

## Improving Productivity through Mistake-proofing of Construction Processes

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**Abstract.** Construction defects are always the key concern of the construction industry. Research shows that, the estimated costs of rework for residential construction are almost equal to 4-5% of contract value. One of the successful devices in lean production to eliminate waste caused by errors is ‘mistake-proofing’ or ‘Poka-yoke’. Mistake-proofing is one of the effective approaches that prevents inadvertent errors and helps workers to be mistake-proof and does not allow defective products to flow to next processes. In this paper, application of Poka-yoke to construction industry is investigated. The results show that the construction operations have high potential of mistake-proofing, and therefore the application of Poka-yoke devices can finally lead to drastic promotion in construction industry. At last section, a case study related to the simple operation of a trolley hoist also conducted to evaluate productivity improvement due to the process mistake-proofing in practice.

**Keywords:** Construction process, mistake-proofing, productivity improvement.

### 1. Introduction

Construction defects are always the key concern of the construction industry. Different constructed facilities generate different types of defects and demand different levels and types of quality, depending on the functions, system types, and materials used. Once a defect occurs, and it is rectified then this can be known as rework, which is defined as the unnecessary effort of redoing an activity or process that was incorrectly implemented the first time [1]. Estimated rework costs for residential construction have been reported to be almost 5% of the contract value [2, 3], and unfortunately, this is acceptable as the nature of construction industry.

Lean construction is a management philosophy with new methods, which decreases the cost of construction through its techniques, methods and concepts. Actually, lean construction is transplantation of lean production philosophy, which is a series of cultural and technical changes, into the construction industry after its successful implementation in Toyota Motor Company. Mistake-proofing or Poka-yoke is one of the effective lean production concept that follows the goal of preventing inadvertent errors and incorrect performance by workers. This concept provides great opportunities to bring quality into project delivery and also frees workers from tedious recurring job and increases safety in construction sites.

Applying mistake-proofing methods to the construction processes is the main purpose of this paper. The research may help contractors to manage their sites more effectively. Finally, an innovative and simple example of mistake-proofing implementation is explained through a case study.

### 2. Mistake-Proofing of Production: A Successful Method to Prevent Defects

Shingo [4], a main manager of the Toyota Production System, introduced the concept of ‘Poka-yoke’ in Japan, translated as ‘mistake proofing’ in English. His objective was to eliminate or minimize the

requirement for inspection (which is believed as waste in lean philosophy) by eliminating errors before they occur rather than detecting and mending activities which simply make it fall under unfavorable category of “rework”. In another word, mistake-proofing is an interference device to determine whether the product is of acceptable quality or not.

Some simple examples of mistake-proofing devices exist in everyday life (for instance, the tethered gas cap which prevents you from leaving it behind, or a 3.5 inch diskette which can only be inserted if oriented correctly) [5]. In production, mistake-proofing is implemented using simple objects like fixture, jigs, warning devices, color coding. For instance of color-coding, according to diameter, length and kind of application, the color of nails or screws can be varied in order to minimise the error occurrence. This method releases the worker’s mind from concentrating which is necessitated to distinguish between nails or screws. Consequently, he/she can do their job with more confidence and calmness. In addition, the amount of time that workers spend daily on distinguishing the size of the nails and screws is a significant amount of time. This can be saved by applying the simple methods of mistake-proofing.

### **3. Importance of Mistake-Proofing implementation in Construction**

Research shows that the unwanted cost of rectifications in buildings is about 4-5% of the total construction value [2], [3]. Many things can go wrong in the complex environment of the construction workplace. Everyday, there are possibilities to make mistakes that will result in defective product and dissatisfaction of the users at the end of the production line or even an accident that could threaten the workers health and safety. In construction industry, because of complexity of work and variability of items and environment, we tend to accept the mistakes as natural and an innate part of the work. This kind of attitude makes the construction process likely to overlook defects. These defects may be detected only in final inspection or, worse yet, by the users.

Furthermore, a large portion of defects lies in the workers’ errors, and defects are the result of neglecting those errors. While only workers are considered as responsible to provide quality (regardless of the working environment), a twofold problem will emerge that will lead to failure in the realization of the goals: people ‘don’t know how’ and ‘don’t care’. Sometimes errors happen by a naive worker who does not know how to work correctly. This attitude ‘don’t know how’ could be rectified by training which could increase awareness of workers toward working with quality to prevent defect in the process. Negligence of workers increases the chance of penetrating an error into the process and results in defect on the final product.

Besides being forgetful, people often don’t intentionally make mistakes. Most often, the problem is a poor process design. Many researchers have concluded that designers take the most important role in eliminating defects [6, 7]. Inadequate information, unawareness, wrong assumptions, and lack of knowledge, along-side other organizational and motivational factors, are also identified as contributory factors to defects at the design stage [8]. Hence, another approach to the goal of zero defect products is to design the process and site environment in a fashion which no defect could possibly happen. Mistake-proofing concept is also used in the product design process meaning designing that cannot be physically assembled incorrectly.

### **4. How can make the construction processes mistake-proof**

True mistake-proofing devices should be small, low cost, simple, and are directly integrated into various stages of the construction line. The importance is to find defect and problem in the current work process and find ways to prevent the problem happen again. Poka-yoke’s priority is to prevent defects from occurring in the first step by correcting the condition of work so the product could flow correctly in value stream. A good mistake-proofing device is one that requires no attention from the worker. For example, one of the most important mistakes in reinforcement operations is to deliver, cut or bending the rebars with wrong size. To prevent this kind of mistakes, one of the mistaking-proofing methods is coloring the end of bundled bars in to avoid misuses.

To achieve mistake-proofing concept in a construction site, zones where are prone to error should be identified. These mistakes could be quality problems, delay in delivering a mid-process product, safety issues and so on. By tracking where the problems locate, the project manager could place his/her attention on

investigating and resolving the problem, and implement the mistake-proofing device to prevent recurrence of problems in the future. There are six of main mistake-proofing principles listed in order of preference in fundamentally addressing mistakes: (1) *Elimination* seeks to eliminate the possibility of error by redesigning the product or process so that the task or part is no longer necessary; (2) *Replacement* substitutes a more reliable process to improve consistency; (3) *Prevention* engineers the product or processes so it is impossible to make a mistake at all; (4) *Facilitation* employs techniques and combining steps to make work easier to perform; (5) *Detection* involves identifying an error before further processing occurs so that the user can quickly correct the problem; (6) *Mitigation* seeks to minimize the effect of errors.

## 5. A case study

Electrical trolley hoists are widely used in mid-size (2-7 story) building construction. The hoist is usually mounted at the top of the structure in order to transfer material or equipments to/from different floors. Figure 1(a) illustrates a schematic representation of a trolley hoist process. In this section, after describing traditional trolley hoist process, mistake-proofing of the process is explained.

The traditional process includes loading (material or equipment) at source, hauling to destination, manually adjusting the position of the hoisted load, and disposing on the target. As shown in Figure 1(a), the crew usually consists of at least three workers: worker *A* loads the bucket on the ground. Worker *B* is located at the base (i.e. the mounting level) to control the hoist, and worker *C* stands on the target floor to dispose the material. Worker *B* is involved in starting and stopping the engine, as well as moving the engine horizontally along the boom. Thus, the first observation is that worker *B* is mostly idle while the other two workers are busy. In addition to this idle time, it is evident that communication and coordination between the three workers may turn into an almost impossible task. This is mainly due to the ambient noises and failure to set a reliable communication means that may result in serious injuries. Therefore, mistake-proofing of the trolley hoist process not only can lead to productivity improvement but it also has a great potential to improve workers' safety on a construction jobsite.

### 5.1. Mistake proofing the process

As shown in Figure 1(b), in order to mistake-proof the process, one simple solution can be achieved by omitting worker *B* and instead, providing worker *A* with a remote control. This scheme has several advantages such as: (1) Worker *B* is released and made available to create more value-adding activities, (2) The idle time for worker *A* is reduced, (3) Less communication between workers is needed, (4) Operational complexity is reduced, (5) Safety of worker *A* is improved since he is now in control of lowering and lifting the bucket and knows exactly the bucket location. Figure 2 depicts the flow of activities of a trolley hoist process in both traditional and lean approaches. It also determines the value-adding and non value-adding activities in each process.

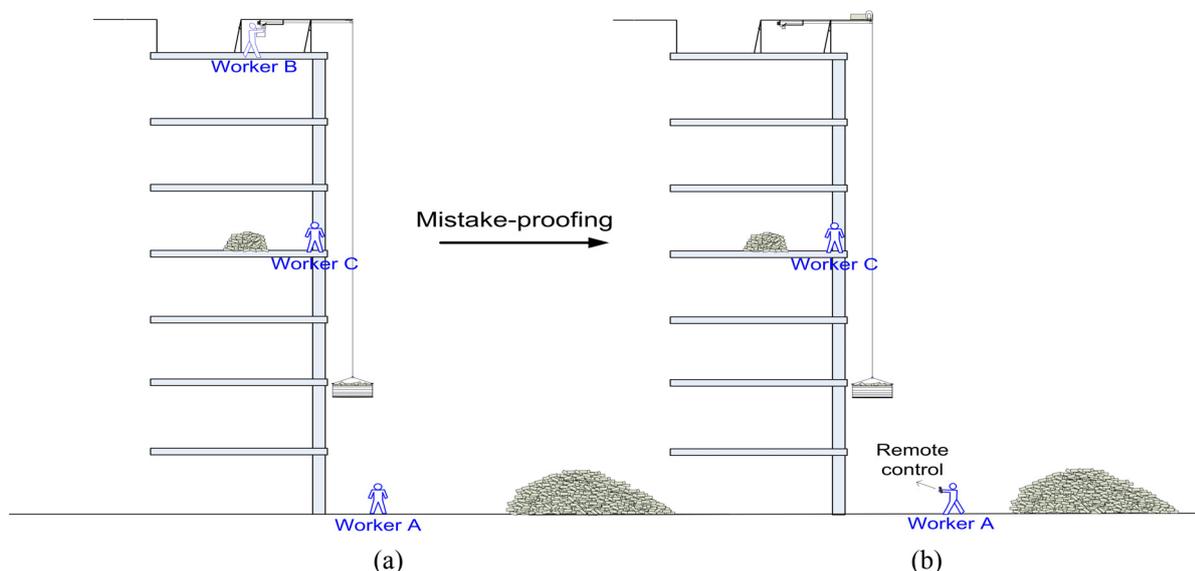


Fig. 1: A schematic view of a trolley hoist process (a) traditional, and (b) lean

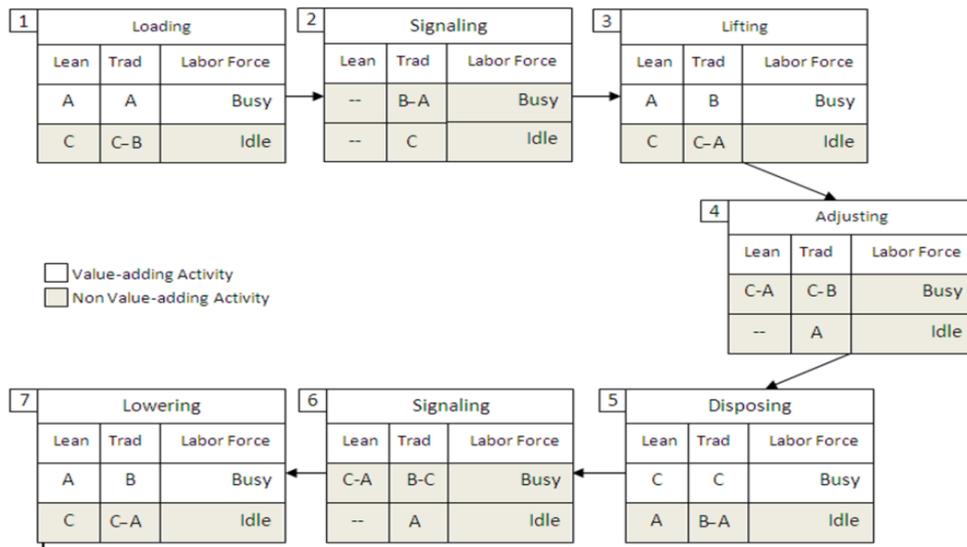


Fig. 2. Flow of activities of a trolley hoist process in both traditional and lean approaches

The effectiveness of the modified trolley hoist process using lean approach was validated in an actual 6-story residential building construction project. A trolley hoist was mounted on the top of the building to haul bricks from the ground level to the fourth floor. The trolley bucket volume was measured to be  $0.3 \text{ m}^3$  and was assumed to remain constant for the entire duration of the project. The trolley crew consisted of three workers operating in a traditional process cycle. Timing data was collected for 50 operation cycles over the course of four days. The collected data included activity durations, idle time for each worker, and cycle times. Using this data, cycle man-hours, time spent on value-adding activities in each cycle, and productivity percentage for each cycle were also calculated. Subsequently, the lean-based trolley hoist process was introduced and used on the fifth day. As a result, only two workers were assigned to the trolley hoist operation and worker *A* was equipped with a remote control to control the movements of the trolley hoist. The same set of data was collected for 50 operation cycles over a period of four days.

Construction productivity can be measured using Single Factor Productivity (SFP) if labor is the only input factor used in the calculations [9]. In this study, the SFP method was used by taking labor as the main factor influencing the performance and productivity rates. It must be noted that by defining labor productivity in form of Equation (1), a lower productivity value corresponds to a better labor performance.

$$\text{Labor Productivity} = \frac{\text{Input}}{\text{Output}} = \frac{\text{Actual Work Hours}}{\text{Installed Quantity}} \quad \text{Equation (1)}$$

Table 1. Results analysis for both traditional and lean processes

Type of Process	Activity Duration (S)							Total Duration (S)	Total man-hours (hrs)	Value-Adding man-hours (hrs)	Value-Adding percent	Productivity (man-hours/ $\text{m}^3$ )
	1	2	3	4	5	6	7					
Traditional	12365	360	556	375	5742	328	482	20478	17.07	5.4	32	1.14
Lean	12208	0	555	55	5735	119	495	19167	10.65	5.28	50	0.71
Improvement (%) ⇨								<b>6.4%</b>	<b>39.8%</b>	<b>-2%</b>	<b>18%</b>	<b>37.5%</b>

Measured productivity values in both traditional and lean processes are summarized in Table 1. Although both methods listed in this Table still consist of the same set of activities, the portion of cycle time spent on

non value-adding activities (e.g. Waiting, Signaling, Adjusting, and Correcting mistakes) and the number of workers used in mistake-proofed approach both decreased. As shown in Table 1, the time spent on non value-adding activities (i.e. activities 2, 4, and 6) using the traditional approach was noticeably reduced in the mistake-proofed process and caused a 6.4% reduction in the cycle time (hence improving productivity by 6.4%). This reduction was a direct result of faster adjustment of the hoisted load (i.e. full bucket) at the target point due to the elimination of unnecessary verbal communications between the workers in the lean approach. At the same time, using one less worker in the mistake-proofed process decreased the total man-hours by almost 40%. Mistake-proofing the operation also improved the time spent on value-adding activities (i.e. activities 1, 3, 5, 7) by 18%. In conclusion, by introducing a mistake-proofed approach into the trolley hoist process, the overall productivity was increased by 37.5%.

## 6. Conclusion

Mistakes-proofing involves a change in the mindset of an organization as first the belief that “it is unacceptable to allow for even a small number of product or service defects” must be promoted and accepted by the employees. The concept of *Poka-yoke* can be applied to virtually every type of project by exploring ways to present how an activity is supposed to be done, make it impossible to do it incorrectly, or make it obvious (known) when it has been done incorrectly. *Poka-yoke* devices are categorized by three attributes: smartness, simplicity and inexpensiveness. Mistake-proofing also releases workers from tedious and repetitive activities while giving them an opportunity to maximize their roles in building quality, in the process, by decreasing product deficiencies and the related cost of rework.

A case study was conducted in an actual building project in which a trolley hoist was used to haul bricks between the ground level and various floors. The case study demonstrated that with a small investment, a simple poka-yoke technique can bring about a drastic change in productivity. Noticeable improvement in the trolley hoist process due to the application of lean-based approach not only did save a remarkable amount of project time and cost in a period of a few days, but also reduced the time spent on non value-adding activities which are considered “waste” in lean thinking. While this case study only took into account a relatively small portion of a larger building construction project, it is conceivable that the methods and techniques discussed in this paper have high potential of mistake-proofing in construction processes through the use of (even small and simple) *poka-yoke* devices. Therefore, it can ultimately lead to significant improvements in overall project productivity in a long term.

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