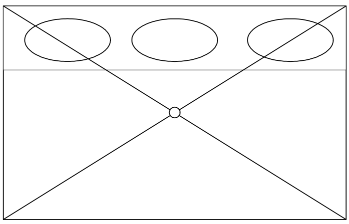

Figure 9: Sketch with Plan View of Sink Layout with Sloping Floor and Drain

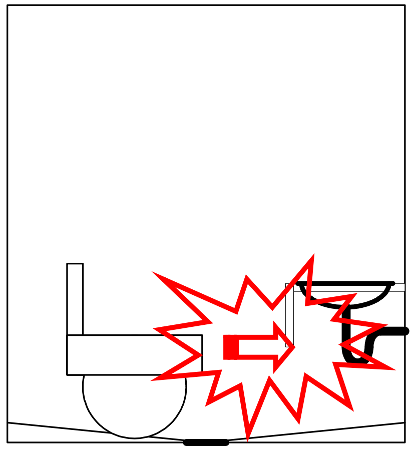

Figure 10: Sketch with Side View of Sink, Drain, and Exaggerated Sloping Floor

Figure 11: 'Bare' Sink in San Francisco Airport, California (© 2006 Iris D. Tommelein)

Figure 12: 'Dressed-up' Sink in Mich. State Univ. Conf. Center, East Lansing, Michigan (© 2007 Iris D. Tommelein)

Figure 13 shows another way of covering up the plumbing, but it is unclear if this solution would meet ADA requirements. Figure 14 presents a solution that acknowledges the challenge. Here, the apron is cut back to ensure sufficient clearance, at least in a few locations.

Figure 13: Sink with Covered Apron in Brussels Zaventem Airport, Belgium (© 2007 Iris D. Tommelein)

EXAMPLE 7: HINGED CONNECTION TO ALLEVIATE IMPACT OF TOLERANCE ACCUMULATION

Finally, figure 15 shows a solution designed with mistake proofing in mind. Here, a section of the apron is cut and attached from the top using a hinge, so that it can turn up when the need arises. This need may stem from the drain not being located exactly where it was designed to be (in height or in horizontal position relative to the drain), the floor not sloping exactly as shown in the design, the apron not being perfectly horizontal, etc. The hinged section is clearly marked with a handicapped sign to help restroom users and to point out to inspectors that ADA requirements have been met.

Figure 14: Sink with Cut-out Apron in San Francisco Airport, California (© 2007 Iris D. Tommelein)

Figure 15: Sink with Adjustable Apron at Oakland Airport, California (© 2004 Iris D. Tommelein)

The example in figure 15 like that in figure 3, showed the use of a mistake proofing device (flexible hose or duct, and hinged apron) to 'buffer' or alleviate the impact of variation. Unlike other mistake proofing devices, these do not in-and-by themselves prevent or reduce the occurrence of variation in the system.

SUMMARY

This paper described the concept of mistake proofing and illustrated how it applies to the AEC industry by drawing on examples from current practice. These examples showed not only that but also how mistake proofing applies to various project delivery phases in this industry. The examples illustrated that mistake proofing can be practiced within a specialty (e.g., plumbing, electrical, or mechanical work), it can be practiced by designers, manufacturers, or fabricators to benefit a product as it is being constructed or throughout its lifecycle performance, or it can be practiced by designers to benefit a system (e.g., assembly of multiple components by multiple trade specialists).

AEC industry researchers and practitioners are not taking advantage to the extent they could of opportunities to mistake proof their processes and products. This paper was written to help people see where opportunities may exist for mistake proofing, to help them gauge what value may stem from it, and to sharpen everyone's thinking about opportunities to mistake proof AEC products and processes.

Mistake proofing is an active area of research that falls under the Built-in Quality Initiative of the Project Production Systems Laboratory (P^2SL) at the University of California at Berkeley, California. In pursuit of this research, broadening theoretical understanding and use of this lean concept in the AEC industry, we would appreciate receiving your examples of and thoughts on mistake-proofing practices. Please email pictures of examples with a description to tommelein@ce.berkeley.edu. We will gratefully acknowledge all contributors and add selected submissions to those already posted at http://p2sl.berkeley.edu/pokayoke/. This website has been set up to grow into a community knowledge base to promote lean thinking.

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