Use of Safety and Lean Integrated Kaizen to Improve Performance in Modular Homebuilding

Laura H. Ikuma1; Isabelina Nahmens2; and Joel James3

Abstract: The two biggest challenges in the construction industry, low productivity and high injury rates, may be addressed simultaneously through the combination of lean production strategies and traditional safety-analysis tools. This case study used Safety and Lean Integrated Kaizen (SLIK) in a modular housing manufacturing facility by applying one lean production tool, kaizen, and a safety-analysis tool, job safety analysis (JSA). The research team used SLIK with the base-framing crew, and the method consisted of analyzing the current process, determining and implementing process improvements, and analyzing the improved process. The changes resulted in a 16% increase in value-added activities and increased the framing crew’s overall output by 55%. By making quick, low-cost changes that were intended to improve productivity to the station layout and work design, safety and ergonomic hazards, including reduced trip hazards, pinch points, and back strain, were also reduced or eliminated. These results support the hypothesis that productivity and safety can be improved simultaneously through combined lean and safety tools. DOI: 10.1061/(ASCE)CO.1943-7862.0000330. © 2011 American Society of Civil Engineers.

CE Database subject headings: Occupational safety; Lean construction; Productivity; Residential buildings; Construction management.

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Introduction

Safety is one of the most significant challenges in the construction industry, along with low productivity rates. Traditionally safety and productivity have been addressed separately, but both are critical for operational success. In the current study, the researchers propose a unified framework for addressing productivity and safety simultaneously as the most effective method of improving the construction industry, in particular modular homebuilding. This framework, Safety and Lean Integrated Kaizen (SLIK), is composed of lean production strategies combined with safety analysis methods. The purpose of this case study was to test this unified framework in a modular homebuilding plant and assess effectiveness on productivity and safety.

Modular Homebuilding

Modular homebuilding relocates many field operations to a controlled factory environment and adheres to local building codes similar to site-built homes. Modular homes are composed of three-dimensional sections and leave the factory 95% complete (Carlson 1991). After leaving the factory, the sections are taken to the home site and lifted or rolled onto the foundation. Manufactured housing has a high injury rate of 10.2 per 100 workers (NAICS 321992 prefabricated wood building manufacturing), which is much higher than the rate for on-site residential construction (3.5 per 100 workers) (Bureau of Labor Statistics 2009). Manufactured housing does have potential advantages in safety over on-site construction because of the controlled environment and ability to standardize processes, but the high injury rate suggests that safety programs in these environments need drastic improvements.

Lean and Lean Construction

Lean production is an approach to improve manufacturing efficiency and product quality. Originating with the Toyota Production System, lean production is the result of decades of development by automotive manufacturers, resulting in improved productivity, quality, and safety (Ohno 1988). Lean production is established on five fundamental principles: (1) identify what the customer values; (2) identify the value stream and challenge all wasted steps; (3) produce the product when the customer wants it and keep the product flowing continuously through the value stream; (4) introduce pull between all steps where continuous flow is impossible; and (5) manage toward perfection (Womack and Jones 1996). In practice, these principles are implemented through kaizen, an intensive and focused approach to process improvement. Hence, lean offers a systematic approach to change a homebuilder’s culture to one that is proactively productive.

After the success in manufacturing, lean has been applied to various industries, including construction. Steps are now being taken to analyze the effect of lean in the construction sector (Salem et al. 2006). Construction and manufacturing differ in their processes and the techniques of assembly. The construction industry involves complex and changing work environments, which may result in new hazards to workers on a daily basis (Ahmed et al. 2000). Construction is distinguished from manufacturing through three main features: on-site production, large level of customization, and high complexity (Koskela 2002). The combined effect of these features of construction makes it uncertain and complicated, whereas manufacturing has higher levels of control over
production and thus reduced uncertainty (Salem et al. 2006). Less control over production makes the application of lean strategies more difficult in construction, which may explain why lean production strategies do not fully fit in construction industries (Salem et al. 2006).

Salem et al. (2006) studied the application of six lean tools in a construction project: Last Planner, increased visualization, huddle meetings, first-run studies, 5S (sort, set in order, shine, standardize, and sustain), and fail-safe for quality. The implementation of these lean tools helped in completing the project within the set schedule, under budget. It reduced the incident rate and also helped in improving the relationship between subcontractors and general contractors. The outcome of the study showed that the lean strategies can be implemented in the construction sector with small modifications in the construction industry environment (Salem et al. 2006). Some of the benefits of implementing lean in construction include waste reduction, production cost reduction, decreased production cycle times, labor reduction, inventory reduction, capacity increase of existing facilities, higher quality, higher profits, higher system flexibility, and improved cash flow (Thomas et al. 2003; Diekmann et al. 2004; Höök et al. 2008; Nahmens and Mullens 2009).

Relationship between Lean Production and Safety

Work processes pose various levels of risk according to the safety hazards present in each step required to complete a process. By carefully planning processes to minimize risks, work can be made safer. Use of two lean principles, reducing waste and increasing efficiency, often results in a reduction of process steps, materials used, and motions required. These reductions in turn may eliminate or reduce safety hazards associated with those extra steps or materials. Improved safety translates to fewer work-related injuries and illnesses, which reduces costs for workers’ compensation insurance, rehabilitation and retraining, and worker turnover.

Previous studies have examined the link between safety and lean strategies, and have found a positive relationship between the implementation of lean and improved safety. Nahmens and Ikuma (2009) stated that lean is not only a beneficial process improvement and waste reduction tool, but its application is significantly related to improved safety in the construction industry. Through their survey of 141 homebuilders, homebuilders that implemented a lean program had significantly better safety records than those not using lean strategies. Thomassen et al. (2003) found that the use of a lean construction program in a large contracting firm was associated with lower incidence rates and absenteeism. The lean techniques implemented did not focus specifically on safety, but safety appeared to improve as a side effect of lean construction (Thomassen et al. 2003). Wong et al. (2009) conducted a survey of 44 manufacturing managers to explore the 14 key areas of lean manufacturing, namely, scheduling, inventory, material handling, equipment, work processes, quality, employees, layout, suppliers, customers, safety and ergonomics, product design, management and culture, and tools and techniques. The researchers found that the degree of success in the lean program was significantly correlated with lean tools used in ergonomics/safety. These results indicate that lean programs may result in positive safety and ergonomics outcomes.

However, implementation of lean may not always have positive effects on safety and ergonomics, as shown in several studies. Womack et al. (2009) investigated the relationship between lean job design and work-related musculoskeletal disorders by comparing exposure to injury in an automobile manufacturing plant that implements lean and a traditional automobile plant that does not implement lean. The results showed that the workers were exposed to musculoskeletal disorders more in the plant that implemented lean because of an intensified work schedule and a greater ergonomic risk attributed to reduced cycle time. Also, the nonneutral posture of the wrist, shoulder, and lower back were greater for the lean manufacturing plant. However, exposure to high hand force was lower in the lean manufacturing plant because lean focused on process quality that used quality tools, parts, and work methods. Landsbergis et al. (1999) claimed that implementation of lean manufacturing intensifies work pace and demands, which leads to musculoskeletal injuries. Furthermore, implementation of lean in a process tends to increase decision authority and skill levels, but such skills are temporary and modest. This temporary increase in skill level and decision authority can result in job strain and pressure on workers. These disparate results further increase the need to study the effects of combining lean and safety programs.

Proposed Method to Integrate Lean and Safety

The case study presented here used a general kaizen event structure that incorporated specific attention to safety. Kaizen is a lean tool used for rapid process improvement. Most notably, it involves line workers in decision processes for improvements and focuses on making quick, feasible changes. Safety analysis was incorporated into kaizen here through the use of job safety analysis (JSA) performed before and after improvements and through the inclusion of safety in team discussions on improvements. The specific steps of the resulting process, SLIK, are shown in Fig. 1, and details of each step as carried out during the case study are presented in the “Methods” section.

Case Study

Setting

The methods of this case study follow the SLIK process steps outlined in Fig. 1. The current application of the SLIK process took 2 months, from June to July 2009. The setting for the present study was a modular housing plant in the United States. The plant employed roughly 40 workers and had a production rate of 12–15 homes per month at the time of the study. This plant produces modular homes, which are either stick built (base, walls, and ceiling) or a combination of stick built with structural insulated panels (SIP) (walls and ceiling). Homes can be produced up to 90% finished, although the level of completion varies according to customer needs. The company uses precise assembly equipment and repetitive assembly line techniques. The plant layout follows the sequential building process according to the manufacturing process for the modular homes, which includes 19 distinct workstations (25 workstations total, including float spaces and multistep processes) located in a 15,329 m² facility. Owing to market pressures at the time of the study, this modular manufacturer was preparing to increase production. However, their production process was experiencing several areas of concern that will hinder or prevent their planned production expansion, including: (1) inadequate material flow and procurement, (2) variable production rate among stations, in particular the base-framing station, and (3) insufficient workforce. This study focused on the base-framing station (Station 1). Because of the sequential nature of the construction process, the cycle time of other stations is affected by the cycle time of Station 1. In the past, delays at this station had a major effect in meeting the production schedule.
### Methods

**Lean Concepts Introduction, Form Lean Team, Identify Problem Area**

The researchers first met with upper-level management (president, vice president, and plant supervisor) to explain the goals of the project and timeline for completion. The research team was given 1 month to complete process improvements in one station of the plant. After meeting with management, the base-framing station was selected as the focus of the study. Afterward, the researchers met with the line leader to explain the purpose of the study and the process steps in which the base-framing crew would be involved. The lean team consisted of two authors (researchers), three graduate students, plant supervisor, plant vice president, line leader, and the base-framing crew (two to four workers).

**Analyze Current Process**

Approximately 1 week after selecting the base-framing station, 1 day was spent observing the current base-frame assembly process without interaction with the workers. Fig. 2 shows the space for the workstation before the start of work. Base framing is the first step in the modular homebuilding process and therefore is the first station of the plant. Any delays at this station will influence every station later in the process. The workers completed nearly two base frames during the day (e.g., 8-h shift), which was somewhat faster than the historical average of one frame per day, although the second frame was smaller than average (see Table 1 for dimensions). During the first frame assembly, a three-person research team observed the process to become familiar with the steps. Time and activity data were taken during the second frame assembly only. The following steps made up the basic tasks needed to assemble one base frame for any size house (Fig. 3):

1. Assemble rim joists (outer base frame);
2. Install joists and blocking (inner frame);
3. Install decking (first layer of flooring);
4. Attach casters used to transport the frame through the main production line; and
5. Transport frame to next station.

The first step involves preparation of rim joists, which includes marking and cutting treated wood boards followed by nailing of the treated boards at the bottom of the rim joists. The rim joists are then laid on to the iron fixtures and concrete blocks to stabilize and elevate the frame for ease of construction. The second step involves installing joist and blocking (all wood) between the rim joist frame. The third step, installing decking, is carried out by laying and gluing OSB over the frame made up of joists and rim joists. After

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**Fig. 1.** SLIK process steps (Ikuma and Nahmens 2010, with permission of the Institute of Industrial Engineers)

**Fig. 2.** Base-framing station work area

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| Step 1 | • Lean concepts introduction  
| • Form lean team  
| • Identify problem area |
|---|---|
| Step 2 | • Analyze current process (problem area)  
| • Perform initial JSA  
| • Identify possible improvements  
| • Select improvement alternative |
| Step 3 | • Implement process improvement  
| • Assess and document process performance after improvements |
| Step 4 | • Implement improvement refinements (if required)  
| • Assess and document process performance after improvement refinement  
| • Perform post-improvement JSA  
| • Initial and post-improvement comparative analysis |
| Step 5 | • Present results  
| • Celebrate success  
| • Plan next kaiZen |
the laying and gluing, OSBs are nailed to the frame. The fourth step is placement and nailing of the base frame over the casters in preparation for Step 5, transportation of the base frame to the next station.

The current layout of Station 1 consists of a large open area bordered by six columns, out of which two columns support the overhead crane for lifting materials and host the electrical outlets and air lines. The base station had several iron fixtures for supporting the base frame on one side of the station, and the other side of each frame was supported by concrete blocks. The materials for each base frame, such as rim joists, precut joists, oriented strand board (OSB), and casters, were staged around the perimeter of the working area. Tool carts were located against the factory wall, across the transportation lane from Station 1.

Time study and work sampling procedures were used to quantify the times and activities present in the second assembly process

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Initial</th>
<th>Postimprovements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base-frame dimensions</td>
<td>23.5 ft × 18 ft (7.16 m × 5.49 m)</td>
<td>48.9 ft × 18 ft (14.9 m × 5.49 m)</td>
</tr>
<tr>
<td>Base-frame area</td>
<td>423 ft² (39.3 m²)</td>
<td>880 ft² (81.8 m²)</td>
</tr>
<tr>
<td># of joists (inner)</td>
<td>17</td>
<td>35</td>
</tr>
<tr>
<td># of blockings</td>
<td>12</td>
<td>32</td>
</tr>
<tr>
<td># station workers</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Clock hours observed (excluding breaks)</td>
<td>4.22 hr</td>
<td>3.28 h</td>
</tr>
<tr>
<td>Total work hours observed</td>
<td>15.9 hr</td>
<td>14.9 h (does not include huddle)</td>
</tr>
<tr>
<td>Work hours/area</td>
<td>0.0375 h/ft² (0.405 h/m²)</td>
<td>0.0170 h/ft² (0.182 h/m²)</td>
</tr>
</tbody>
</table>

**Table 1. Characteristics of Observed Processes**

**Fig. 3. Process flow for base-framing station**

RIM JOIST

CUT RIM JOISTS

NAIL TREATED BOARDS
(BOTTOM OF RIM JOIST)

LAY RIM JOIST

GLUE & SCREW RIM JOIST

JOIST

CUT JOISTS

SCREW JOIST HANGERS

POSITION & SCREW JOISTS
TO RIM JOIST

NAIL JOISTS INTO JOIST
HANGERS

BLOCKING

CUT BLOCKING

LAY BLOCKING IN BETWEEN
JOISTS

SCREW BLOCKING TO
JOISTS

DECKING

GLUE THE RIM JOIST,
JOISTS AND BLOCKING

LAY THE DECKING OVER
FRAME

SCREW DECKING

CASTERS/WHEEL

LAY THE BASE OVER THE
WHEELS

SCREW BASE TO THE
CASTERS/WHEELS

FLOOR BASE

CUT EXCESS DECKING
(FLUSHED WITH RIM JOISTS)
for the first three steps of the process. One researcher collected
time study data for the first three steps, which are the most
time-consuming steps in the assembly process. Caster placement
and frame transport to the next station were not included in the data
collection. Two other researchers performed a modified work
sampling procedure to determine the percentage of time spent
on various activities (Aft 2000). Each researcher observed two
workers (there were four workers total at the station that day)
and recorded each worker’s activity once every minute. Activities
were classified as follows, with all activities after V considered
types of nonvalue-added (NVA) activities:
V: Value-added activity
I: Idle
W: Walking
M: Measuring
MT: Materials handling
A: Assisting another worker
D: Directions (giving or receiving)
T: Tools (transporting, loading, adjusting)
C: Cleaning
B: Break (personal)
IN: Inspection
NA: Not available (away from the station with no recognized
activity)

Perform Initial JSA

JSA is a systematic method of identifying hazards and controls of
each step of a process and is considered an important tool in system
safety (Friend and Kohn 2007). Each of the five steps identified
previously were analyzed in the initial JSA along with any materi-
als or tools needed to complete each step. Hazards present at each
step were identified, and any control measures for each hazard
that were currently in place were noted. The initial JSA revealed several
safety and ergonomic hazards that can be grouped into five general
categories.
1. Struck by: The use of electric or pneumatic nail and screw
guns, circular saws (table and handheld), large wood planks
(joists), other tools, and sawdust could all strike the body (legs,
feet, hands, eyes) and cause injury.
2. Slips/trips/falls: Tangled electric cords and air hoses, sawdust
on the floor, and not using proper means of ascending and
descending the base frame could lead to slips, trips, and falls.
Portable wood steps are available at the station to assist with
accessing the frame under construction, but observations indi-
cated that the stairs were seldom used.
3. Pinch points: Handling joists, floor casters, and cement blocks
all presented pinch hazards to the hands and feet.
4. Ergonomics: Awkward postures and forceful exertions during
cutting and assembly of heavy components and use of manual
hand tools could lead to muscular strain on the back, legs, and
hands/lower arms.
5. Industrial hygiene: Excessive noise during the use of auto-
mated tools and from the general factory environment elevated
noise levels to the point where crew members frequently
needed to shout to be heard. Sawdust presents hazards from
inhalation, and glue may also be hazardous if volatile organic
compounds (VOCs) are inhaled.

Implement Process Improvement

The crew was tasked with completing these changes in 1 week with
support from management. The researchers returned to the plant the
next week to assist with any layout changes, to train the line leaders
on new procedures, and to observe the process with the changes
in place. The base-frame assembly group was still adjusting to
the new process, so no postimprovement data was collected at
this time.

Assess and Document Postimprovement Process
Performance

The researchers returned 2 weeks later to perform data collection of
the improved process. The exact same methods were used as the
initial data collection, except five observers were used because
of an increase in crew size from four workers to five.

Implement Improvement Refinement (If Required)

The improvements implemented initially were readily accepted by
the crew and did show improvement in process times. Therefore, no
refinements were made

Assess and Document Process Performance after
Improvement Refinement

Not applicable, since no refinements were implemented.
Perform Postimprovement JSA
The same procedure for documenting safety hazards that were used in the “perform initial JSA” step was repeated with the improved process. Safety and ergonomic hazards in four of the five original categories were reduced or eliminated by implementing the process improvements.

Comparative Analysis of Initial and Postimprovement Processes
The process improvements were analyzed in terms of reduced process times, increased percentage of time spent on value-added activities, and decreased safety hazards. The results of the comparative analysis are shown in the “Results” section.

Present Results and Celebrate Success
The final comparative analysis was presented to the lean team approximately 1 week after the postimprovement processes were observed.

Results
The base-frame assembly crew was observed formally twice, 1 month apart. Two meetings to discuss improvements and to assist

with implementation occurred between these two observations. The characteristics of each observation (initial and postimprovements) are provided in Table 1.

The base assembly crew was able to implement the three proposed suggestions (morning meeting, angle irons, and sawhorses), and they made several more changes discussed during the meeting and implementation phase. The crew built two new rolling tool boxes to store frequently used items closer to the work area and changed material and tool staging to be more efficient. Materials were staged as close to points of use as possible, and tools were arranged such that cords and tools caused less interference with work surfaces, materials, and walking paths. All of the changes affected potential safety hazards, as discussed in the following sections.

Time Study and Work Sampling
Each step of the process was timed (time study), and specific activities of each worker were recorded each minute (work sampling) to determine the percentage of time spent on value-added activities, as described previously. These data are shown (Table 2) for initial and postimprovement observations. The addition of the morning meeting (huddle) is not included in the postimprovement
Changes in Safety
The following safety improvements resulted from the process improvements and follow the five categories defined in the initial JSA (Table 3).

Discussion
The purpose of this case study was to investigate the possible synergies in improving lean production strategies and safety levels simultaneously. The case study performed a kaizen in one station (base framing) in a modular homebuilding plant over the course of 2 months by using the SLIK process. Three major changes and several smaller changes were implemented through a series of meetings and working sessions, particularly layout improvements and revised standard procedures. These changes resulted in a 55% decrease in work hours needed to complete one base frame, a shift in activities from nonvalue-added to value-added in a 55% decrease in work hours needed to complete one base frame, a shift in activities from nonvalue-added to value-added of 16%, and a decrease or elimination of specific safety hazards. Because this was a case study and a sample size of one, no conclusions can be drawn regarding the statistical significance of these results. However, the practical implications of these results indicate success in reducing safety hazards and increasing productivity. These results are supported by Saurin and Ferreira (2009), who studied the effect of lean production on working conditions such as work content, work organization, and health and safety. The workers interviewed in that study reported improved health and safety with the implementation of lean production, mostly attributed to improved housekeeping and material handling (Saurin and Ferreira 2009).

Work hours per base frame decreased primarily because activities were made more efficient. Starting the day with a morning huddle or meeting ensured that all workers knew what work needed to be completed that day and what role each person would take on. In the postimprovement observations, the researchers noticed a decrease in the NA category from 6–10% to less than 1%. This category was primarily used when workers wandered away from the station but had not requested a break. This decrease may have resulted from workers being informed of their responsibilities during the morning huddle, or could also be attributed to having an outside group observing the process.

One concern in making processes more efficient is allowing enough rest and recovery time during physically demanding work

Table 2. Initial and Postimprovement Time Study and Work Sampling Results

<table>
<thead>
<tr>
<th>Step</th>
<th>Initial hours h/ft² (h/m²)</th>
<th>Postimprovement hours h/ft² (h/m²)</th>
<th>% improvement (reduction) labor hours</th>
<th>% value-added activity Initial</th>
<th>% value-added activity Postimprovement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Rim joist</td>
<td>0.00767 (0.0818)</td>
<td>0.00483 (0.0515)</td>
<td>37%</td>
<td>21%</td>
<td>51%</td>
</tr>
<tr>
<td>2. Joist and blocking</td>
<td>0.0123 (0.131)</td>
<td>0.00567 (0.0669)</td>
<td>53%</td>
<td>42%</td>
<td>63%</td>
</tr>
<tr>
<td>3. Decking</td>
<td>0.013 (0.140)</td>
<td>0.00533 (0.0573)</td>
<td>59%</td>
<td>32%</td>
<td>64%</td>
</tr>
<tr>
<td>4. Casters/wheels</td>
<td>0.0045 (0.049)</td>
<td>0.00117 (0.0126)</td>
<td>74%</td>
<td>36%</td>
<td>36%</td>
</tr>
<tr>
<td>Total</td>
<td>0.0375 (0.404)</td>
<td>0.017 (0.183)</td>
<td>55%</td>
<td>41%</td>
<td>57%</td>
</tr>
</tbody>
</table>

Note: Step 5 Transportation was estimated to last the same for both observations (0.00015 h/ft²) and is not included in the totals (improvements did not affect this step).

Table 3. Initial Safety Hazards and Improvements from SLIK

<table>
<thead>
<tr>
<th>Safety hazard category</th>
<th>Initial safety hazards</th>
<th>Changes after improvements to reduce hazards</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Struck by</td>
<td>Use of electric or pneumatic nail and screw guns, circular saws (table and handheld), large wood planks (joists), other tools, and sawdust</td>
<td>Using tools at waist/hip height with the introduction of sawhorses provided more control and thus reduced chance of striking the body</td>
</tr>
<tr>
<td>2. Slips/trips/falls</td>
<td>Tangled electric cords and air hoses, sawdust on the floor, and not using proper means of ascending and descending from the base frame (portable wood steps available but seldom used)</td>
<td>Optimizing tool placement by use and by power source reduced cords in walking paths</td>
</tr>
<tr>
<td>3. Pinch points</td>
<td>Handling joists, floor casters, and cement blocks</td>
<td>Replacing the concrete blocks with angle irons eliminated possible pinch points from kicking/shoving the blocks in place with the legs or foot</td>
</tr>
<tr>
<td>4. Ergonomics</td>
<td>Awkward postures and forceful exertions during cutting and assembly of heavy components and use of manual hand tools</td>
<td>Excessive walking was reduced by assembling all materials before starting construction, thus reducing fatigue</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Obtaining a second screw gun, eliminating the need to use a manual screwdriver repetitively</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Using sawhorses to cut material rather than bending over at ground level reduced strain on the back</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Replacing the concrete blocks with angle irons eliminated kicking/shoving the blocks in place with the legs or foot (None)</td>
</tr>
</tbody>
</table>
tasks. After SLIK, workers at the base-framing station had approximately 29% allowance that included time spent giving/receiving directions, idle, NA, and breaks (personal and plantwide breaks). Plantwide breaks consisted of a 15-min break in the morning and a 30-min break for lunch. Furthermore, idle time at the station did not change over the course of SLIK, accounting for approximately 8% of the working time. This category included pauses and micro-breaks. Therefore, while the work became more efficient, rest and recovery time for employees remained sufficient.

Overall the percentage of time spent on nonvalue activities decreased 16% after the improvements. The largest decrease in non-value-added activity occurred in walking. Because all materials and tools were setup before starting work and staged more efficiently, workers no longer needed to stop work, get materials/tools, and return. Walking decreased from 15–22% (depending on the process step) to less than 8%. Although not measured here, future studies should include the preparation time for obtaining these materials and tools at the beginning of each day, as this may offset some of the gains reported here.

Installing angle irons and using sawhorses for cutting improved productivity and safety. The non-value-added steps of arranging concrete blocks to support the frame was eliminated with the installation of permanent angle irons. This not only reduced the time needed to provide support to the frame, but also it eliminated several safety hazards related to potential muscle strains and pinch points associated with moving the concrete blocks. Using sawhorses for cutting reduced the possibility of material and tool damage, since the previous method was to cut joists on top of other joists, usually while leaning over. Cutting in an upright position also reduced back strain and improved control over the handheld powered tools, thus improving safety.

The results of this case study demonstrate that lean production strategies combined with safety analysis techniques may yield both improved productivity and safety (Table 4). From the table, lean strategies applied to several categories of lean waste (all except overproduction and excess inventory) showed a positive effect on safety. Although productivity and safety issues were presented as topics for improvements, the kaizen discussions focused on production rather than safety, possibly because of the company culture and goals. All improvements suggested were done so with the purpose of improving productivity and efficiency. Despite this, safety still improved as a by-product of making the process leaner. Additionally, several hazards were reduced through changes made outside of the improvement meeting. The crew voluntarily built tool boxes and rearranged the placement of powered tools, which reduced walking times and tripping hazards from multiple cords crossing walking paths. Again, the main motivation for these changes was to improve production, but the changes positively influenced safety as well.

Lean tools such as kaizen directly change processes and, as this study shows, change safety levels in construction environments. A closely related concept, safety in design, can also be integrated into this discussion of process planning and effects on safety. Safety in design incorporates safety considerations and features into construction designs from early stages of planning. Although poor design has been attributed to up to 42% of fatalities in construction (Gambatese et al. 2008), researchers (e.g., Fritjirs and Swuste 2008; Gambatese et al. 2005; Seo and Choi 2008; Weinstein et al. 2005) have found success in using the safety in design concept to improve construction safety. In future work, lean tools and principles may be used as part of safety in design efforts. With a focus on safety and efficiency, construction management can meet the challenges of productivity and safety in construction processes.

### Limitations

The SLIK process was largely successful, although time constraints prevented the research team from conducting part of the fourth step, implementing refined process improvements. Future studies should investigate the effect of continual process improvement with feedback rather than a single event, as was done in this study.

Despite the reduction or elimination of several safety hazards, many safety hazards still remained in the base-frame process and work environment. These safety hazards were plantwide concerns, such as noise, which made tackling these issues a larger problem than could be addressed during the 1-month duration of the project. Future work may investigate the possible reversal of this observation: making safety the goal of the process improvement and see if productivity and efficiency increase as a side effect of improved safety. There is evidence that safety programs can positively influence productivity (Maudgalya et al. 2008), so explicitly including safety in lean production has the potential to benefit safety and productivity. The idea of safety and ergonomics positively affecting process improvement efforts is also supported by an industry study in which ergonomics interventions led to increased productivity.

<table>
<thead>
<tr>
<th>Lean waste</th>
<th>Implemented change</th>
<th>Effect on productivity</th>
<th>Effect on safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overproduction</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Excess inventory</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Excess transportation of goods</td>
<td>Moved materials closer to point of use, built tool boxes to keep tools closer to point of use, power tools moved closer to power source and point of use</td>
<td>Reduced time and distance needed to retrieve materials and tools</td>
<td>Reduced trip hazards from excess cords, reduced fatigue from less walking required</td>
</tr>
<tr>
<td>Excess movement of people</td>
<td>Materials and tools gathered for the day once</td>
<td>Less wasted time retrieving tools and materials during the workday</td>
<td>Reduced fatigue from less walking to get materials and tools</td>
</tr>
<tr>
<td>Defects</td>
<td>Used sawhorses to cut material</td>
<td>Reduced chance of damaging material</td>
<td>Reduced awkward postures and reduced chance of striking body with cutting tools.</td>
</tr>
<tr>
<td>Overprocessing</td>
<td>Installed angle irons to position frame</td>
<td>Reduced time needed to position cement blocks and helped align frame to be square</td>
<td>Reduced chance of pinch point for foot/leg and reduced chance of muscle strain from kicking blocks in place</td>
</tr>
<tr>
<td>Waiting</td>
<td>Morning huddle conducted to assign tasks for the day</td>
<td>Workers did not need to stop and ask for directions, thus less wasted time</td>
<td>Any safety precautions could be noted during this meeting.</td>
</tr>
</tbody>
</table>

Table 4. Effect of Changes on Productivity and Safety, by Lean Waste Category

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and cost savings along with decreased safety concerns and risk for musculoskeletal injury (Lee 2005).

Another limitation of the study was the use of one specific work environment: modular homebuilding. Although modular homebuilding is essentially a residential construction process, this industry has characteristics of manufacturing attributed to standardized processes and controlled environments. On-site residential construction is less predictable because of the weather, the coordination of various contractors, and constantly changing job sites. Implementing lean concepts and tools on construction sites raises many challenges inherent with the changing environment and the “parade of trades” (Tommelen et al. 1999). Salem et al. (2006) found that there is need for behavioral changes and training for effective use of lean tools and concepts for the site construction. This variability may make the outcomes of using the SLIK process more difficult to maintain because decisions made at a particular time may not be optimal in changing environments. The JSA process used in the current SLIK model is ideal for processes that are repeated under the same conditions. However, variability in on-site construction indicates that safety risk also fluctuates. The JSA may need adjustments to adapt to variable on-site construction environments, such as by using construction job safety analysis (CJSA) instead (Rozenfeld et al. 2010). Rather than evaluating hazards and mitigation alternatives for a set process, CJSA provides a probability of incident occurrences and could be used to estimate risk (Rozenfeld et al. 2010).

**Lessons Learned**

In the interest of continuing the SLIK process in future studies, several lessons learned are presented either as cautions or recommendations.

1. Focus on the process rather than personal issues: The tendency to blame other workers for shortcomings or to allow personality conflicts to influence decisions was very high. It was critical for the researchers to maintain a focus on process improvement and avoid allowing employees to blame conditions beyond their control. Once employees realized that this was not a personal fault-finding process, they were very willing to discuss process improvements.

2. Determine the kaizen purpose before the first brainstorming meeting. As mentioned previously, company culture may have influenced the focus of the kaizen events. Although the researchers encouraged the workers to think about safety in developing improvements, production remained the focus. In observing the everyday workings in the plant, the researchers noticed that safety seemed to be of lower importance than production. Supervisors often set a poor example by not wearing personal protective equipment (PPE) on the floor, and management did not attend the monthly safety meeting that occurred during the 2-month study period, which was given by a third-party consultant. The behavior of employees also showed a lack of safety awareness through inconsistent use of PPE, despite clear signs and taking shortcuts, such as jumping from platforms rather than using steps, using nail guns as arm supports, and not stopping to take care of small injuries.

3. Ensure understanding of the kaizen method and purpose throughout the work crew and management. Another meeting after the first brainstorming meeting would have improved the current study to make sure employees were able to make the proposed changes and provide any assistance needed for unforeseen obstacles. Management needed to be better informed of the purpose and method of data collection. In our first post-improvement measurement attempt, supervisors kept jumping in to help out. Because of the misunderstanding of our purpose, the research team had to disregard this data and conduct a second data collection effort to avoid the bias from this help that was out of the ordinary.

4. Use process ownership for motivation to improve results. The researchers learned that the workers overall were very willing to make improvements, especially when they could be in control of those changes. Although the original goal was to make only three changes because of the time constraints, the workers were willing to make several other changes that came up during the meeting. Once the workers had permission from the plant supervisor to change what they thought would help them the most, the workers built sawhorses and two tool boxes in the course of a week. Having ownership over their work area was a powerful motivator.

**Conclusion**

This case study illustrates the potential power of combining lean and safety strategies through the SLIK process to improve production and safety. Anecdotal evidence obtained through ongoing discussions with management indicates that this group of workers has been able to maintain most of the momentum in work efficiency. At the beginning of the study, the base-framing crew was considered one of the weakest in the plant. Now they serve as an example of what teamwork, motivation, and creativity can do for the work environment. The SLIK process used to achieve these results can be adapted to other areas of construction and general industry to improve processes. By using the SLIK process as the lean strategy, productivity and safety improved through relatively simple, low-cost improvements to the immediate environment surrounding the work area.

**References**


