Lean and Safety Manual

for Electrical Construction

Hyun Woo Lee, Ph.D.
John Gambatese, Ph.D.
Yong-Woo Kim, Ph.D.
Mohammad Sadra Fardhosseini
Jamie Stuart
Chris Reigelsperger

SHIP Grant Program
Safety and Health Investment Projects
SafetyGrants.Lni.wa.gov
Funding and support provided by the Department of Labor & Industries

Advisory Committee Members

Lyle Eiseman, Director of Lean, Mortenson

Ed Adams, Electrical Administrator & Operations Manager, MacDonald-Miller

Clint Valiton, Vice President, OEG

Jeremy Taylor, EH&S Director, Turner

Jeff Anderson, Seattle Regional Lean Manager, Turner

Robert J. Penney, Continuous Improvement Director, Skanska

Mindy Uber, EHS Director, Skanska

Ken Gulezian, Safety Director, Titan Electric

Front cover photo credit: Sadra Fardhossein

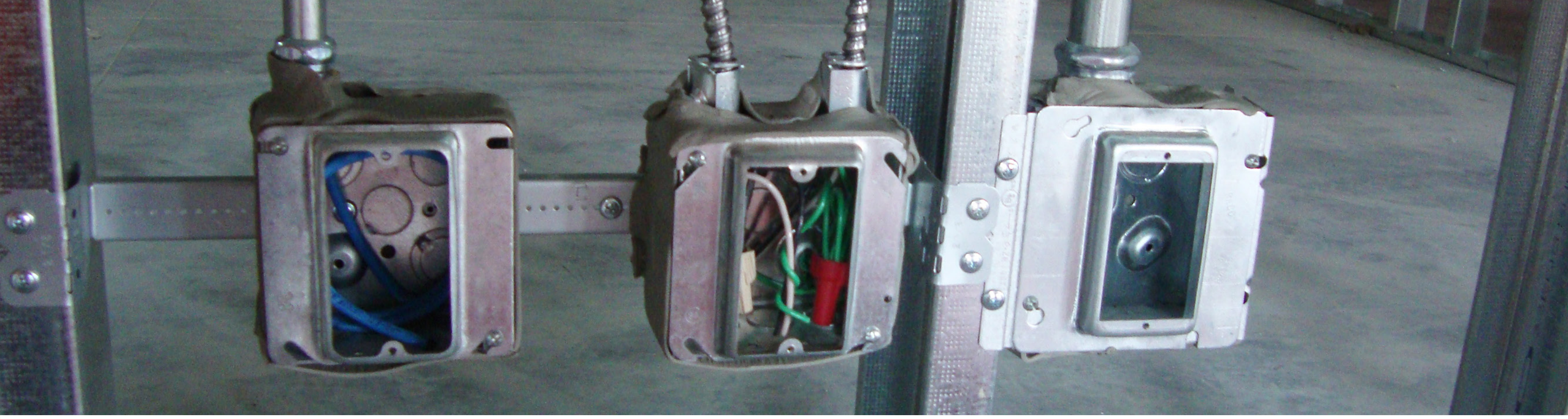


Photo credit: Hyun Woo Lee

Introduction

Lean construction is a comprehensive management approach that aims to enhance value on construction projects and eliminate waste through project lifecycles. The lean approach strives to "develop and manage a project through relationships, shared knowledge, and common goals."[1] A large number of studies have reported the effectiveness of lean practices in optimizing production on construction projects by improving productivity, eliminating waste, and increasing value delivered to customers. As a result, lean construction has gained significant interest from the US construction industry in the last couple of decades.

Initially, lean construction focused mainly on production management; in recent years, the construction industry has begun to realize that the lean approach can also be beneficial for improving worker safety.[2] However, few studies have been done to evaluate the use of lean practices in terms of construction safety, and there is no formal documentation available that specifically details how lean techniques can actually be applied to reduce construction safety risks in practice. This lack of available guidelines appears to be the main barrier to the implementation of lean safety practices in the construction industry.

In response, this document, "Lean and Safety Manual for Electrical Construction," has been developed to show how lean practices and safety practices can be combined effectively to support electrical contractors. Based on interviews with industry practitioners and case studies, this manual is focused on lean techniques that have significant potential to improve worker safety. These techniques include: 5S, Last Planner System (LPS), continuous improvement, prefabrication, and 5 Whys. While the manual is specifically designed as an easy-to-use, step-by-step guideline for electrical contractors, it could prove useful to interested parties in other construction trades when implementing lean practices for worker safety.

Photo credit: Sadra Fardhossein

5S

Photo credit: iStock/emzet70

Overview

5S is an organizational approach that aims to help maintain order in the workplace using visual controls. In other words, 5S is a set of housekeeping-based rules that seek to organize work areas in order to improve efficiency and reduce potential waste.[3] Organized workplaces can lead to high quality production, with reduced safety hazards and risks.[4] 5S commonly refers to five steps:[3]

1. **Sort:** remove clutter and unused items and then sort items that are used frequently so that they are accessible and easy to find when needed.
2. **Set in Order (Storage):** arrange materials and equipment in an orderly fashion in order to make jobs easier to perform; for example, define a place for everything, eliminating wasted worker motion.
3. **Shine/Sweep:** keep work area and equipment clean in order to reduce waste.
4. **Standardize:** standardize the first 3S steps throughout the work area by implementing clear procedures.
5. **Self-Discipline/Sustain:** maintain the 5S by integrating them into the organization's culture through training, promotion, and control.

5S is one of the most significant lean techniques, which if used effectively at project sites, can lead to safe work environments. Safety is so intertwined with 5S that some studies call it "6S."[5][6][7]

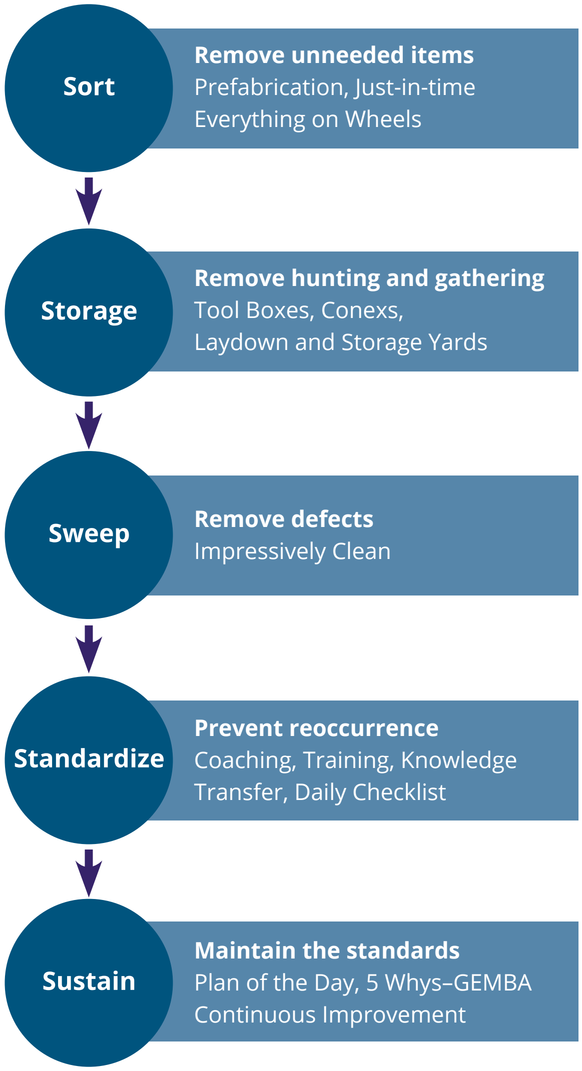


Fig. 1.1: 5S Steps

Suggested Phases

5S can be implemented successfully by a project team that aims to improve safety by organizing the workplace, keeping it clean, maintaining it effectively, and implementing standardized conditions. An effective 5S model is presented in Fig. 1.1.

Sort

The objective of Sort is to first distinguish “wanted” (necessary) items from “unwanted” (unnecessary) items in the workplace and to remove those that are unwanted. Removing the unwanted items will reduce workers’ exposure to unorganized materials and to safety hazards and risks. To this end, the project team can use tags with different colors to signify frequency of use. For example, a red tag would indicate that an item can be removed because it is used infrequently or not at all. Based on the practice in place, all items with red tags would be collected together and then the team would decide which items should go where. A yellow tag can indicate an item which might need safety considerations. Fig. 1.2 presents a summary of the Sort phase.

The Just in Time (JIT) technique can be implemented to support the Sort phase. JIT is a lean technique in which a systematic approach is used to produce or deliver the right amount of parts or products at the right time as they are needed. This technique prevents items from stockpiling at the jobsite and therefore helps to prevent unnecessary handling of stockpiled materials.

The following benefits can be expected when implementing the JIT technique:

- Ergonomic hazards, such as back injuries, can be reduced. For example, using barcode tags, workers can find exactly where to deliver equipment.
- Slip, trip, and fall hazards can be reduced when items and equipment are not stockpiled at the job site.
- Workers are less exposed to equipment, resulting in reduced struck-by hazards.

In addition, the everything-on-wheel rule can help further prevent ergonomic hazards by supporting both the Sort phase and JIT (Fig. 1.3).

Why:	To remove unwanted items
How:	When in doubt, throw it out
Purpose:	To distinguish “wanted” items from “unwanted” items in the workplace and then remove those items that are unwanted.

Fig. 1.2: Sort Phase Summary

Photo credit: Hyun Woo Lee

Photo credit: Mortenson

Fig. 1.3: Just In Time – Kitted Lighting Fixture Carts (Assembled off site, delivered on wheels, and taken to installation locations)

Implementing the Sort phase in the workplace can lead to easy storing, error reduction, and reduced search time, all of which can improve safety. In general, the following steps help to successfully perform the Sort phase:

- Ask workers from different trades about defective tools and equipment and outdated/ unnecessary items on site.
- Specify the use-frequency of items or tools (e.g., daily, weekly, monthly)
- Adopt a tagging technique (e.g., red tag for unnecessary items and yellow tag for items of safety concern). Removing tagged items needs to be verified before taking action. See Fig. 1.4 for color coding based on trades.
- Temporarily store items that are difficult to classify.
- Reduce the amount of materials and equipment on the site to the minimum amount required
- Develop a disposal procedure that includes reuse, resale, recycling, and waste disposal.

Set in Order (Storage)

The objective of this phase is to store items in an appropriate and easy-to-find manner to prevent any unnecessary time searching for them. This phase allows workers to not only improve their operation efficiency, but also enhance their safety. To store items in a safe manner, the following three main questions must be asked: 1) What items to position, 2) What quantity, and 3) Where to place items accordingly. Fig. 1.5 presents a summary of the Storage phase.

Implementing this phase will lead to neat storage of items, and the reduction of human errors and time taken for searching, both of which improve

Photo credits: Mortenson

Fig. 1.4: Color coding the materials on site with paint sprays, based on trades

Why:	To eliminate time taken for searching
How:	Designate a place for everything
Purpose:	To arrange items in a manner such that they are found easily

Fig. 1.5: Storage Phase Summary

safety. Fig. 1.6 shows some examples of Set in Order in practice. In general, the steps to successfully perform Set in Order are:

- Store items in available and navigable spots (allocated spots such as tool boxes, Conexus, lay down areas, and storage yards).
- Categorize items on the basis of their function and label them to facilitate easy retrieval.
- Limit the height of storage spaces for heavy items and materials to help workers pick up and carry them.
- Highlight potential safety hazards that workers may face in storage areas.

Sweep (Shine)

The objective of the Sweep phase is to keep the work area free of dirt, stains, filth, soot, and dust and to maintain equipment and facilities in a high level of cleanliness. In other words, any waste and foreign items should be removed to prepare the work area ready for operations. Sweeping and housekeeping can significantly reduce fall and trip hazards. The Sweep phase also involves making sure the work area is free of any hazardous material or equipment. Implementing the Sweep phase in the workplace leads to a cleaner and more pleasant environment, improves job quality and equipment lifespan, and reduces safety risks and hazards. Fig. 1.7 presents a summary of the Sort phase.

Photo credits: Sadra Fardhossein

Fig. 1.6: Set in order examples

Why:	To eliminate defects
How:	Clean and correct defects
Purpose:	To make the workplace free of dirt and stains

Fig. 1.7: Sweep Phase Summary

In general, listed below are steps to successfully perform this phase:

- Develop cleaning rules that include targets and responsibilities.
- Inspect the work area after every shift.
- Clean the work place after every shift.
- Make sure that items, equipment, and materials are cleaned and ready for use.
- Check for oil spills, excess fluids, leaks, equipment damage, worn out cables, burned out bulbs, etc.
- Set up enough lighting to identify dirt and dust easily.

Standardize

The objective of Standardize is to systematize the previous three phases—Sort, Set in Order, Sweep—and adapt them as a culture. To this end, a systematic work structure is necessary to convert these phases into routines/culture. This structure will ensure that all workers follow the same procedure and use the same names for items and the same size of signalization/floor marking, shapes, colors, etc. This structure can be implemented in conjunction with visual management that supports workers to act quickly when facing hazards. Fig. 1.8 presents a summary of the Standardize phase.

Effective communication of key information to the workforce is achieved by posting signs and labels around the job site, reinforcing safety, schedule, and quality regulations (Fig. 1.9). These visuals can help workers remember important elements for their operations, such as workflow, performance targets, and specific required actions.

Implementing the Standardize phase in the workplace leads to simplifying tasks against potential hazards, achieving consistent work practices reducing errors, and improving efficiency through visual management, all of which improve safety. In general, listed below are steps to successfully perform this phase:

- Place visual signs through the work area that remind workers of proper and improper workplace setup.
- Allocate roles and expectations of individuals' accountability to keep the culture of cleanliness.
- Employ checklists to perform routine audits and regular maintenance.

Why:	To eliminate defects
How:	Clean and correct defects
Purpose:	To make the workplace free of dirt and stains

Fig. 1.8: Standardize procedure summary

Photo credit: Mortenson

Fig. 1.9: Example of Visual Management

Sustain

The objective of Sustain is to create a workplace with a safety culture to sustain 5S practices. Meeting this objective requires the commitment of workers to a healthy and safe working environment. This phase employs other techniques such as 5 Whys (Appendix), Gemba, and Continuous Improvement (Chapter 4). Toward this goal, workers should be prepared to accept suggested improvements and employ new approaches. Fig. 1.10 presents a summary of the Standardize phase.

Implementing the Sustain phase leads to improving work procedures and teamwork, achieving a healthy and safe atmosphere, and providing safety managers with data to use for safety improvement. Listed below are factors that contribute to successful implementation of this phase:

- Communication: Make sure that workers know about required procedures and obtain feedback
- Education: Offer training and coaching
- Recognition and Rewards: Encourage workers to speak up about how procedures can be done better and reward them for their contribution
- Time: Set up a regular schedule for auditing and using safety checklists.

Why:	To maintain the set standards
How:	Create simple solutions
Purpose:	To develop a healthy and safe working environment

Fig. 1.10: Sustain Procedure Summary

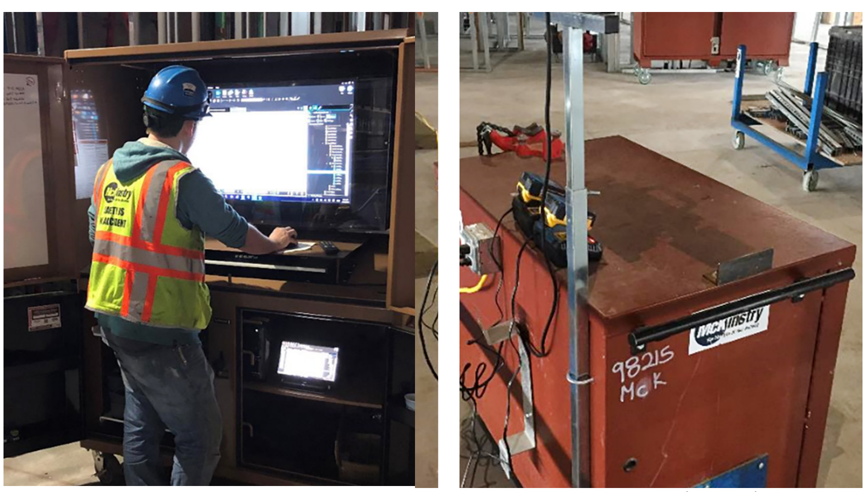


Photo credits: Mortenson

Fig. 1.11: An example of Sustain, where a contractor removed moving waste by using a workstation.

Terminology

Gemba

By seeing "how things are really done and where there is opportunity to eliminate or reduce waste"[3], Gemba aims at allowing safety managers to observe the actual work procedure, get involved with workers, gain knowledge about the work process and find opportunities for continuous improvement

Last Planner System (LPS)

Photo credit: Sadra Fardhosseini

Overview

One of the most widely used lean techniques, the Last Planner System (LPS), is a collaborative, commitment-based system that supports project teams to create a reliable and predictable production plan.[3][8] The key phases of LPS are:

1. **Master Planning:** Highlights all major milestones in a project and their corresponding timing. It accounts for an agreement between the owner and the project team, indicates the possibility of completing the project as required, and identifies major milestones.
2. **Pull Planning:** Promotes working collaboratively from a milestone backward. In pull planning, the project team defines activities and their sequences, based on downstream needs.
3. **Look-Ahead Planning:** Breaks down activities into detailed tasks to be performed in the next 3-to-6 weeks. During look-head planning, the project team also identifies and addresses constraints that could prevent upcoming tasks from starting on time. (This is called the make-ready process.)
4. **Weekly Work Planning:** Makes sure that only constraint-free tasks are on the weekly work plan. (This is called the shielding process.) The output of weekly work planning is a set of promises for the work that will be done that week.
5. **Learning:** Based on the results of the first four steps, the project team measures Percent Plan Completion (PPC) and identify the reasons identified for failure to keep promises.[3]

Terminology

Constraints
Any conditions that might prevent a task from being started on time. A shop-drawing approval is an example of a constraint.

Make-ready process
A planning process to determine how to make tasks constraint-free. Identifying constraints is the first step in a make-ready process.

Shielding process
A planning process to release only constraint-free tasks to a crew.

PPC (Percent Plan Completion)
A metric to measure planning reliability: The number of tasks completed / the number of tasks assigned.

Suggested Phases

The phases of the LPS system for safety should involve integrating safety practices, such as Job Hazard Analysis (JHA), Method of Procedure (MOP), and Pre-task Planning. Fig. 2.1 illustrates how LPS and safety practices are connected during the course of a project.

- **JHA** is a safety technique that analyzes required tasks in order to identify potential hazards and find risk-reduction solutions. A fundamental, long-range planning tool, JHA considers the relationship between the worker, the task, the tools, and the work environment to enhance project safety.[9]
- **MOP** analyzes critical activities that have significant safety implications. It involves a process analysis in completing required tasks, with potential hazards identified. The MOP process allows a project team to agree to the developed sequence and achieve the desired outcome by closely controlling each step.
- **Pre-task Planning** explores potential hazards, safe work practices, and controls in detail before starting tasks each day.

Pull Planning Process

Every 2-to-3 months, the project team gathers to develop the project's schedule for the next milestone. Fig. 2.2 present a summary of pull planning. The pull planning whiteboard is a visual tool that combines time (on the horizontal axis) and trade responsibilities (on the vertical axis) (Fig. 2.3). The milestones of the project and the descriptions/durations of the various activities are written on sticky notes of different colors, each representing the tasks of each trade. JHAs should also be discussed during the meeting.

Step 1. Working backward in time from the milestone of the phase, the project team:

- Reviews and lists all significant milestones.
- Starts from the last major milestone in the project and works backward.
- Identifies activities (what should be done) derived from the scheduled activities in the primary schedule .
- Determines when and how long each activity should be done.
- As soon as the project team develops the pull planning, the team identifies the constraints that take more than three weeks to remove.

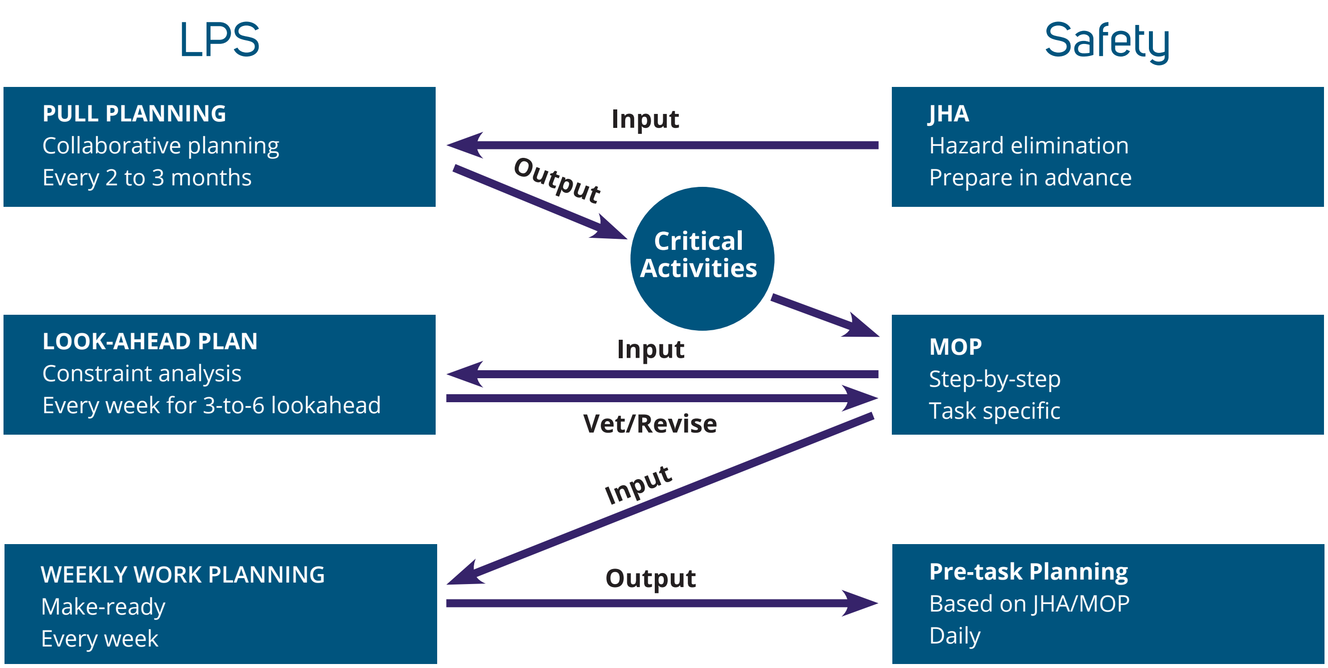


Fig. 2.1: LPS for Safety

When:	Each phase of scheduling or every 2 to 3 months
Purpose:	To develop the workflow and identify and assess safety risks in each phase
Expected Attendees:	Superintendents, project engineers, and safety managers

Fig. 2.2: Pull Planning Summary

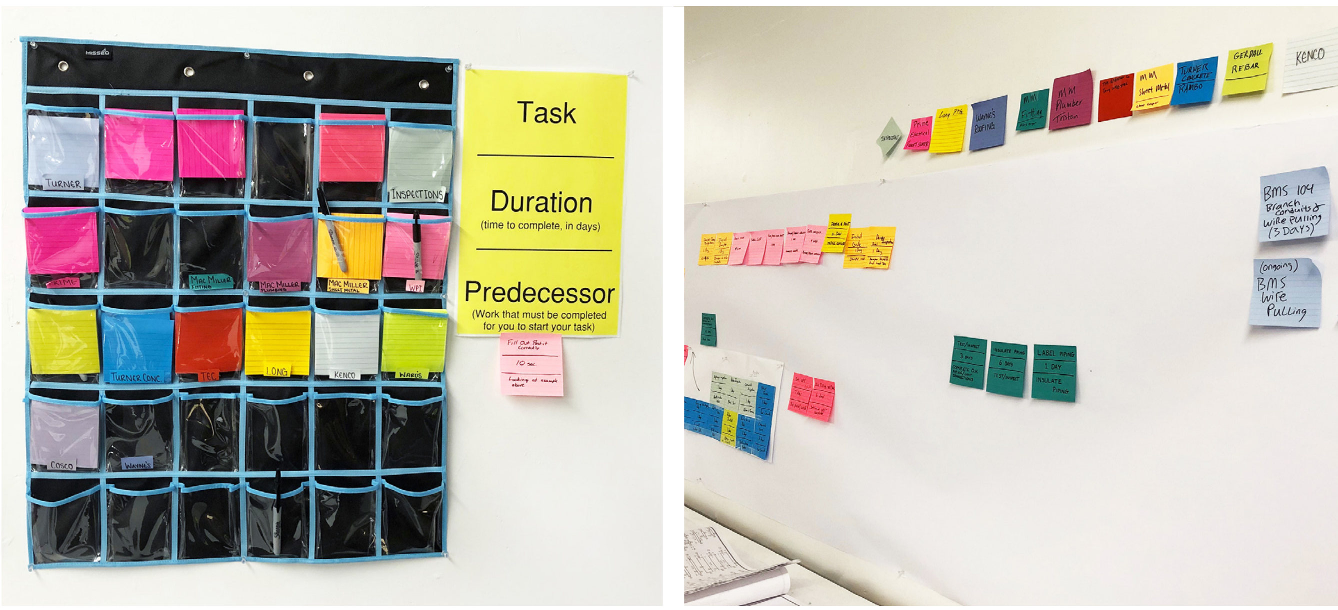


Photo credits: Sadra Fardhosseini

Fig. 2.3: Pull Planning White Boards and Sticky Notes

Step 2. The safety manager(s) on the project team needs to identify and perform safety risk assessment in terms of the likelihood and severity of potential hazards. JHAs are the most important input to this step. In particular, the team should identify and assess any critical activities that might present significant safety hazards and risks. During Step 3, the project team should:

- Review JHAs and highlight any potential safety issues (risks and controls).
- Identify critical activities.
- Set up separate meetings to perform safety planning for the identified critical activities by inviting project stakeholders who are involved in each critical activity to participate.
- Perform the MOP analysis
- Fill out an MOP form (a sample is shown in Fig. 2.4) and have it signed by all of the involved stakeholders.

Responsibility Party Completed			Detailed Steps	Steps		
Step #	Responsible Party 1	Responsible Party 2	Description of Work Operation	Date	Responsible Party 1	Responsible Party 2
			Preliminary Work Operation			
			MOP Steps for Work Actions			

Fig. 2.4: MOP Sample Form

Fig. 2.5 is a graphic depiction of the pull planning process, including safety activities. The master schedule and the list of milestones are given as the outcome of the master planning. Therefore, the team can use these data as the input for the pull planning meetings. During the pull planning session, the team collaboratively uses sticky notes and coordinates the timing of activities. Finally, a Pull Plan, a list of long-term constraints, a safety risk assessment, and MOPs of critical activities are determined. These are the outputs of the pull planning meetings.

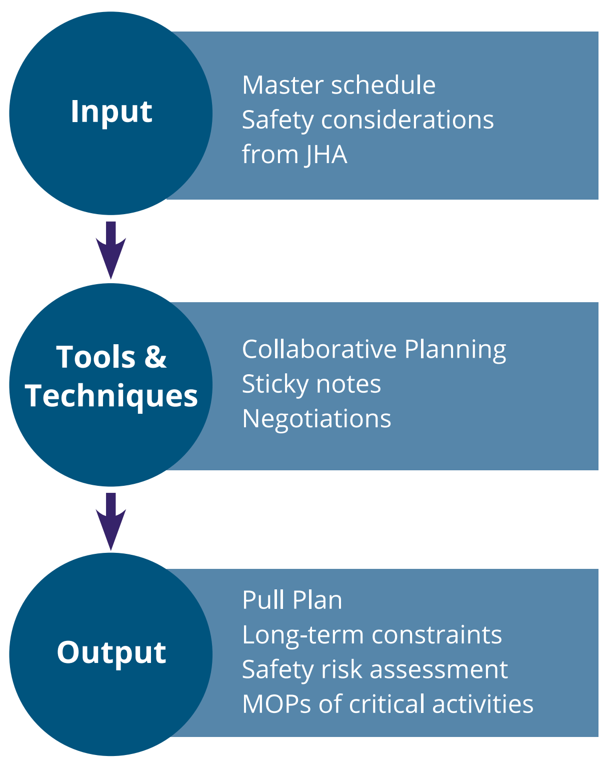


Fig. 2.5: Pull Planning Procedure

Look-Ahead Planning:

Every week, the project team should discuss the 3-to-6-week look-ahead plan to gain consensus among the team members for constraint removal. (Safety constraints identified during MOP meetings are discussed in look-ahead meetings.) MOP focuses on the safety issues of critical activities to determine how to remove any associated safety constraints from the schedule. Fig. 2.6 presents a summary of look-ahead planning.

When:	Every week
Purpose:	To develop workflow and identify constraints by make-ready process. Safety constraints identified during pull planning are to be assessed in greater detail.
Expected Attendee:	Superintendents, project engineers, and safety managers

Fig. 2.6: Look-Ahead Planning Summary

Step 1. The project team develops tasks from the pull planning for the 3-to-6-week look-ahead plan and breaks down the tasks into more detailed tasks if needed.

Step 2. The team identifies all constraints that affect those tasks. Once constraints are identified, the team determines who has personally promised that the constraint will be removed and by when. The details regarding removal of constraints are recorded in a constraint log. The status of constraint removal is tracked in every look ahead plan meeting. During Step 2, the project team should:

- Identify the constraints that prevent the implementation of each task. To this end, answering the following questions can help:
  - Is the area ready for work to be performed?
  - Is the equipment available for installation?
  - Are the materials/tools available to complete the specific portion of work?
  - Are the drawings/plans available?
  - Are safety risks and hazards properly mitigated?
- Make the constraints list the priority topic of the weekly meeting.
- Update the project schedule created by the team in order to demonstrate milestone dates as planned, or revise them if needed.

Step 3. The safety manager(s) should lead the team discussion to identify safety constraints based on safety risk assessments and MOPs developed during the pull planning. The team should determine the level of action in order to:

- Identify the safety constraints of critical activities based on MOP meetings
- Eliminate the constraints
- Mitigate the likelihood of the constraints
- Mitigate the impact of the constraints

The status of actions on safety constraints should be tracked in every look-ahead plan meeting. Fig. 2.7 shows an example of a look-ahead constraint log form that can be used to track the status of safety constraints associated with each activity. On the form, the project team records the types of

Activity ID	Activity Description	Planned Start date	Person in Charge	Constraints								Date Required	Promise Date	Status
				AE Complete	Submittals	RFI's	Materials	Labors	Equipment	Prerequisites	Safety			

Fig. 2.7: Look-ahead Constraint Log Form Sample

constraints applicable to each activity along with a project team member responsible for addressing each constraint, the date required, and the status as of the current date.

Fig. 2.8 shows a summary of look-ahead planning, including safety activities. The phase pull plan, project status, safety risk assessment, and MOPs serve as the input for the weekly look-ahead meetings. In the look ahead meetings, the project team analyzes constraints and makes tasks ready to be assigned in the main schedule. The look-ahead planning and constraint log are the outputs of the look-ahead meetings (Fig. 2.8). Fig. 2.9 shows a project team conducting a look-ahead meeting.

Weekly Work Planning

Weekly work planning is a process that assesses each task's readiness and safety criteria to make sure only workable and risk-free tasks are included on the list of available activities for each week. The representative of each trade needs to confirm his or her tasks by explaining the work to be performed, the number of days required, and the constraints that must be removed before the task can begin and be completed without disrupting the workflow. This conversation at the beginning of the weekly work planning meeting promotes a better understanding of task commitments for all participants and helps them achieve a reliable plan. The risk-free tasks are ready for pre-task planning at the start of each shift prior to implementing significant tasks. The team reviews the planned tasks and their associated safety risks and hazards. The pre-task planning aims to find alternative work plans to remove the identified hazards, or at least minimize their impacts. Fig. 2.10 present a summary of weekly work planning.

Step 1. The project team makes sure that all constraints, including safety constraints, are removed before finalizing weekly tasks. During Step 1, the project team should:

- Review all of the previous week's planned activities. The sticky notes of the completed tasks can be taken down. The team should set new completion dates for the tasks that were not completed in the previous week.
- Label the risk-free tasks that are ready for pre-task planning prior to performing them.

Fig. 2.11 shows an example of a short-term production plan form that can be used for weekly work planning.

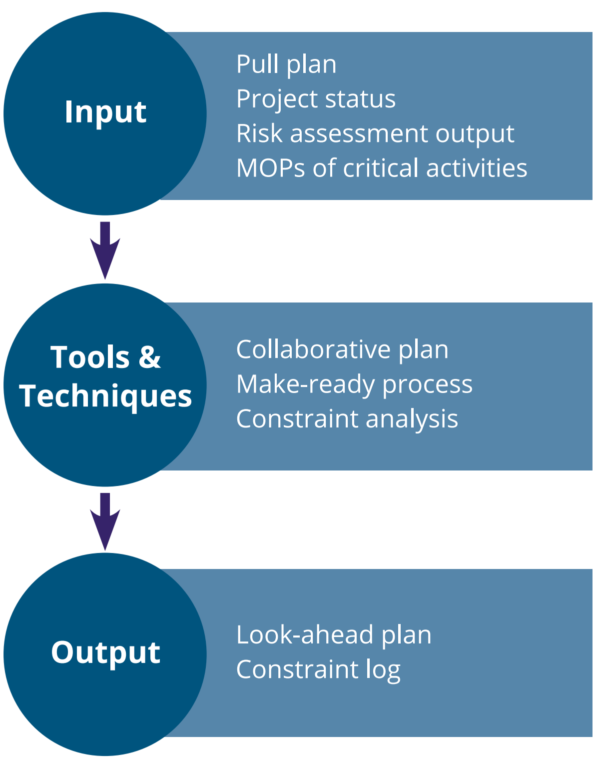


Fig. 2.8: Look-Ahead Planning Procedure

Photo credit: Sadra Fardhosseini

Fig. 2.9: Look-Ahead Meeting

When:	Every week (weekly work planning can be concurrently carried out with look-ahead planning)
Purpose:	1) To make commitments for each trade's planned tasks by confirming the removal of constraints; 2) To make sure the planned action on each safety constraint is properly executed before releasing each task to a crew; and 3) To prioritize safety inspections on weekly tasks
Expected Attendees:	Project team's superintendent, project engineers, foreman, and safety managers.

Fig. 2.10: Weekly Work Planning Summary

Short-Term Production Plan

	Monday	Tuesday	Wednesday	Thursday	Friday
Last Weekly Work Plan [N-1]	DATE				
Weekly Plan[N]	DATE				
Lookahead Plan[N+1]	DATE				
Lookahead Plan[N+2]	DATE				

Plan Reliability(PPC)		Make Ready Performance (PCR)	
#Task Completed		#Planned Tasks in [N+2] Two wks Prior	
# Task Assigned		#Planned Tasks in [N] This Week	
PPC			

Fig. 2.11: Short-term Production Plan Sample Form

Step 2. The safety manager(s) on the team should prioritize weekly tasks that require special attention based on the constraint log and MOPs.

Fig. 2.12 summarizes the process of weekly work planning, including safety activities. In the meetings, the project team can work together to carry out the shielding process, resulting in the weekly work plan and constraint log.

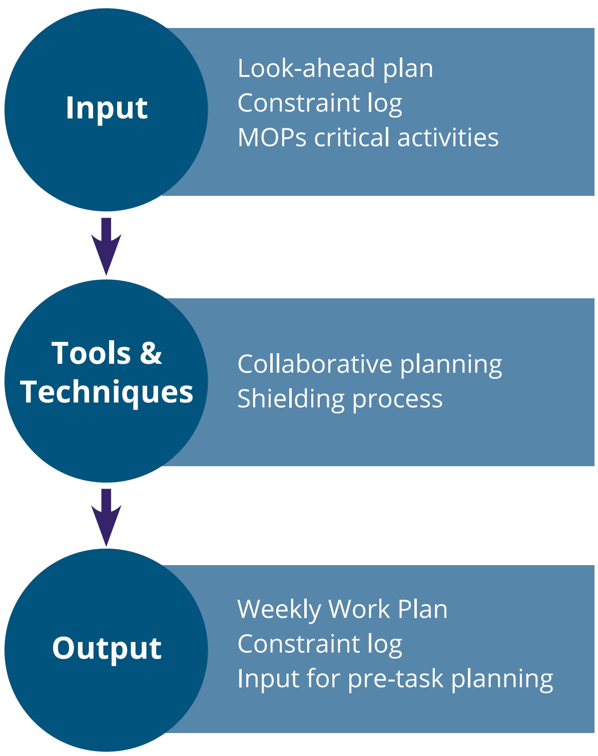


Fig. 2.12: Weekly Work Planning Procedure

Prefabrication

Photo credit: Hyun Woo Lee

Overview

Prefabrication refers to a systematic approach that targets moving fabrication and assembly activities from a jobsite to an off-site, controlled environment.[10][11] Prefabrication is typically applied to the work of a single craft, and is extensively promoted and supported during lean design and construction processes.

Preassembly and modularization are variations of prefabrication used in construction projects. Preassembly is generally applied to a system-level operation, while modularization focuses more on the work of combined systems. In particular, modularization can be defined as "the preconstruction of a complete system away from the job site that is then transported to the site." [12] Modules are typically large in size and may need to be disassembled into several smaller pieces for transport[12].

Listed below are benefits expected from prefabrication [13]:

- Stable work location; working in a familiar environment
- Avoiding work in tight spaces at the site
- Implementing on-ground assembly instead of working at height
- Avoiding work in harsh weather
- Monitoring unsafe activities simpler
- Spending less time on construction site (30% to 50% reduction)
- Reducing the number of contractors and workers on site

From an electrical construction point of view, prefabrication can support project teams to increase productivity and safety, decrease jobsite congestion, reduce waste, improve product quality, and generate cost savings. Overall, using the prefabrication approach on projects can reduce safety hazards such as ergonomic issues, fall hazards, exposure to adverse weather, and so forth. Risk factors such as work positioning, handling heavy tools, and environmental controls, including heating and air conditioning, can be controlled by prefabricating the needed materials in fabrication shops.[11] In other words, by integrating prefabrication in the project plan, chances of ergonomic injuries can be reduced. Listed below are some risky tasks that can potentially be reduced/eliminated by implementing prefabrication for electrical contractors:[11][14]

- **Lifting heavy loads**: Many electrical components have a considerable amount of weight (spools of wire, bundles of rigid steel conduit). Lifting these loads, specifically those weighing more than 50 pounds, may increase the risk of injury
- **Contact stress:** Over time, the pressure caused by holding short handles on hand tools could result in pain and inflammation by restricting blood flow to the compacted tissues. Resting arms and wrists for a long time on sharp edges of a desk is an example of this safety risk.
- **Stressful postures**: Awkward postures, such as bending or twisting, place stress on muscles and soft tissues and eventually could cause ergonomic-related injuries. Remaining in the same position for a long period of time may potentially result in workers developing musculoskeletal problems.
- **Repetitive motions**: Performing a repetitive task many times could lead to strains.

Working in a controlled environment with ergonomically designed tools and under expert supervision is known to lead to better worker safety. The following sections present general safety instructions that should be taken into consideration in electrical prefabrication shops. Note that some of the ergonomics-related risk factors highlighted by OSHA are integrated in this chapter.

Prefabrication for Safety

Handling Wires and Cables

Wire and cable are usually wrapped around reels for storage or for shipment to job sites. To streamline moving the reels around, and to make moving the reels more effective (with substantially less manual exertion), use of devices such as reel carts, racks, stands, and portable workstations carrying reels of wire can be adopted.[15] In particular, instead of trying to lift heavy wire reels, electrical contractors can use a reel handler attachment device for carrying the reels (Fig. 3.1). This device can also support workers by preventing awkward postures during pulling activities. Multiple, free-spinning reels can be added to the device to simplify precuts and custom paralleling. The device can be assembled in prefabrication shops and sent to job sites.

Conduit Bends

Prefabricating conduit can bring benefits such as increased productivity and quality, reduced field work and installation time, decreased potential safety issues on site, increased efficiency in material handling, and ultimately cost and time savings. [15]

Photo credits: Sadra Fardhosseini

Fig. 3.1: Reel handler attachment for handling wire and cable

In particular, prefabricating conduit enables workers to work in a controlled environment with better lighting and tools, and without being impacted by adverse weather conditions.

Lifting large-gauge steel conduit can expose a worker to ergonomic risks by putting extreme pressure on a worker's back and waist. Manual lifting of these heavy materials should be avoided, unless they are handled by at least two people.[11]

Conduit can be stored in a rack and then the rack can be moved by using a conduit carrier cart (Fig. 3.2; refer to the *everything-on-wheels* rule in Chapter 1). A forklift or other equipment should be used for transporting the conduit. Even during loading and unloading racks of conduit, it is suggested that a customized lifter should be used (Fig. 3.3). As it is shown in Fig. 3.2, for some cases, it might be possible to palletize bent conduit for safe, easy shipment to the job site. In addition, because it can take significant time to bend customized conduit, electrical contractors can use a soft and flexible floor to reduce the impact of standing for long periods of time (Fig. 3.4).

Multi-Trade Racks

Multi-trade racks support prefabricated multiple components, including vertical and horizontal mechanical/electrical/plumbing (MEP) systems, assembled offsite in a controlled environment (Fig. 3.5). This prefabrication approach offers benefits such as faster assembly, improved safety, reduced cost, higher quality, and reduced risk/time at the point of installation. The following are safety benefits associated with using multi-trade racks:[16][17]

- Most typical overhead work, including welding, can be performed at "bench height"
- Easier to perform lighting and ventilation Installations
- More space for moving modules and installing ceiling components
- Reduced tripping hazards

Assembly

Assembling electrical parts in a controlled environment with suitable light and comfortable temperature enhances overall worker safety

Photo credits: Sadra Fardhosseini

Fig. 3.2: Conduit bends

Photo credit: Sadra Fardhosseini

Fig. 3.3: Customized lifter for moving racks of conduit when loading and unloading

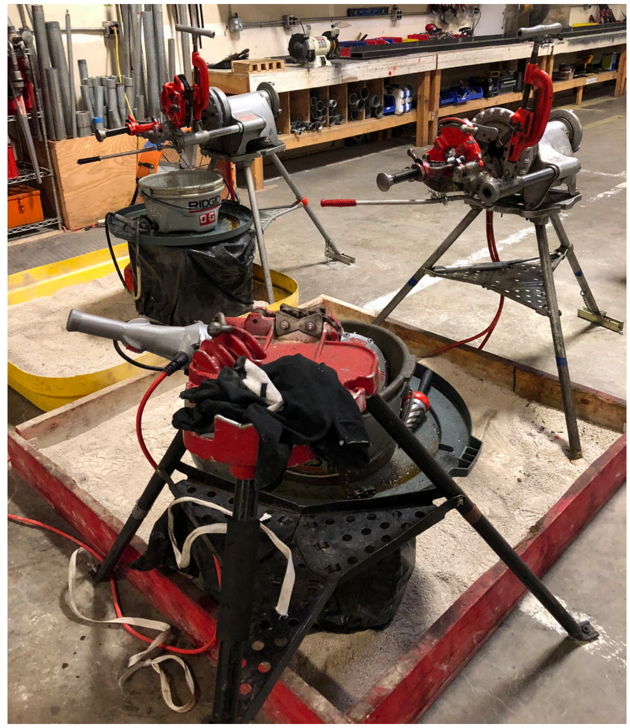


Photo credit: Sadra Fardhosseini

Fig. 3.4: Soft floors reduce the impact of standing for long periods of time

Photo credits: MacDonald-Miller

Fig. 3.5: Multi-trade racks

(Fig. 3.6). Workers can function in appropriate musculoskeletal positions during assembly tasks to mitigate safety risks. Adjusting the height of workstations can also enable a safe range of motion. In addition, sufficient tools and equipment can be placed close to the main assembly area to reduce the waste of excessive worker movements in prefabrication shops.[11]

Just-in-Time Delivery

As a well-known lean practice for prefabrication, Just-in-Time (JIT) delivery requires effective collaboration among fabricators, the shipping team, and the construction team. Based on JIT, shipped products must not occupy space for a long time on job sites because housekeeping issues on site could lead to safety risks such as tripping.[3][15]

A couple of ideas are suggested to support JIT in prefabrication, depending on product size. First, for large prefabricated parts, electrical contractors can divide the parts into pieces and then deliver them to job sites. For example, for the prefabrication of raceways in an underground project, electrical contractors can separate long conduit into parts and reassemble them on site.

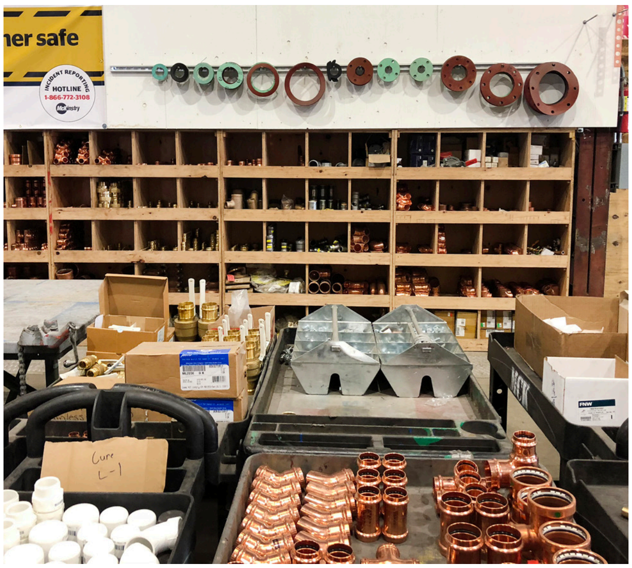


Photo credit: Sadra Fardhosseini

Fig. 3.6: Assembling

For small prefabricated parts, small mashed bags ("onion sacks") can be used (Fig. 3.7). Onion sacks can help workers easily identify what parts are in the sacks, preventing unnecessary misplacement and damage. These bags should be placed on the cart along with other associated parts. The following are suggested steps for delivering products from prefabrication shops to job sites:

- Fabricators put the needed parts on a shipping rack in their prefabrication shop.
- A crane can be used to load the shipping rack to a truck. Workers need to pay attention to ergonomic rules when picking up small parts and putting them on a truck.
- The truck driver hands over a delivery order to the material handler at the job site.
- The material handler passes the order to the electrical foreman.

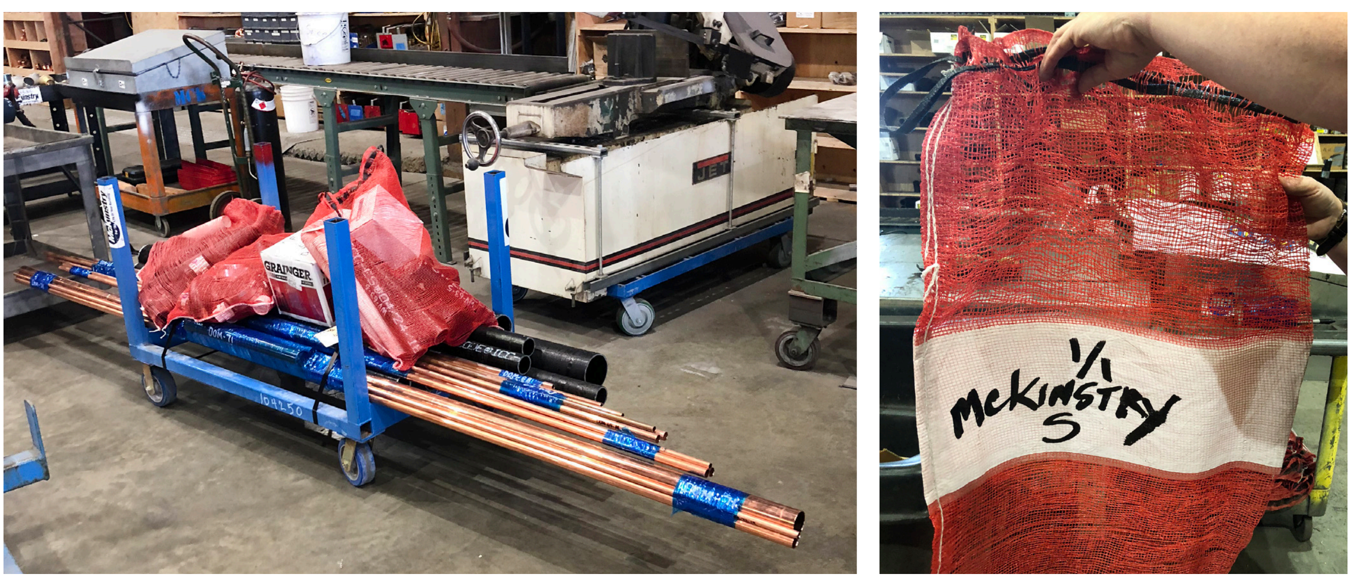
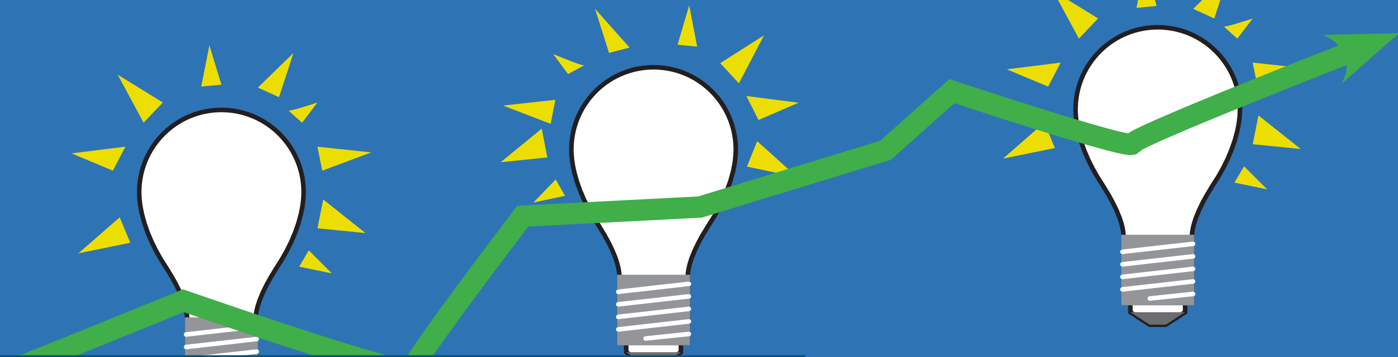


Photo credits: Sadra Fardhosseini

Fig. 3.7: Onion sacks for parts delivery



Continuous improvement

Overview

Also known as Kaizen (the Japanese word for "continuous improvement"), Continuous Improvement is a lean technique that means "change for the better" or more specifically, "take it apart and put it back together in a better way."[3][18] This technique aims to eliminate waste in the process, system, product, or service which can be also applied in construction projects. Similarly, a construction project team can use the Kaizen technique to simplify steps, movements, or tools required for each activity, as well as for orientation and pre-task meetings.[19][20] In addition, Kaizen can be applied to the design management process in terms of setting up file saving/sharing in order to reduce time lost looking or waiting for drawing updates.[20]

Kaizen can be discussed in a meeting ("Kaizen event") by highlighting particular steps of the process with the purpose of enabling the involved people to identify opportunities for eliminating waste and reducing extra work. The focus of the discussion should be on small, incremental improvements.[[18][21] A Kaizen event refers to a gathering of employees to improve the practices in place. Depending on the problems at hand, engineers, superintendents, general foreman, architects, and owners can be invited to the meeting.[21]

Suggested Phases

The goals of Continuous Improvement for safety are to address safety risks and hazards in planning and problem-solving tools, provide support for workers to get more involved in safety processes, and create a safety climate.[22] The following three phases are suggested to achieve the goals (Fig. 4.1):

- Phase 1 – Identify areas of improvement (Pre-Kaizen)
  - Identify improvement opportunities
  - Capture performance data
- Phase 2 – Rapid improvement (Kaizen)
  - Analyze performance data
  - Improve performance
- Phase 3 – Follow-up (Post-Kaizen)

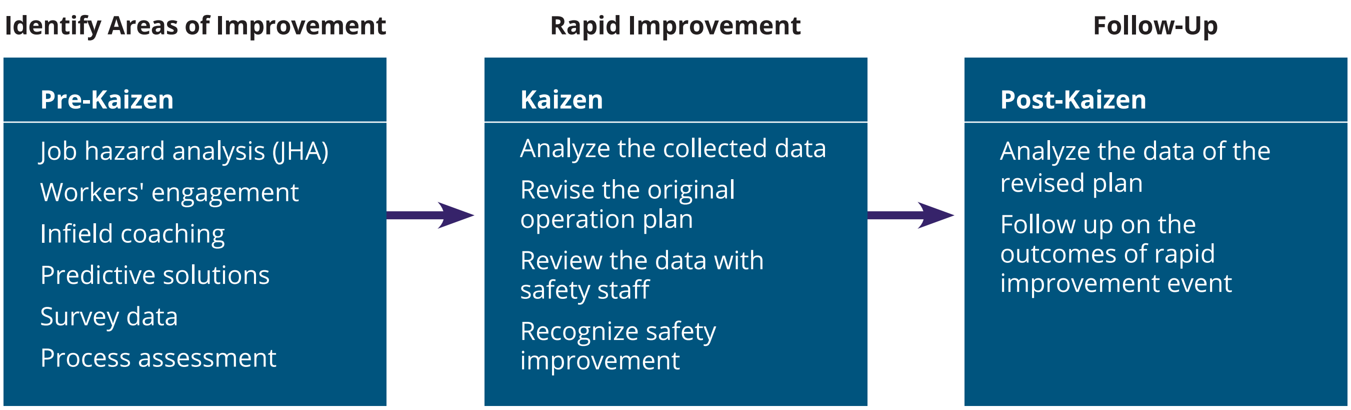


Fig. 4.1: Continuous Improvement for Safety

Phase 1: Identify Areas of Improvement (Pre-Kaizen)

Identify Improvement Opportunities

The aim of this step is to evaluate the current conditions based on job hazard analysis (JHA), daily briefing meetings, and engaging workers. For more information about JHA, refer to Chapter 2: Last Planner System. The safety Kaizen team, including a group of six to eight workers from both upstream and downstream of the workflow for the selected work area (where the work is performed), should go for a Gemba walk and gain a firsthand understanding of current conditions. They might conduct a safety audit and perform observations or interviews to assess any safety risk factors in the targeted area. Fig. 4.2 presents a summary of this step.

In general, the key to successfully performing this step requires the following components:

Daily Briefing

Pre-task planning and daily briefings provide an opportunity for workers to get connected with other members of the project team to discuss hazard identification and risk reduction. The pre-shift safety huddle is a task undertaken by each crew on the jobsite. The objectives of huddles include: 1) to plan the day's work with a proactive approach to prevent all potential incidents, 2) to enable workers to take control of their safety process, and 3) to gain a better understanding of hazard identification and risk assessment.

Engaging Workers

Listed below are opportunities that can promote the engagement of workers.

- Active caring (promoting a zero-incident culture)
  - Take responsibility for each other's safety.
  - Commit to supporting each other (provide safety feedback to colleagues)
- Daily safety huddles (Fig. 4.3)
  - Participate in the huddles
  - Review "huddle boards"
  - Compare boards to highlighted pre-task-planning documentation
  - Ask random workers about the huddle content
  - Worker gatherings (facilitating the identification and elimination of barriers to safe performance)

Photo credit: Sadra Fardhosseini

Fig. 4.3: Workers Engagement

When:	Every month
Purpose:	To evaluate the effectiveness of safety practices.
Expected Attendees:	Workers from different groups, foreman working on that area, and safety manager

Fig. 4.2: Identifying Improvement Opportunities

- Conduct worker gatherings on a regular basis based on the size of the project team
- Select five workers from five different groups (one from each group)
- Start the conversation with questions, such as What's working? What's not working?
- Explain what actions are being taken based on worker suggestions and why some of the suggestions cannot be implemented.

- Safety perception survey
  - Conduct quarterly and anonymously
  - Understand workers' perceptions and perspectives
  - Change approaches based on survey results (what is working and what is not working)
  - Track for continuous improvement
  - Show the workers that their opinions matter!

Capture Performance Data

In order to enhance safety in a continuous improvement process, safety goals should be set and safety performance data need to be captured. The captured data enable safety managers to address safety gaps and add to future projects. Fig. 4.4 presents a summary of this step

The following components can be applied for data collection:

Predictive Solutions

Every month, a safety manager should write a comprehensive predictive solutions report based on the safety data collected. This data could be collected from JHAs, daily meetings, and worker engagements. The report highlights the need for safety tasks, such as observation/feedback and coaching, and/or just-in-time training on target topics. Then, the needed tasks should be highlighted in the project's monthly safety report.

Worker Engagement

The project team can benefit from field workers' suggestions, which can be captured as data and analyzed for safety improvements. Opportunities to meet, such as lunchtime meetings, could encourage workers to be actively engaged in giving feedback. Worker engagement is a feedback-based procedure that supports safety continuous improvement. A facilitator can be involved, whose role is to encourage the workers to receive feedback from each other so that the project team can continue to evaluate and improve the effectiveness of the safety program. Workers should be made aware that the entire conversation is confidential and no names are attached to any comments.

Survey

Every month, conducting a safety survey with a random sampling of at least 25% of the project workforce is suggested. A safety survey asks how to improve safety in different tasks or at different locations on the site. The results of the collected data can be reflected in the predictive solutions safety survey form. These results should be reviewed initially in the staff meeting and then, the findings can be shared with the workforce.

Coaching Data

It can be important for a team that is observing to reflecting on all of the observed tasks through infield coaching. In particular, certain types of observed

When:	Every month
Purpose:	To capture data from implemented safety practices for safety improvement.
Expected Attendees:	Workers from different groups, foreman working on that area, safety manager, and someone with "a different set of eyes"

Fig. 4.4: Capturing Performance Data

unsafe behaviors should be identified and eliminated before they might lead to accidents. The observational team should use a checklist, determining the safe and at-risk behavior of each of the actions. Fig. 4.5 provides an example of a simple safety checklist that observers might use.

Process Assessment

Process assessment is a quality control tool that safety managers use every month. Process assessment may include safety procedure, the safety supervisor's responsibilities, and the key safety performance indicators. The final result should be a report indicating potential opportunities to improve core processes. The project team can achieve improvement can be achieved by collecting data and getting recommendations from workers (who perform the tasks). The report can be provided by safety managers for further analysis and to prepare for safety meetings.

Phase 2: Rapid Improvement Analyze Performance Data

The purpose of this step is to identify the root causes of accidents, derived from the collected data (Fig. 4.6). 5 Whys is one of the most beneficial lean techniques that can be used to identify the root causes of incidents. (For more information about 5 Whys, refer to the Appendix.) Based on the data collected, this step can involve identifying the causes of near-misses, and even further upstream, to examine system discrepancies that can lead to unwanted, unplanned events. The lessons learned from a root cause analysis could support the evaluation of the safety continuous improvement program. Multiple continuous improvement forms can be adopted to facilitate the analysis of the collected data and provide support to find a better strategy. Fig. 4.6 presents a summary of this step.

Safety Category	Desired Behaviour	Safe	At-Risk	Comments
Organization & Housekeeping	Clean work area and safe path of travel			
	Safe staging of materials			

Fig. 4.5: Coaching Data Form Sample

When:	Every month
Purpose:	To analyze the collected data to identify the potential faults and to suggest safer approaches for workers in future projects.
Expected Attendees:	Safety manager, project manager, foreman working on that area, and subcontractor supervisor

Fig. 4.6: Analyzing performance data

Fig. 4.7 is an example of a time observation sheet that could assist the project team with evaluating the time allotted to prevent accidents based on the data collected.

A standard work sheet is another form that can be used to support the safety Kaizen team in preparation for a Rapid Improvement event (Fig. 4.8). It is suggested that the standard work sheet is used for the motion study of a crew, aiming to streamline the movement of workers and optimize the layout of a workplace. The form can effectively communicate the benefits of being organized in the project (i.e., housekeeping). Streamlining tasks and placing needed materials in a way to reduce exposure to unsafe materials and equipment can be facilitated by using the worksheet.

Another form that can be useful while preparing for a Rapid Improvement event is an improvement idea proposal sheet (Fig. 4.9). In general, the sheet is intended to illustrate any issues and to highlight how the suggested solution can solve them.

Based on the collected data, using approaches such as 5 Whys will empower the project team to find the root causes of accidents and near misses. Then, by adopting any of the aforementioned strategies, a better and safer approach to a task can be suggested to replace the prior approach.

TIME OBSERVATION SHEET

Page _____ of _____
☐ Before ☐ After

Date / Time: ___/____/____/__________

Process: ____

Observed by: ______________________

Project: ____

										Category			
Step	Description	Man	Mach	Travel	1	2	3	Avg.	Best	VA	NVAR	Waste	Observations (Safety/Quality/Efficiency)
	Complete Cycle Time							Total VA		Total NVAR		Total Waste	

Fig. 4.7: Time Observation Sheet Example

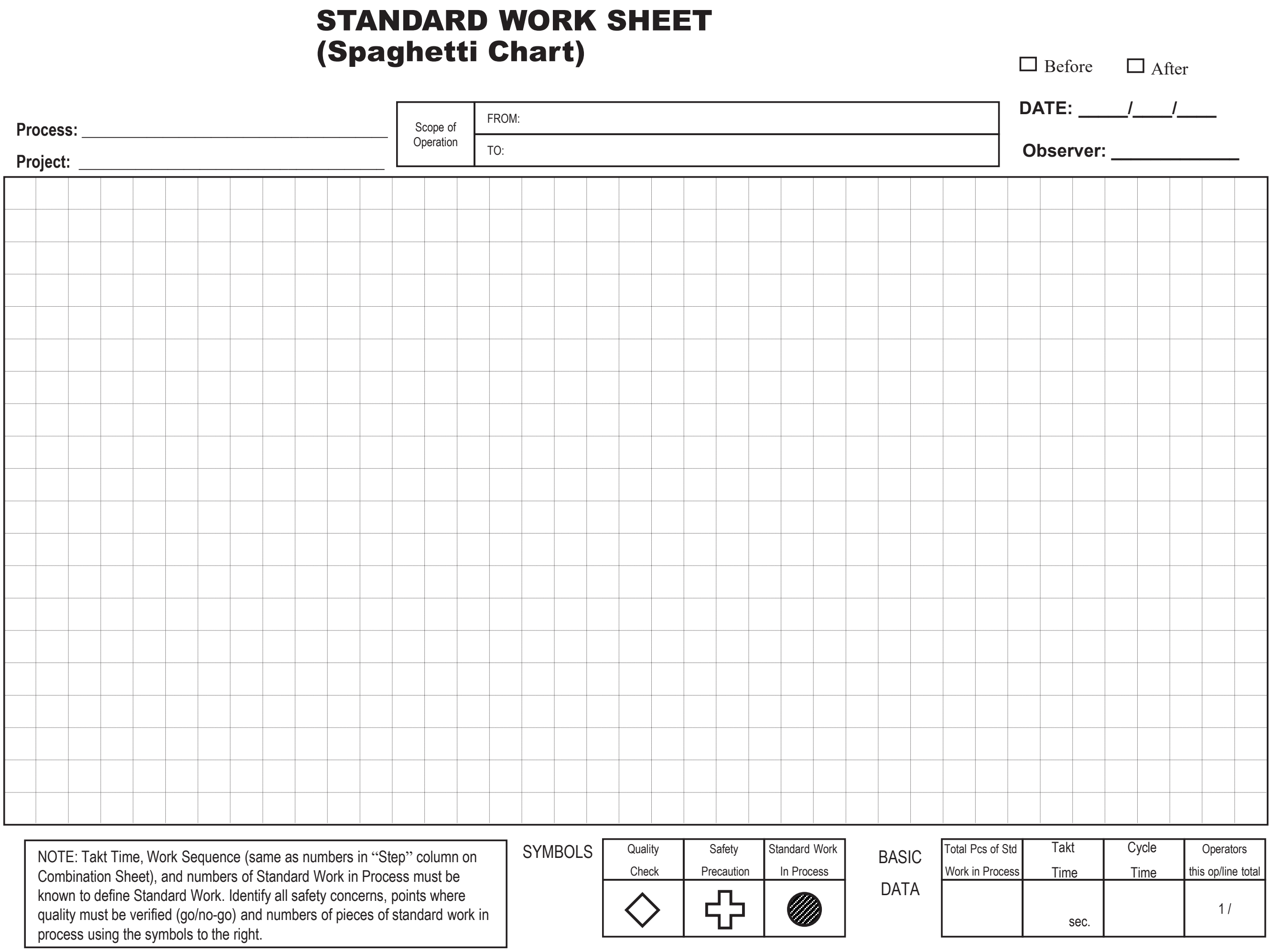


Fig. 4.8: Standard Work Sheet Sample

Improve Performance

The objectives of this step are to 1) identify improvement opportunities, 2) revise the original operational plan, 3) review the data with safety staff, and 4) perform safety recognition and improvement. To achieve these objectives, the project team as a whole can discuss the overall process and results of the safety continuous improvement (in a Rapid Improvement event). The event allows for enhancing the strength and quality of pre-task plans, such as JHAs, and ensuring that all major tasks have been optimized for safety, efficiency, and quality. The team needs to consider the current plan, including the JHA pre-task planning, and review the tasks as they happen. This process also reviews the life-cycle of material handling as safety risks and hazards are embedded in the material handling process. Listed below are some sample questions that can be asked during the event:

- Are the tasks being performed in the field listed on the JHA or other plan?
- Does the JHA/plan recognize all hazards or risks?
- Are the established hazard controls adequate to prevent all incidents?
- Could this task be made more efficient? produce less waste?
- Is there something we could do differently to improve the quality of the work?
- Could material handling or logistics be improved to make the work easier?

Kaizen Improvement Idea Proposal Sheet Page ____ of ____

Process: ______________________ Date / Time: ___/___/___/________

Project: ______________________ Observed by: __________________

Operation	Problem	Actions Taken	Results

Before	After
(Sketch) / (Picture)	(Sketch) / (Picture)

Remarks:

Fig. 4.9: Improvement Idea Proposal Sample

Based on the answers to the questions, an improvement suggestion can be made and implemented, followed by collecting data in the form shown in Fig. 4.10. This form tracks an improvement trajectory toward the goal by checking daily progress. Then, the project team can perform a comparative analysis between before and after the implementation.

Finally, the Rapid Improvement team should review the outcomes of the process and reflect on them in the next safety meeting by sharing how improvements were made. Fig. 4.11 illustrates an overall outline of a Rapid Improvement event.

Phase 3: Follow up

To determine whether or not the revised plan has improved the safety process in the project, a follow-up action should be taken into consideration. During this phase, the project team should collect and analyze data to compare it with the previous procedure. If, according to the results of the follow-up step, the revised plan is determined to be a successful improvement strategy, the following actions should be taken:

- Standardize the solution for similar issues
- Specify the standardized solution as a normal operating procedure
- Review the previous stages for additional improvement
- Document the improvement solutions as lesson learned for adoption on future projects

On the other hand, if the revised plan is deemed unsuccessful, the team needs to review the previous stages in detail to determine the reasons for failure. Finally, all of the steps taken should be documented for future reference.

TARGET PROGRESS REPORT

Page _____ of _____

Process: ____ Date / Time: ___/____/____/__________

Project: ____ Observed by: _____________________

Takt Time: ____

CATEGORY	CURRENT	TARGET	DAY 1	DAY 2	DAY 3	DAY 4	FINAL RESULT	% CHANGE
SPACE (sq. ft.)								
INVENTORY								
WALKING DISTANCE								
MATERIAL TRAVEL DISTANCE								
LEAD TIME (sec.)								
CYCLE TIME (sec.)								
OUTPUT (units / day)								
CREW SIZE								
PRODUCTIVITY								
CHANGEOVER TIME (sec.)								

Fig. 4.10: Data Recording Form for Improvement

Kaizen Event Calendar

Page _____ of _____

Process: ____

Date / Time: ___/____/____/_______

Lead by: ____________________

Project: ____

Participants: ____

____

Before Event	Day 1	Day 2	Day 3	Day 4 (if Required)	Last Day (Day 4 or 5)	After Event
1. Select Process to improve. 2.Select Project. 3. Select Team. 4. Classroom Kaizen Training. 5. Prepare Standard Kaizen Forms. 6. Establish Kaizen Event Objectives.	1. Kickoff Meeting. 2. Refresher Classroom Kaizen Training. 3. Observe Process & ID Safety, Quality, and Waste. 4. Identify Process Improvement Opportunities. 5. Plan Process Improvement Approach.	1. Finalize plan and prepare “Kaizen Follow Up Check List” 2. Engage crew & discuss opportunities. 3. Make process improvement changes. 4. Observe changes. 5. Summarize change impact. 6. Update “Kaizen Follow Up Check List” .	1. Prepare “Kaizen Follow Up Check List” 2. Engage crew & discuss more opportunities. 3. Make new process improvement changes. 4. Observe new changes. 5. Summarize change impact. 6. Update “Kaizen Follow Up Check List” .	1. Prepare “Kaizen Follow Up Check List” 2. Engage crew & discuss more opportunities. 3. Make new process improvement changes. 4. Observe new changes. 5. Summarize change impact. 6. Update “Kaizen Follow Up Check List” .	1. Make new Best Practice or Work Instruction based on new Standard Work. 2. Final update “Kaizen Follow Up Check List”. 3. Summarize Status & Findings. 4. Prepare Report out. 5. Give Report Out to Project Team. 6. Celebrate	1. Input Best Practice or Work Instruction to Best Practice Database 2. Ensure all crews are trained to new process. 3. Periodically follow up and audit new process. 4. Kaizen again to continuously improve performance.

Fig. 4.11: Rapid Improvement Calendar

Appendix

Photo credit: Sadra Fardhosseini

5 Whys

Root cause analysis is an organized team procedure that aims at identifying the underlying factors or causes of an incident. Identifying these factors or causes of failure helps lead to corrective actions. As one of the most widely-used root cause analysis techniques, 5 Whys is a problem-solving approach aimed at investigating the root causes of a circumstance by repeatedly asking "why" (at least five times) until contributing factors or causes are highlighted. Once the response to each why question is stated, an additional question may be asked concerning that response.[3] A typical 5 Whys process follows:

- Form a team: Involve people with knowledge and experience about the problem being discussed. (There should be a representative from each trade on the team.)
- Define the problem: Defining the problem clearly and concisely helps the team focus and save time, potentially making the solving procedure easier.
- Ask Why: Ask why the problem occurred and document the responses. The responses should be based on data or facts.
- Ask about the details in the responses: Ask about the identified contributing factors or causes, and determine whether the problem can still occur. If the answer is "yes," then the second "why" should be asked.
- Keep asking why: Loop back to the previous step until a consensus is achieved by the team that the root causes of the problem have been identified.
- Determine and perform corrective actions: According to the identified root causes, develop a list of corresponding corrective actions. The effectiveness of each of the suggested actions should then be evaluated. Finally, the optimal action should be selected for implementation on the project.

Overall, implementation of 5 Whys in the construction industry can bring multiple benefits to project teams. These benefits include: reduced risk of reoccurrence (i.e., by dealing with the root causes, the symptoms are less likely to happen again), preventing problems before they occur, gathering information for identifying other issues, being more aware of how a system works, and emphasizing quality and safety over speed.[23]

5 Whys can be specifically beneficial when problems involve human factors or interactions. For example: the United States Department of Energy (DOE) used the 5 Whys approach and developed the "Human Performance Improvement (HPI)" concept. The aim of HPI is to find safe and reliable task behaviors for certain operations and to determine the root causes of unsafe behaviors as they could lead to incidents.[24] The HPI concept can be applied in the construction industry. Fig. 5.1 presents the root cases that have been identified which lead to unsafe worker behavior (Fig. 5.1).

A fishbone diagram is one of the most widely used tools for 5 Whys. The fishbone diagram enables users to write down the identified problems along with the associated whys. In this diagram, the tail represents the main problem and each of the whys

Task Demands

- Time pressure
- High workload
- Multiple tasks
- Repetitive actions
- Irreversible actions
- Interpretation actions
- Unclear goals
- Lack of standards

Individual Capabilities

- Unfamiliarity with tasks
- Lack of knowledge
- New techniques which have not been used before
- Improper communications
- Inexperience
- Indistinct problem-solving skills
- Being risk averse
- Illness or fatigue

Work Environment

- Distractions
- Departures from routines
- Confusing displays
- Work-arounds
- Hidden system responses
- Unexpected equipment conditions
- Lack of alternative Indication
- Personality conflicts

Human Nature

- Stress
- Habit pattern
- Assumptions
- Overconfidence
- Mind set
- Inaccurate risk perception
- Mental shortcuts
- Limited short-term memory

Fig. 5.1: Root causes leading to unsafe worker behavior

are written down along the sides (Fig. 5.2). Although 5 Whys is an easy and effective method to identify root causes, it is subject to some limitations as follows[23]:

- Identifying a symptom as a root cause: Finding the true root cause may require a considerable amount of practice.
- Lack of consistency: It is possible that different groups of people using 5 Whys on the same problem will get different results.
- Premature conclusion of the process: In cases with multiple root causes, participants may not identify all of the root causes contributing to the problem since people usually stop the process once they have found one root cause.
- Being limited to the knowledge of the performers. The people performing 5 Whys should be familiar with the problems/issues at hand to be able to ask the right "why" questions.

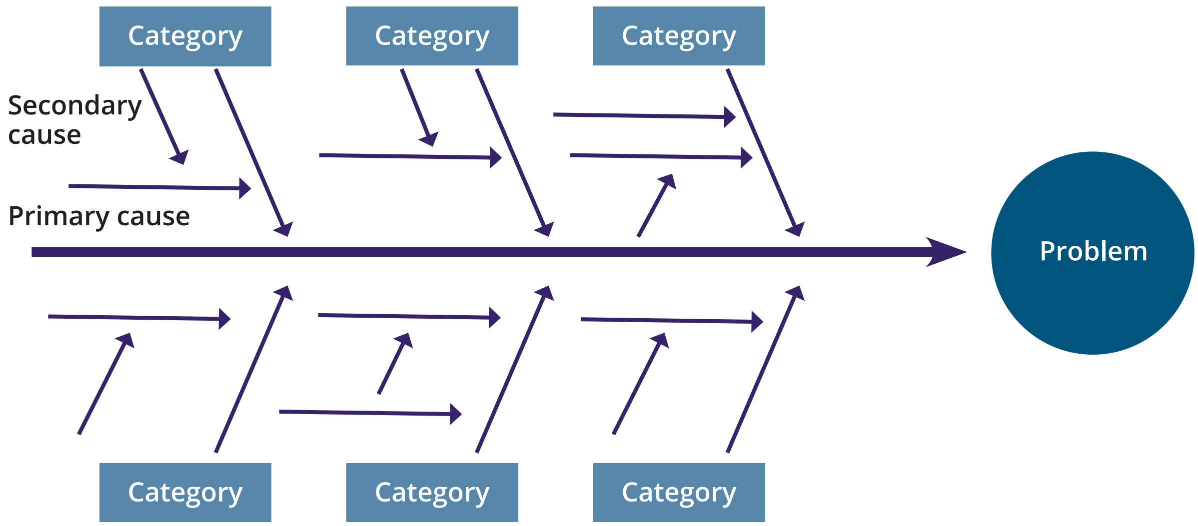


Fig. 5.2: Fishbone diagram

References

Photo credit: Sadra Fardhosseini

[1] Lean Construction Institute, "What is Lean Design and Construction?," (2017). https://www.leanconstruction.org/about-us/what-is-lean-design-construction/ (accessed December 19, 2018).

[2] J.A. Gambatese, C. Pestana, H.W. Lee, Alignment between Lean Principles and Practices and Worker Safety Behavior, Journal of Construction Engineering and Management 143 (2016) 04016083.

[3] Lean Construction Institute, "Glossary of Lean Construction Institute", (2017). <goo.gl/N26PNN> (accessed December 19, 2018).

[4] A. Enshassi, M.A. Zaiter, Implementation of Lean Tools on Safety in Construction Projects in Palestine, in: 22nd Annual Conference Proceedings IGLC Oslo Norway, 2014.

[5] S. Edwards, A Guide to the 5S Lean Production Method for Occupational Health and Safety, Occupational Health and Wellbeing, (2015). goo.gl/eQhgoR (accessed January 20, 2019).

[6] International Trade Center, 5s: Good Housekeeping Techniques for Enhancing Productivity, Quality and Safety at the Workplace, (2012). goo.gl/DcM16q (accessed January 20, 2019).

[7] I. Nahmens, L.H. Ikuma, An Empirical Examination of the Relationship between Lean Construction and Safety in the Industrialized Housing Industry, Lean Construction Journal (2009).

[8] H.G. Ballard, The Last Planner System of Production Control, PhD Thesis, University of Birmingham, 2000.

[9] Occupational Safety and Health Administration (OSHA), Job Hazard Analysis, (2002). goo.gl/fJq9SK (accessed December 19, 2018).

[10] Construction Industry Institute (CII), Prefabrication, Preassembly, Modularization, and Offsite Fabrication (PPMOF)–Instructor's guide, (2004).

[11] Occupational Safety & Health Administration (OSHA), Ergonomic Tools: Solution for Electrical Contractors, (2018). https://www.osha.gov/SLTC/etools/electricalcontractors/prefabrication/index.html (accessed December 19, 2018).

[12] C.T. Haas, J.T. O'Connor, R.T. Tucker, J.A. Eickmann, W.R. Fagerlund, Prefabrication and Preassembly Trends and Effects on the Construction Workforce, Rep. 14 (2000).

[13] M.M. Fard, S.A. Terouhid, C.J. Kibert, H. Hakim, Safety Concerns Related to Modular/Prefabricated Building Construction, International Journal of Injury Control and Safety Promotion 24 (2017) 10–23.

[14] BHS, Improving Safety at Electrical Prefabrication Shops, (2017). goo.gl/XtMUxW (accessed December 19, 2018).

[15] Y. Yang, H.W. Lee, Investigating the Relationship between Lean Principles and Electrical Prefabrication, (2014).

[16] Skanska, Multi-Trade Prefabrication Executive Summary, (2017). goo.gl/LRwJAL (accessed December 19, 2018).

[17] J.T. O'Connor, W.J. O'Brien, J.O. Choi, Critical Success Factors and Enablers for Optimum and Maximum Industrial Modularization, Journal of Construction Engineering and Management 140 (2014) 04014012.

[18] R. Hafey, Lean safety: Transforming Your Safety Culture with Lean Management, Productivity Press, 2009.

[19] J. Gambetese, C. Pestana, Connection between Lean Design/Construction and Construction Worker Safety, CPWR–Center for Construction Research and Training, Oregon (2014).

[20] Safe Build Alliance, A User's Guide to Lean and Safety, (2017).

[21] G. Santorella, Lean Culture for the Construction Industry: Building Responsible and Committed Project Teams, Second Edition, CRC Press, Taylor & Francis Group, Boca Raton, Florida, 2017.

[22] Turner, Building L.I.F.E. Instruction Manual, (2017).

[23] The Creative safety Supply, Understanding the Five Whys, (2017). https://www.creativesafetysupply.com/articles/understanding-the-five-whys/ (accessed December 18, 2018).

[24] United States Department of Energy, DOE Standard Human Performance Improvement Handbook, (2009). http://www.hss.energy.gov/nuclearsafety/ns/techstds.

For more information, contact:

Prof. Hyun Woo “Chris” Lee, PhD, LEED AP BD+C

Department of Construction Management

College of Built Environments

University of Washington

120 Architecture Hall, Campus Box 351610

Seattle, WA 98195

hyunwlee@uw.edu

206.616.4937 office