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## Impact of Lean production on workers' exposure to risk in modular home building manufacturing

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# **IMPACT OF LEAN PRODUCTION ON WORKERS EXPOSURE TO RISK IN MODULAR HOME BUILDING MANUFACTURING**

A Thesis  
Submitted to the Graduate Faculty of the  
Louisiana State University and  
Agricultural and Mechanical College  
in partial fulfillment of the  
requirements for the degree of  
Master of Science in Industrial Engineering  
In  
The Department of Construction Management & Industrial Engineering

By  
Joel James  
B.S., Visvesvaraya Technological University, 2006  
May 2012

## **DEDICATION**

To my father, who stood by me always and knew I would succeed. Gone but not forgotten. I will miss you forever dad. Thanks for all you have done. This thesis is dedicated to my God, you, my mother and my brother.

## **ACKNOWLEDGEMENTS**

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## **ABSTRACT**

The construction industry records the highest number of work-related injuries and fatalities in the United States according to the Bureau of Labor Statistics. Workers' exposure to risk may be affected by implementing Lean concepts. This study describes the effects on worker's safety environment after a Kaizen event, a Lean tool, conducted in three workstations within a modular home manufacturer: base-framing, sheet-rock hanging, and painting. The effects of Lean on safety hazards at each of the three workstations were determined by conducting a Job Safety Analysis (JSA) before and after each Kaizen. Based on the JSAs a risk assessment tool (questionnaire) was developed to determine the workers' exposure to risk before and after each Kaizen. This study also focused on determining the reliability of the risk assessment tool. Twelve students with prior knowledge of safety and four certified safety experts completed the questionnaire by rating probability and severity of a list of hazards potentially present in each workstation. According to students there was a significant reduction in risk values for base-framing station and sheet-rock hanging station. Whereas, according to safety experts significant reduction in risk values was confined to base-framing station. Based on the reliability analysis the risk assessment tool was reliable in measuring risk at each of the three work station as per safety experts, and as per students the reliability was confined to only sheet-rock hanging station. As per the reliability analysis the finding of safety experts should be supported. The safety experts supported the finding that Lean showed significant reduction in risk values in base-framing station. Thus, it could be concluded from the study that Kaizen could occasionally reduce or eliminate specific safety hazards.

# **CHAPTER 1**

## **INTRODUCTION**

Occupational safety is one of the major concerns throughout the world. Of all industries the construction industry is one of the most dynamic and hazardous industries (Rozenfeld et al., 2010). Frequent work team rotations, exposure to weather conditions, and high proportions of unskilled and temporary workers are some of the unique factors of construction sites (Rozenfeld et al., 2010). Unlike other production facilities, construction projects undergo changes in topography, topology and work conditions throughout the duration of the projects (Rozenfeld et al., 2010). According to the Bureau of Labor Statistics (BLS, 2011) the construction industry is the most hazardous, which records the highest number of work-related injuries and fatalities, and therefore occupational safety has been a major concern in this industry. Compared to private industries and construction industries, prefabricated wood building manufacturing experiences higher injury and illness rate (BLS, 2011).

Lean, a managerial approach was developed by Toyota (Ohno, 1988) in a manufacturing industry, helped to reduce waste and improve quality, cost, and productivity of the manufacturing industry (Wong et al., 2009). After the success of Lean implementations in the manufacturing industry, Lean was also adopted in the construction industry (Salem et al., 2006; Thomas et al., 2003).

Studies have stated that implementing Lean affects workers' exposure to risk. Nahmens and Ikuma (2009) stated that Lean is not only beneficial in process improvement and waste reduction, but its application is associated with improved safety in the construction industry. A study by Landsbergis et al., (1999) had a contradicting opinion about the impact of Lean on workers' health. Landsbergis et al., (1999) claimed that implementation of Lean manufacturing

intensifies work pace and demands which could result in musculoskeletal injuries. Also, the increase in skill level and decision authority obtained by implementing Lean can result in job strain and pressure on the workers. These contradicting opinions of various researchers motivated the need to further study the impact of Lean on safety.

There is no considerable evidence to conclude whether implementing Lean in the construction industry has any positive effect on workers' exposure to risk. To understand the relationship between Lean and workers' exposure to risk a study was conducted in a modular homebuilder in the United States. The modular home building industry manufactures stick build houses and SIP (Structural Insulated Panels) houses within a factory environment. Kaizen was implemented on three workstations of the modular home building unit: base-framing, sheet rock hanging, and painting stations. A risk assessment tool was used to calculate the risk values of activities performed before and after implementing Lean. The aim of this study is to determine the impact of Lean production on workers' exposure to risk in modular home building manufacturing.

The scope of this research is to evaluate the impact of Lean principles on workers' exposure to hazards in a modular home building manufacturer. A questionnaire containing a detailed explanation of the procedures carried out at individual workstation, and a list of hazards identified for each activity was to evaluate the workers' exposure to hazards for the baseline and the improved processes. Individuals having knowledge on safety was asked to participate in the experiment and to rate the probability and severity of the identified hazards. Statistical analysis was performed to determine the impact of Lean on workers' exposure to hazards in modular home building manufacturing and the reliability of the rating instrument. Some of the limitations associated with this study are:

1. The study is limited to only three workstations (base-framing station, sheetrock hanging station, and interior painting station) of a modular home manufacturer.
2. The results of this study can be summarized only to the modular home building industry and not for all construction industries.

The overall goal of this study was to further explore the effects of Lean on workers' exposure to hazards, and whether these effects are positive or negative. The result of this study provided a better understanding of the impact of Lean on workers' exposure to risk in the modular home building industry.

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 Lean Construction Overview

The Lean production system was developed by Toyota (Ohno, 1988) in a manufacturing industry where it led to ground-breaking changes. Ballard (1998) stated that Lean focused in getting right thing at right place and in the right quantity to improve productivity while reducing waste. A Lean production system continuously seeks to minimize waste. These wastes are grouped into seven categories (Madden, 2005):

- **Correction** (doing it twice): Repair or reworks, quality problems (defective parts), schedule variances.
- **Overproduction**: Producing more than that is needed or before it is needed (parts, production, information etc).
- **Motion waste**: Movement that is inefficient and/or adds no value to the process.
- **Material movement**: Unnecessary transport of raw materials, parts paper work information, and finished goods.
- **Waiting** (delays): Any non working time like, waiting for tools, parts supplier's information, etc.
- **Inventory**: Maintaining excess inventory of raw materials, work in progress, and finished good.
- **Processing** (over processing): Doing more work than that is necessary or making work more complex than that is necessary.

Lean production focuses on reducing these wastes by following five fundamental principles (Womack and Jones, 1996):

- Identifying the value of the product from the customer prospective.
- Identifying the value-stream from the production to the time the product is delivered into the hands of the customer.
- Making the product flow continuously through the value stream by eliminating waste.
- Introducing pull between all steps.
- Seeking perfection.

A few of the Lean tools developed by TPS (Toyota Production System) which are commonly used by industries to reduce waste are continuous improvement (Kaizen), just-in-time (JIT), Poka-yoke, 5S, standardized work, product mix leveling (Heijunka), quality control (Jidoka), Plan-do-check-act (PDCA), Single-Minute Exchange of Die (SMED), and total preventive maintenance (Wong et al., 2009).

Implementing Lean in a production industry yields several benefits including waste reduction, production cost reduction, reduction in production cycle time, inventory reduction, higher quality, higher profits, higher system flexibility and improved cash flow (Wong et al., 2009). Lean production also helps in improving labor utilization, which leads to better labor performance and productivity (Thomas et al., 2003). Implementing Lean is not always an easy process; it may face some obstacles like lack of support from top management, failure of past Lean projects, not recognizing financial benefits, time constraint to implement Lean, lack of knowledge to implement Lean, company culture not supporting the implementation of Lean, budget constraints, employee resistance to change and backsliding to the older ways of working (Wong et al., 2009).

Lean has been applied in various industries. After the success of Lean in the manufacturing sector a step has been taken forward to analyze the effects of Lean in the

construction sector (Salem et al., 2006). Both industries focus on meeting customer requirements within the time period with high quality and low cost. The Lean production concept was introduced in the construction industry because of its success in the manufacturing industry.

Construction and manufacturing differ in their processes and the techniques of assembly. Despite differences in assembly environments and processes, Lean production and Lean construction techniques share many common elements. In manufacturing the end products can be moved as a whole directly to the customer. The three different features of the construction industry that distinguish it from manufacturing are on site production, large level of customization, and complexity (Koskela, 2002). The combined effect of these features of construction makes it uncertain and complicated; whereas, in manufacturing processes one can have control over the production thus uncertainty can be reduced (Salem et al., 2006). This could be the reason why Lean production theories do not fully fit in construction industries (Salem et al., 2006).

Implementing Lean production principles has yielded positive results in the construction industry. Ballard and Howell (1994) proposed a way of implementing Lean on fast and complex projects. Ballard and Howell (1994) showed that implementing Lean on fast and complex projects helped in improving productivity and reducing costs and duration of projects. This was achieved by using Lean tools like Last Planner which helped in scheduling the project and stabilizing the work environment through proper planning processes. Salem et al., (2006) conducted a case study on general contractors in Ohio. This study implemented six Lean tools namely: Last Planner, increased visualization, huddle meetings, first run studies, 5S, and fail safe for quality on a parking-garage project for a period of six months. These tools were separately implemented in planning and working phases. The planning phase focused on operational

planning, and included the involvement of subcontractors and the staff; whereas, the working phase focused on improving the work activities, and included the involvement of the work team, led by the foreman, laborers and carpenters. The research team collected data to monitor the progress on the implementation of each Lean construction tool. Their implementation helped in completing the project within the set schedule and under budget. It reduced incident rates, and also helped in improving the relations between sub contractors and general contractors.

Hook and Stehn (2008) discussed the implementation of Lean principles in construction, particularly in the industrialized homebuilding industry. A production questionnaire survey conducted by Hook and Stehn (2008) on seventeen Lean practices showed that industrialized housing production displayed a project-based culture similar to that found in on-site construction, where the workers show lower motivation for error proofing and continuous improvement. Hook and Stehn (2008) stated that successful implementation of Lean in industrialized housing required the involvement of top management as well as the employees working within the organization.

## **2.2 Kaizen**

The term 'Kaizen' is a Japanese word for 'improvement' or 'change for better' (Brunet et al., 2003). The main aim of Kaizen is to enhance the process and the work environment by reducing waste (Brunet et al., 2003). Kaizen helps in adding value to the product and reducing waste or non-value added activities (PPDT, 2002). Brunet et al., (2003) said that Kaizen helps in creating a mindset in which the organization begins to accept changes and new technologies to improve the process. Kaizen consists of team activities, and it provides opportunities for employees to contribute to the company's development (Brunet et al., 2003). A Kaizen team is generally cross-functional to achieve goals (Farris et al., 2008). Kaizen are usually short and



focus on achieving their goals in a limited time period (Farris et al., 2008). An increasing number of companies are using Kaizen, and its application has led to improvement in the performance of companies (Farris et al., 2008).

According to the Productivity Press Development Team (2002), Kaizen events are divided into three phases. The initial phase is the planning and preparation. In this phase the Kaizen team observes the current process and identifies the process that has significant bottleneck or major impact on productivity, and determines the area where the Kaizen has to be implemented. In the intermediate phase the Kaizen team observes and gathers data about the baseline process to analyze the process. Upon the presentation of these data, the Kaizen team along with the workers brainstorms to determine the root cause of the problem and eliminate waste. The team implements the improvement ideas and compares the improved process with the old process. The final phase includes the presentation of results, celebration, and follow-up. In this phase the team members prepare a presentation and present the results to the organization. The Kaizen team circulates the results to the top management and to all employees and celebrates their success.

The Productivity Press Development Team (2002) also claims that Kaizen benefits both the organization and the employees working within the organization. Kaizen is easy to implement, and implementing Kaizen does not require large time commitment (Jacobson et al., 2009). In terms of organizational benefits, Kaizen helps in eliminating hidden costs, improves the operations by eliminating the non value added activity, and improves the quality of the product (Styhre 2001). Implementing Kaizen in organizations also helps to achieving low-cost, low-risk improvement (Jacobson et al., 2009). In the case of individual benefits, Kaizen helps in eliminating wasted motions and delays in the work. The elimination of wasted motion and delay

may reduce the workers exposure to risk. Thus, the individual benefits gained from Kaizen events can help to improve the safety of the workers environment. According to Styhre (2001) Kaizen provides an opportunity for easier operation, low cost, new possibilities for work operations, and opportunities for personal development.

Other than improving the process and reducing the waste, Kaizen can also reduce the manufacturing cost of a product. Initially many US firms had used the traditional standard costing system to control manufacturing process cost, but such systems were inefficient (Modaress et al., 2005). Methods like Kaizen costing which focuses on incremental improvement of production cost in manufacturing cost, and value added analysis has reduced the manufacturing cost of a product (Modaress et al., 2005).

### **2.3 Safety Issues in the Construction Industry**

Occupational safety is one of the major concerns throughout the world. The construction industry is one of the most dynamic and hazardous industries, which makes it both unique and challenging. This is due to the diverse and complex nature of work tasks, trades, and environments, as well as the temporary and transitory nature of construction workplaces and the construction workforce (Ringen et al., 1995). Modular home building industries are subjected to higher injury and illness rate in comparison to other private construction industries (BLS, 2011). The injury and illness rate for modular home building industries and other private industries in the United States between the years 2003-2007 are shown in Figures 1 and 2 respectively. The high injury and illness rate in modular home building industries provided the motivation to analyze the safety issues in this thesis.

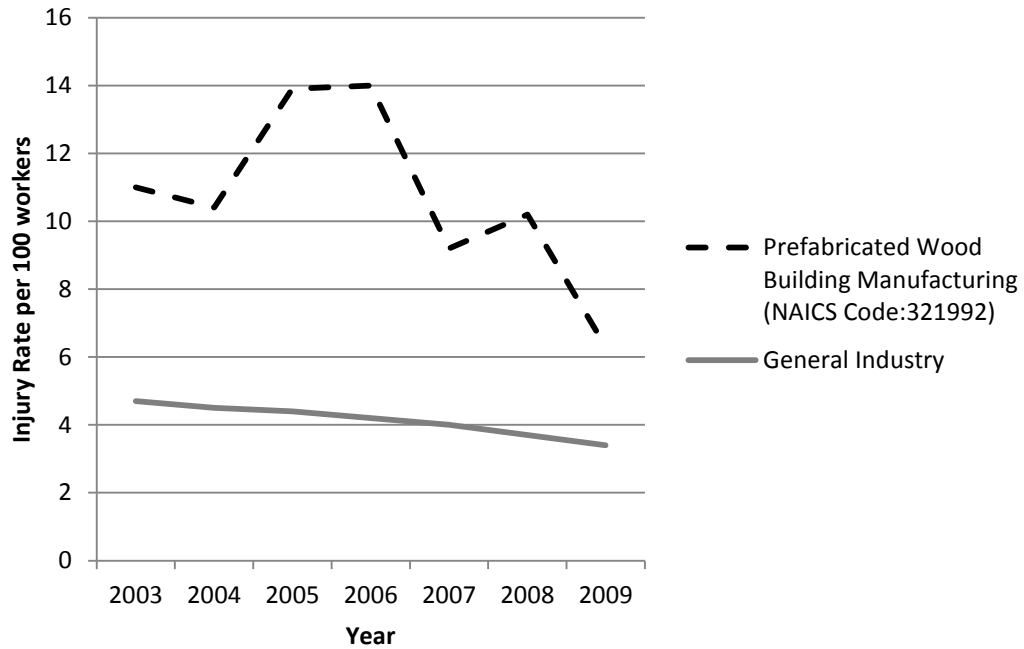


Figure 1: Injury rate per 100 full time workers for private industries, and modular home building industries in US

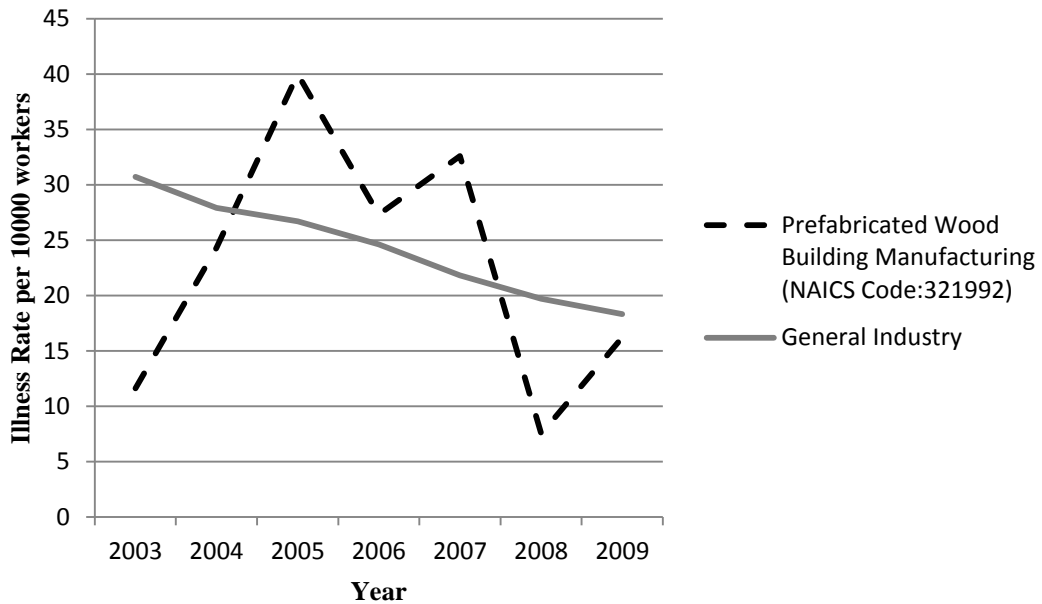


Figure 2: Illness rate per 10000 full time workers for private industries, and modular home building industries in US

The construction industry experiences high rates of work-related fatal and non-fatal injuries. According to Zeng et al., (2010), roof related falls, elevator shaft falls, falls from holes in flooring of construction sites, hit by falling objects, and run over by operating equipment were considered the most risky events in the construction industry. BLS (Bureau of Labor Statistics) stated that the work related fatal and non-fatal injuries in the construction industry are mainly caused by struck-by or struck-against object, falls including slip-trips, and overexertion (2010). The most frequent types of injuries in the construction industry are sprains and fractures, and the most common injured body part is the lower extremities (BLS, 2010). These injuries not only result in human suffering but also result in large economic burden on workers and employers (Findley et al., 2004).

Struck-by object has been a serious cause of injury worldwide. Zeng et al., (2010), stated that struck by and run over by operating equipment on site caused serious fatal injuries. Dufort et al., (1997), stated that the external causes of injuries in construction industry was mainly caused due to struck by or thrown against an object. Heavy equipment used to perform lifting operations can cause serious struck-by object hazards. Such operations cause risk of falling objects when materials are moved over-head. Sertyesilisik et al., (2010) investigated the effects of lifting operations on workers safety in construction sites by exploring different options, their effectiveness, and their effect on safety. The researchers investigated three construction sites, and studied their processes, the factors taken into consideration when placing and using lifting equipment, and the skills required by the operator while operating equipment. The researchers interviewed the general site staff, managerial staff, and appointed persons to gain advice to improve the safety at the workplace. The study revealed that planning, training, equipment selection, communication, appointed person's role, and database could help in improving safety

in lifting operations. Sertyesilisik et al., (2010) further stated that these six recommendations are also applicable for improving all forms of work, health, and safety at a construction site.

Falls to lower level represent a significant portion of fatal and non-fatal injuries among construction workers. Falls from roofs, scaffolds, and ladders account for approximately 30% of the total work-related fatal accidents in the construction industry, and 90% of these fatal accidents involved workers in private industry (BLS, 2011). According to Cheng et al., (2010), workers in the construction industry do not take their personal safety seriously. The main reason for workers to suffer fall injuries when working in high elevated platforms is because of the absence of personal protective equipment (Cheng et al., 2010). To reduce the number of fall accidents in the construction industry, Benjaoran and Bhokha (2010) introduced an integrated rule-based system using 4D CAD model for managing safety and construction activities. This system integrated safety with the construction management process throughout design, planning, and control phases. The rule-based system analyzed the design information about building components and planning information about activities to automatically detect any working-at-height hazards. Necessary safety measures in terms of activities and requirements were provided by the system. According to Benjaoran and Bhokha (2010), such systems are beneficial for small companies having medium to small construction projects in which full time safety officers are not present. Such a system will help the project engineers to manage safety and construction simultaneously and make the construction site a safe work place.

Slips, trips, and fall to the same level are also considered to be a serious source of injury in the construction industry. About \$6 billion per year was the estimated annual direct cost in the US of occupational injuries related to slips, trips, and falls (Courtney et al., 2001). The musculoskeletal injuries caused by non-fall slips and trips were considered to be the most costly

injuries (Lipscomb et al., 2006). According to Lipscomb et al., (2006), the most frequent contributor to slip and trip injuries in the construction industry are environmental factors including walking and working surface conditions, weather, and terrain. Age also played an important factor in such injuries. Lipscomb et al., (2006) claimed that older workers were subjected to a greater number of slip and trip injuries compared to younger workers. A similar finding was found by Kemmlert and Lundholm (1998), who stated that lack of orderliness of the work place and unsecure climbing devices were the causes of slip trip and fall accidents. Lipscomb et al., (2006) concluded that in order to reduce the occupational injuries caused due to slip and trip in the construction industry, the organization needs to focus on environmental and organizational solutions that evolve as the site changes and the construction project evolves.

Few studies have examined the effect of over exertion on worker safety within the construction industry. Fung et al., (2008) studied the frequency of musculoskeletal disorders among workers in the construction industry. According to Fung et al., (2008) the construction industry involves repetitive and laborious tasks like transporting, lifting, and moving heavy equipment or materials. Moreover, the construction work is also categorized by heavy lifting, pushing, and pulling (Holtermann et al., 2010). Such activities in the construction industry are responsible for musculoskeletal disorders, particularly in upper extremities and lower back (Fung et al., 2008; Sobeih et al., 2009). Lipscomb et al., (1997) studied work related musculoskeletal injuries among carpenters and stated that the drywall workers, handling heavy and awkward loads were exposed to high risk of musculoskeletal injuries. Fung et al., (2008) stated that good on site housekeeping would help reduce unnecessary accidents and symptoms occurrence.

Management also plays an important role in controlling work related occupational accidents. Occupational injuries are also caused due to negligence of management or workers

(Cheng et al., 2010). Companies with fewer than 10 employees and insufficient work experience are associated with more occupational accidents (Cheng et al., 2010). Most accidents are caused by the failure of management to implement adequate safety measures to protect the workers from the hazardous working environment and because of the unsafe acts practiced by the workers themselves (Cheng et al., 2010). Cheng et al. (2010) also stated that lack of training and poor safety awareness on the part of the project managers were the major causes of high accident and illness rates. Thus, in order to minimize job-site accidents the organization should promote safety management in the working environment, provide training for workers, and enhance management emphasis on proper safety procedures (Cheng et al., 2010).

Overall, the most industry spends millions of dollars on workers compensation due to occupational injuries and illness. The construction industry is very hazardous and needs good occupational safety programs. According to the BLS (2011), construction workers experienced the highest number of work-related injuries and fatalities. Comparatively modular home building industries are more risky to private construction sites which lead to fatal injuries, risks and economic burden to workers and employees of construction industry. Struck-by or struck-against object, falls including slip-trips, and over exertions are the major work related fatal and non-fatal injuries in the construction industry (BLS, 2011). The causes of such injuries needs analyzed and appropriate protective measures should be taken to reduce the number of injuries and illness.

## **2.4 Safety Analysis Tools**

Most construction projects are dynamic and unique. The construction industry involves several activities which are dependent on physical environmental conditions. The construction industry also involves tasks that require involvement of main contractors and sub contractors at the same time. This dynamic nature of the construction industry makes it difficult to manage

safety as compared to manufacturing industries. Past studies have introduced new methods and tools to analyze and reduce the workers' exposure to risk.

Several field measurement methods and tools have been used by safety experts to estimate workers exposure to risk. Spielholz et al., (2001) provided an overview of three primary methods of risk factor exposure assessment:

- **Self-report questionnaires:** This type of analysis is mostly used in field studies. Generally, the workers performing the task are asked to estimate their exposure to risk while performing the task. These estimates can be used alone or can be used in combination with measurements obtained by using other methods.
- **Direct observation/Observational video analysis:** Such analysis is used where the workers are directly observed or video taped and studied. The workers performing the task are directly observed or videotaped, and then analyzed by researchers. One of the advantages of video analysis is that it allows more detailed and reproducible evaluation because of the availability to review the data from the video tape.
- **Direct measurement:** This type of analysis is used in field based studies. Various instruments like electromyography (EMG) to record muscle action, electrogoniometer to record joint/limb movement, and video-based motion measurements are frequently used in such type of analysis.

Of the above tools, self-report analyses are usually considered economical, convenient, and non-interruptive for the worker while he performs the task. Further, these require less data collection and assessment time. The results of the study by Spielholz et al., (2001) indicated that of the three methods, self-report overestimated the exposures to risk factors, and were considered to be the least accurate assessment method. Moreover, the self reported analysis captures only



low level of details. Details such as joint angle and muscle activity could not be determined by using self-report analysis. Such details can be determined by using observational video analysis and direct measurement. Spielholz et al., (2001) stated that the observational video analysis would be an appropriate method to be followed for measures of repetition, and for measures of duration in a large study; whereas, for a small study direct measurement method could be considered appropriate.

A study by Juul-Kristensen et al., (2001) evaluated the postures and movements of workers during repetitive work using video-based observation and direct technical measurements, and concluded that the direct technical measurement were more accurate than the video-based observation method. The advantage of direct technical measurement is that it provides opportunities to perform detailed and precise data collection, which are required in jobs with different work tasks (Juul-Kristensen et al., 2001). On the contrary, the equipment cost, difficulty of use, detailed data collection and data analysis time, restricts the use of large number of subjects for the data analysis. Risk assessment tools have the advantage of being cheap, systematic, qualitative, and easy to understand and use. Risk assessment tools are considered to be effective in assessing hazards and unsafe conditions within industries.

Reniers et al., (2005) presented an overview of the following six most popular risk analysis techniques and underlined the following techniques.

➤ **HAZOP (Hazard and operability) study:** This method is a structured and systematic examination of a process to identify and document hazards through imaginative thinking. A HAZOP is a qualitative technique to rank risks, and is usually carried out by teams.

➤ **Checklists:** This method consists of lists of questions about process or operations, organizations, and other areas of safety concerns. Checklists are easy to understand and use, and are generally used for operational safety and hazard identification.

➤ **Risk Matrix:** The risk matrix method is a systematic and effective method of estimating risk. It calculates the probability and severity of an individual hazard, and categorizes the risk. Based on the priority list suitable prevention and protection measures can be taken. This method is a risk evaluation method, and is used to rank risks. Marhavidas and Koulouriotis (2008) presented a decision matrix risk assessment technique for calculating the quantified risk. The risk of a particular hazard was calculated by determining the probability and severity of a hazard. The formula was given by the equation:  $R=PS$ ; where R is the risk, P is the probability of occurrence of a particular harm factor, and S is the severity of the harm factor. This equation helps safety management to set priorities for attention to hazardous situation.

➤ **What-if analysis:** What-if analysis is a brainstorming approach which analyzes the consequences of an accident. In this approach the team uses broad and loosely structured questioning to determine the consequences that may result in an accident or system performance problem.

➤ **FTA (Fault Tree Analysis):** Fault Tree Analysis focuses on one particular accident event and presents a method for determining causes of that event. This method breaks down the chains of failures and identifies the combination of faults that causes other faults. In this method an undesired state of a system is analyzed using boolean logic to combine a series of lower-level events. Fault Tree Analysis provides a systematic description of the combinations of all likely occurrences in a system that can result in failure.

➤ **Safety audits:** In this method the analyst examines the existing process. Upon analyzing the existing process analyst focuses on identifying the potential hazards in the process. Moreover, action needed to mitigate or eliminate these hazards are discussed and implemented.

Of these methods, the HAZOP, What-if analysis, and FTA techniques were used to check process safety; whereas, Checklists and Safety audits were used to analyze operational safety (Reniers et al., 2005). Such tools have proved to be useful in attaining the goals. The risk assessment tools are proactive, and try to identify all possible hazards in the work environment leading to precaution measures. Marhavilas and Koulouriotis (2008) stated that risk matrix helped in mathematical evaluation of risk, and was more convenient in usage. One drawback of decision matrix is that its end result mainly depended on the opinion of the safety managers or production engineers (Marhavilas and Koulouriotis 2008). The application of risk tools usually required a lot of time and involvement of efficient safety managers to record the hazardous events. To overcome such difficulties Job Safety Analysis (JSA) methods were adapted by many safety analysts. JSA had the advantage of being proactive, easy and convenient to use.

JSA is frequently used by safety specialists to analyze hazards at work sites. JSA, also known as Job Hazard Analysis, was first developed at manufacturing sites, and was used as a proactive measure for assessing the risk levels for various activities in industrial manufacturing settings (Rozenfeld et al., 2010). The JSA method is an effective tool for analyzing safety and planning the safest way to perform a task (Rozenfeld et al., 2010). The implementation of JSA in its current state has not been so successful in the construction industry (Rozenfeld et al., 2010). This could be because construction projects are characterized by team rotations where the workers have to move through the site in the course of work, and due to this the workers are

often endangered by activities performed by other teams (Rozenfeld et al., 2010). The standard JSA is not designed to reveal the risk caused by activities performed by other workers, since it focuses on production activities in isolation at a particular workstation (Rozenfeld et al., 2010). To address this fact “Constructional Job Safety Analysis” (CJSA) was developed to analyze hazards for construction activities (Rozenfeld et al., 2010). This method is used to collect detailed information about individual construction projects, and its end result provides information about the likelihood of exposure to various safety hazards through the execution of the project. The CJSA is comprised of three steps (Rozenfeld et al., 2010):

- **Identify potential hazards at the workplace-** In this step the analyst selects the job to be analyzed, observes the current procedure practiced to accomplish the job, breaks down the process into a sequence of activities, and identifies the workers’ exposure to hazards while performing the task.
- **Assess the probability of accidents-** In this step the analyst evaluates the probability of occurrence of each activity, the influence of the different managerial and environmental factors that affect the expected rates of occurrence, and the degree of use of personal safety equipment. The probabilities of accidents are determined by surveying the construction superintendents. The survey instrument involves a set of questions for individual activities.
- **Assess the severity of the accident-** In the final step of the CJSA method the analyst determines the relative probabilities of severity for each of the hazards identified in the initial step. The ratings for the severity of accidents are obtained by interviewing the safety experts.

The process of CJSA is closely related to the standard JSA approach. The first two stages of CJSA (identification of hazards and evaluating the relative level of risk) are similar to the

standard JSA approach, but CJSA does not focus on controlling the risk by taking sufficient measures to reduce or eliminate the risk; it provides a large knowledge-base describing all possible loss-of-control events (Rozenfeld et al., 2010).

JSA and CJSA are detailed, complicated and required greater time in collecting and analyzing data; thus, restricting the frequency of use. Usually techniques which are systematic, easy to use, qualitative, and efficient are more preferred in analyzing the safety of a work place. The current study used JSA tool to list the hazards, and then used a pictorial analysis to rate the probability and severity of individual hazards.

## **2.5 Analysis**

To determine the impact of Lean on safety multiple raters were required to rate the probability and severity of hazards, identified for different activities. The judgments made by human subjects could have errors. Errors occurred during analysis can affect the statistical analysis and interpretation. Denegar and Ball (1993) stated that it is necessary to quantify estimates of reliability and measurement precision before basing decisions and drawing conclusions from measurement. Thus, it is considered extremely important to ensure that the measurements made as a part of research are adequately reliable and valid. Shrout & Fleiss (1979) stated that errors could be determined by calculating the reliability index. The reliable measures require similar results to be attained from repeated measurements under the same conditions. Other measurements like ICC (Intraclass Correlation Coefficient) and SE (Standard Error) measurements can help to quantify estimates of reliability and measurement precision (Denegar and Ball 1993).

A few studies have discussed methods of calculating the reliability of data. Intraclass correlation coefficient (ICC) can help in determining the reliability for a single observation while

accounting for any systematic bias (Shrout & Fleiss, 1979). Landis & Koch (1977) stated that the inter-rater reliability can be determined by calculating the kappa value. Kappa value is a value that will determine the statistical measure of inter-rater agreement. According to Landis & Koch (1977) the Kappa value ranges from -1.0 to 1.0. The Kappa value less than 0.00 is considered to be poor, between 0.00-0.20 is considered to be slight, and between 0.21-0.40 is considered to be fair, between 0.41-0.60 is considered to be moderate, between 0.61-0.80 substantial, and between 0.81-1.00 almost perfect (Landis & Koch 1977). The ICC values ranges between 0.00 to 1.00. The ICC value is considered to be high if the value is 0.75-1.00, good if the value is 0.60 to 0.74, fair if the value is 0.40 to 0.59, and poor if the value is less than 0.40 (Chicchetti and Sparrow 1981). The ICC values can help in determining the reliability for a single observation while accounting for any systematic bias (Shrout & Fleiss, 1979). Atkinson and Nevill (1998) stated that a few methods like standard error of measurement (SEM), coefficients of variation (CV), and limits of agreement (LOA) could be used to determine absolute reliability. Furthermore, Denegar and Ball (1993) stated that estimates of reliability and precision of measurement can be quantified through analysis of variance. Such methods are used to ensure that the measurements made while conducting the experiment are reliable and valid.

## **2.6 Relationship between Lean and Safety**

According to Kumar et al., (2006) Lean tools are well acknowledged process improvement strategies available to organizations to reduce cost, improve quality, and enhance process performance, by eliminating the non-value added activities from the process. The effects of Lean may influence the safety and health of working employees within organizations, which is the scope of this research. Few studies have actually examined the link between safety and Lean-job design by assessing physical risk factors. Nahmens and Ikuma (2009) stated that Lean is not

only a beneficial process improvement and waste reduction tool, but its application may also improve safety in the construction industry. The implementations of Lean strategies in the construction industry have been associated with lower OSHA incident rates (Nahmens and Ikuma 2009).

Saurin and Ferreira (2009) studied the impact of Lean production on working conditions like work content, work organization, and health and safety. The workers interviewed in this study reported that health and safety had improved with the implementation of Lean production mostly because Lean implementation helped in improving housekeeping and handling of materials. The authors further concluded that the companies which implemented Lean principles considered health and safety to be in line with Lean production philosophy, where accidents were considered to be inefficient and should be avoided at any circumstances. According to Nahmens and Ikuma (2009), Lean principles, like reducing waste and increasing efficiency, leads to a reduction in process steps, material used, and motion required to perform the activity, which results in reducing the probability of accident occurrence. A speculation was stated in this study that implementation of Lean helped in reducing accidents like slip, trip, and falls to lower level hazards which in turn resulted in lesser number of days away from work, restriction to perform certain work, and transfer to a lesser demanding jobs (Nahmens and Ikuma 2009).

Wong et al., (2009) conducted a survey to explore the 14 key areas of Lean manufacturing: scheduling, inventory, material handling, equipment, work processes, quality, employees, layout, suppliers, customers, safety and ergonomics, product design, management and culture, and tools and techniques. A questionnaire survey of these 14 key areas conducted on managers of 44 manufacturing companies resulted in a significant difference for scheduling, inventory, work process, employee, safety and ergonomics, and tools and techniques. These

results indicated that attention to safety and ergonomics within a Lean program can improve safety, productivity, and cost of the product.

Lee (2005) showed that the implementation of ergonomics in industry has also helped to improve the process and quality of the product. Lean's primary focus is to improve the process and quality of the product by reducing waste. Lee (2005) revealed that an ergonomic team consisting of safety, health personnel, process engineers, and management innovation personnel used ergonomics circle as a quality circle in total quality management (TQM). This helped in improving work flow, increased productivity, cost saving, and improved safety by providing ergonomic interventions, which assisted them during the work and helped in reducing the risk musculoskeletal injuries.

Implementation of Lean may not always have positive effects on safety and ergonomics, as shown in several studies. Researchers also had a contradictory opinion about the relationship between Lean and occupational injuries or illness. Landsbergis et al., (1999) claimed that implementation of Lean manufacturing intensifies work pace and demands which could lead to musculoskeletal injuries. Landsbergis et al., (1999) further stated that 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 the workers.

Implementation of Lean may have both positive and negative effect on safety. A study by Womack et al., (2009) investigated the relationship between Lean job design and work related musculoskeletal disorders by comparing workers' exposure to injury in an automobile manufacturing plant that implements Lean, and a traditional automobile plant that did not implement Lean. The workers in Lean plants were subjected to intensified work schedules, and a



greater ergonomic risk due to short cycle times. Also, the non-neutral posture of the wrist, shoulder, and lower back were greater for Lean plants. On the other hand the non-value added activities, predominantly walking time in Lean job cycle was lower in comparison with the traditional plant, which reduced the workers from developing fatigue. Moreover, the exposures to high hand force were lower in Lean-plants because Lean focused on process quality which used quality part tools, part presentation, and work method. The overall finding of this research was that the Lean principle of reducing non-value added activity to increase productivity increased repetition exposure, but focusing on process quality reduced hand force exposure.

Safety has always been a concern in the construction industry because the construction environment exposes workers to high levels of hazards (Ringin et al., 1995). Researchers have observed a relationship between Lean and safety, but in the past only few studies have been done to determine the impact of Lean on workers safety. Most past studies have relied on self-reported survey data and interviews from workers or supervisors, and conclusions based on such designed studies could be considered biased. Furthermore, most past studies investigated the impact of Lean tools on workers safety in manufacturing industries, while only a few studies focused on the construction industry. Moreover, past studies analyzing the impact of Lean on safety had contradicting results. The summary of the past studies and their methods to understand the impact of Lean on workers' safety is provided in Table 1.

**Table 1:** Relation between Lean and workers safety: Studies reviewed

No	Authors and Year	Industry	Research Method	Outcomes/Result
1	Nahmens and Ikuma (2009)	Industrialized homebuilders	Questionnaire Survey	Lean tools may help to improve safety in the construction industry
2	(Saurin et al. 2009)	Automobile (Manufacturer of harvesters and tractors)	Questionnaire Survey	Health and safety improved with implementation of Lean tools
3	Wong et al. (2009)	Electrical and Electronics	Questionnaire survey	Lean tools have positive impact on safety
4	Lee (2005)	Electric appliance company	Questionnaire and ergonomic interventions	Interventions helped in improving productivity and saved cost
5	Womack et al. (2009)	Automobile-manufacturing plant	Observation and comparisons with Lean plan and traditional plant	Lean tools have both positive and negative impact on safety

Such contradicting opinions from various researches influenced the need to further study the impact of Lean on safety. The question of whether Lean improves safety in the construction industry still remains unanswered. The objective of the current research was to determine and analyze the impact of Lean through Kaizen on safety in a modular home building industry. This research focused on analyzing workers' exposure to safety hazards before and after implementing Lean on a particular workstation using JSA and ratings of risk. The results of this study helped in understanding the influence of Lean on workers safety in modular homebuilding industries.

## **CHAPTER 3**

### **RESEARCH METHODOLOGY**

#### **3.1 Background:**

The current study was based on information collected from in a modular homebuilding manufacturer in the United States. This homebuilder manufactures stick built houses and SIP (Structural Insulated Panels) built houses within the factory environment. To improve the overall performance and cycle time the management decided to implement Lean at individual workstations. The Lean tool adapted for process improvement at each of the workstations was Kaizen. Kaizen was implemented on three workstations: base-framing, sheet rock hanging, and interior painting. The Kaizen was conducted in three phases. The initial planning and preparation phase included observing the current process and documenting the list of activities required to perform the task. In the second phase, work sampling and time study was conducted. The results of the work sampling and time study were presented to the workers and the project manager. This was followed by a brainstorming session to determine the root cause of the problems, and to eliminate waste. The feasible ideas generated in the brainstorming session were implemented at the workstations, and work sampling and time study was conducted on the improved procedures to determine the percentage improvement. These results were presented to the workers and the team celebrated success. This process was followed for each of the three workstations. The following improvements were made at each of the three workstations:

### **1) Base-framing station:**

- Concrete blocks were replaced by angle irons to support the base on the left side, and casters were built to hold the right side of the base-frame. This prevented the workers from moving the concrete blocks using their legs.
- 2 new tool boxes were built to store tools near the work area. This prevented the workers from placing tools on the building material, and also reduced the time the workers spent in looking for tools while performing the task.
- Morning huddles where the team gather together in a circle to discuss their roles and the plan for the day. The supervisor motivates his team members and discusses the floor plans and assigns roles.
- Saw horses were used to cut rim joists. Previously, the cutting operations were performed in awkward postures where the workers cut the materials over the stacked materials. Using saw horses helped the workers to perform the cutting operations in standing postures. The new cutting posture helped in reducing fatigue and strain on back and shoulders while performing the cutting operation. Using the saw also reduced the chance of workers cutting the power cord, and accidentally damaging the materials.
- Precut joists were marked with the crown up to avoid mistakes while hanging the joist to the rim joist. Moreover, the precut joist stacks were turned perpendicular to the rim joist- for easy pull of material.
- Oriented strand boards (OSB) are brought closer to the station. This prevented the workers carrying and moving the OSB over a long distance

## **2) Sheet rock hanging station:**

- Materials were staged closer to the doors to reduce time for traveling and lift sheet rock panels.
- Materials were staged appropriately to prevent damage by plant traffic. This also prevented tripping over the materials.
- The walls and ceilings were installed simultaneously to reduce the time spent moving the tools from one room to another.
- Standard Operating Procedure (SOP) were prepared and pasted at the respective workstations to prevent deviations.

## **3) Painting station (Recommended):**

- The walls and trims were spray painted instead of rolling.
- The flooring process was carried out only after the completion of the painting process to prevent interference from other departments while performing the painting process. This reduced the space constraints which were caused when the painting and flooring team performed their activities simultaneously. Moreover, it also prevented the workers from tripping over tools and materials placed on pathways.

A Job Safety Analysis (JSA) was also performed on each of the three workstations for the baseline and improved process. The objective of performing the JSA was to identify the hazards which the workers were subjected to while performing the activities. Upon observing the activities carried out at individual workstations, the team prepared a sequential list of activities performed by the workers at individual workstations. Once the lists of activities were formed the team closely observed each activity mentioned in the list and identified possible hazards. This process was performed for the improved as well as the baseline process. The identified hazards

were further used to analyze the impact of Lean on workers safety in modular homebuilding industry.

Past studies have shown that Lean tools help in improving productivity and quality, and reducing cost by eliminating waste (see Literature Review). This study was done to further explore the usability of Lean concepts in the field of safety, and to determine the impact of Lean on workers' exposure to safety risks in the modular homebuilding industry. The objective of the study was to analyze the impact of one Lean tool (Kaizen) on the exposure of workers to various safety risks in the modular home building industry.

### **3.2 Risk Assessment Tool:**

The risk assessment tool was used to determine the risk value when a worker is subjected to a hazard while performing the task. The risk value was obtained by determining the probability and severity of workers exposure to hazards. This tool consisted a document, which provided detailed explanation of the process carried out at individual workstations. The first section of the questionnaire had an explanation of baseline activities (before implementing Kaizen) performed at individual workstations. On the other hand, the later section had an explanation of improved process (after implementing Kaizen) at individual workstations. The document had pictures of workers performing the activity. This picture provided a clear vision of workers' postures while performing the activity and the work layout. The tool also had a questionnaire, where the raters had to rate the probability of workers exposure to a hazard and the severity of the particular accident (Appendix 1). Based on the probability and severity scores, the risk value for each individual activity, and the overall risk value at individual workstations were calculated. The overall risk value was calculated by summing up the risk value obtained

against each individual activity for a particular station. The formula to calculate the risk value for a particular hazard was (Marhavilaes and Koulouriotis, 2008):

$$R=PS$$

Where,

R= Risk value

P= Probability of occurrence of a particular harm factor

S= is the severity of the harm factor

The overall risk value for an individual workstation was calculated by summing up the risk value obtained for each hazard.

$$R_s=\sum_{hi=1}^n R_i$$

Where,

$R_s$  =Risk value for an individual station

$R_i$  = Risk value for individual hazard

The goal of using the risk assessment tool was to determine the workers' exposure to risk before and after implementing Lean. The calculated risk value helped us in determining whether Lean had any impact on workers' safety in modular homebuilding industry.

### **3.3 Hypotheses:**

This study explores the following hypotheses:

#### **3.3.1 Hypothesis 1**

$H_{01}$ : Kaizen does not reduce workers' exposure to risk in each of the three workstations.

$H_{11}$ : Kaizen reduces workers' exposure to risk in each of the three workstations.

#### **3.3.2 Hypothesis 2**

$H_{02}$ : The new risk assessment tool is not reliable in measuring the risk at individual workstations.

H<sub>12</sub>: The new risk assessment is reliable in measuring the risk at individual workstations.

### 3.4 Experiment Design:

The aim of the experiment was to determine the impact of Lean on workers' exposure to safety risks in the modular homebuilding industry. The independent and dependent variables used in the experiment are mentioned below.

#### 3.4.1 Independent Variables

The two independent variables in the experiment are:

- **Workstations:** Three workstations: base-framing, sheet rock hanging, and painting will be considered in this study to determine the impact of Kaizen on workers' exposure to risks. In the base-framing station the workers initially assembled the rim joist. This process was then followed by installing the joist and blocking, installing decking, and attaching casters for transporting the base-frame to the next station. The second station that was analyzed was the sheet rock hanging station. In this station the workers cut and glued each sheet rock panel of appropriate size, and fixed the panels onto the rafters of walls and ceilings throughout the entire house. In the third station, interior painting, workers' initially primed and then sanded the walls and ceilings of the entire house. Texturing and painting the walls and ceilings of the entire house followed this process. The painting process also included putty, caulking, and painting the shoe base, window trims, door trims, and door.
- **Time:** The workers' exposure to hazards was analyzed at two different times, before implementation of Kaizen and after implementation of Kaizen at each of the three workstations. Before implementing Kaizen the researchers observed and listed the hazards to which the workers' were exposed. Kaizen was implemented at individual workstations to



improve the process. The objective was to improve productivity, quality, material flow, material utilization, and reduce costs at individual workstations by reducing non-value added activities. The implementation of Kaizen resulted in several changes in work design. This resulted in a new sequential work process which may have changed safety hazards. The researchers observed this new process and listed the hazard to which the workers' were exposed.

### 3.4.2 Dependent Variables

The dependent variables in the experiment are:

- **Risk value:** The risk value was determined by determining the probability and severity of the identified hazards. The probability of workers' exposure to a hazard for a particular activity was obtained by asking the participants to rate the probability of each hazard identified for each activity. The probability of workers' hazard was rated on a 1-4 point scale. Where '1' will denote remote probability, '2' will denote unlikely, '3' will denote likely, and '4' will denote very likely. Whereas, the severity of a particular hazard for an activity was obtained by asking the participants to rate the severity of accident identified for each activity. The severity will be rated by considering the most likely outcome that the worker were subjected to if exposed to a particular hazard. The severity of accident was rated on a 1-4 point scale, where '1' denotes accidents that cause minor injuries, '2' stands for accidents that cause moderate injuries, '3' refers to accidents that can cause serious injuries, and '4' denotes accidents that lead to catastrophic injuries. In case of scale 1 accidents, the worker will not be required to visit a hospital and will be able to diagnose the ill health by himself. In case of scale 2 accidents, the worker could either decide on consulting a doctor or be able to diagnose the illness by himself. Instances that cause a serious injury (scale 3) would require

the worker to visit a hospital. Finally, catastrophic injuries would necessitate the worker to undergo a long-term treatment or make him bed-ridden.

- **Additional hazards identified:** The participants will be requested to list any additional hazards (hazards not mentioned in questionnaire) identified for each activity. The additional hazards identified by the participants will be used to determine the validity of JSA.

### **3.5 Participants:**

To meet the objective, 12 students having prior knowledge of safety and 4 certified safety experts were asked to participate in the experiment. The criteria for selecting the student participants was that the students should have successfully completed a course on safety. The course on safety can be either a semester long graduate or undergraduate level course. The criteria for selecting the safety experts were that the safety experts should be OSHA (Occupational Safety and Health Administration) certified.

### **3.6 Procedure:**

1. Initially, a signed consent form explaining the purpose of the study, its benefits, risks, and exclusion criteria was obtained from the participants (Appendix 1). Clear verbal instructions were provided on how to go about the experiment, and what will be required of the participants.
2. The questionnaire (Appendix 2) was handed over to the participants, and the participants were asked to take their seats before a computer monitor. The system had a power point presentation document containing pictures of workers performing the activity. The document containing the pictures of workers performing the tasks was used to give the participants a clear picture of how the workers performed their tasks at individual workstations.

3. Upon getting a clear picture of how the workers performed the task at each workstation, the participants were asked to complete the questionnaire. The participants were allowed to refer to this document while filling out the questionnaire.
4. This process was carried out for the baseline and improved process at each of the three workstations.
5. After completing the survey with the student the entire process was repeated with 4 safety experts.

The data obtained for the baseline and improved process in the current study was used to determine the impact of Lean on workers safety in each of the three workstations. Moreover, the write-in hazards obtained was not used in the analysis, but was used to determine the validity of JSA. The research process flow chart in Figure 3 elaborates the activities of the Investigator (JSA) and the participants (Risk Analysis) to determine the impact of Kaizen on workers' exposure to risk in the modular home building industry.

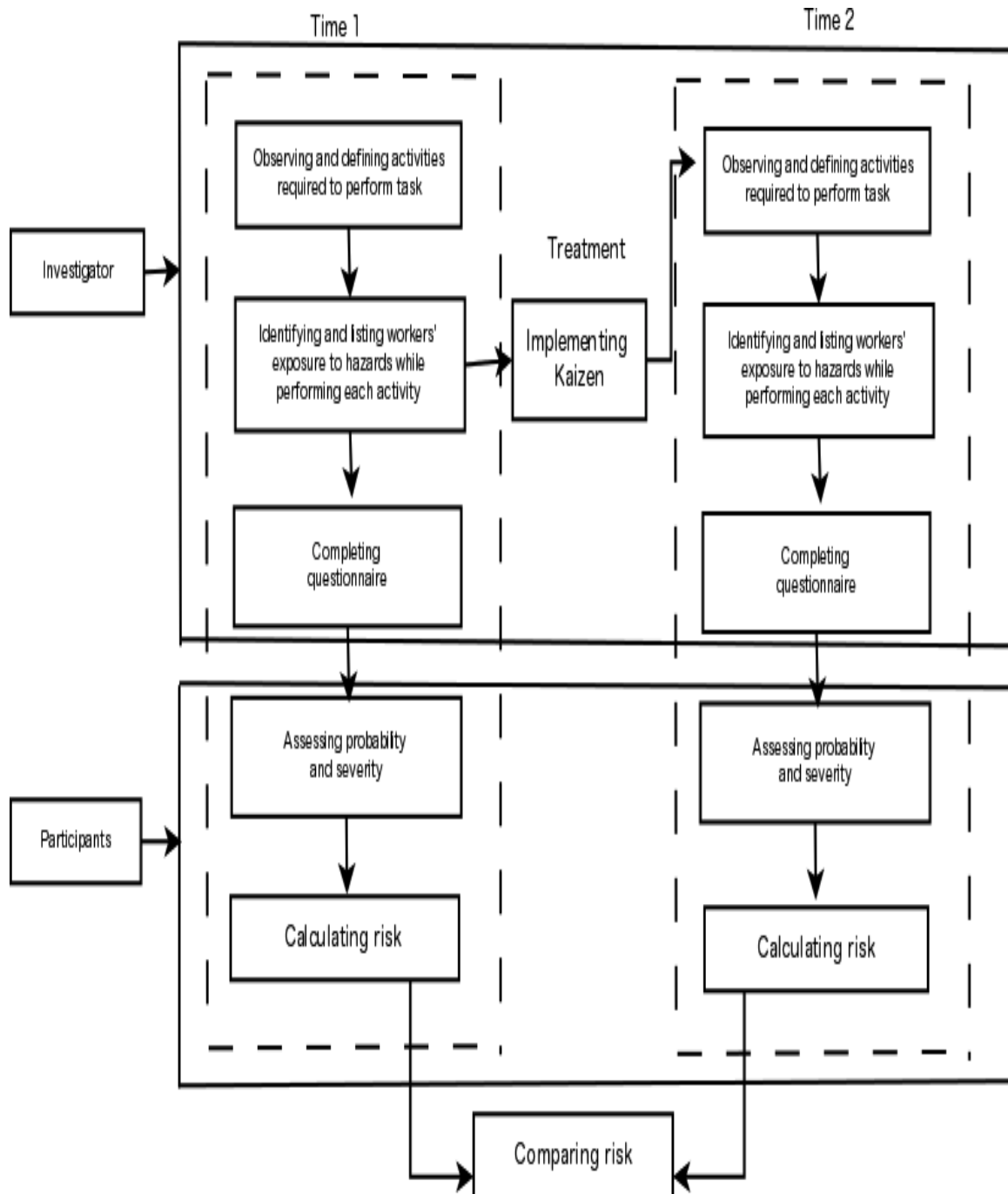


Figure 3: Research process flow chart elaborating the activities of the Investigator (JSA) and the participants (Risk Analysis)

### 3.7 Data Analysis

Data analysis was done to determine if there are significant differences between the risk values for baseline and improved processes. Moreover, analysis was also done to determine if the risk assessment tool was reliable in measuring workers' exposure to hazards at each of the three workstations. In this experiment the participants were asked to rate the probability and severity of each hazard identified for each activity. Then the risk value for a particular hazard was calculated by multiplying the probability and severity value of that hazard. The below equation was used to calculate the risk values of individual hazards.

$$R_i = P_i * S_i$$

Where,

$R_i$  = Risk value for a particular hazard

$P_i$  = Probability of a particular hazard

$S_i$  = Severity of a particular hazard

$i$  = Hazard  $i$ , where  $i$  starts from 1 and goes to  $n$  (total number of hazard identified for an activity)

Secondly, the risk value for a particular activity was obtained by summing up the risk values of individual hazards identified for the particular activity. The activities were steps performed by workers at workstations to move the product along the line. The below equation was used to calculate the risk values of a particular activity.

$$R_a = \sum_{i=1}^n R_i$$

Where,

$R_a$  = Risk value of an activity ( $a$ )

$h_i$  = Number of hazards against an activity

$R_i$  = Risk value against an identified hazard

Finally, the overall risk value for a particular station was calculated by summing the risk values of the activities. The below equation was used to calculate the overall risk value for baseline and improved process.

$$R_t = \sum_{ai=1}^n R_a$$

Where,

$R_t$  = Overall risk value

$a_i$  = Number of activities at a particular workstation

$R_a$  = Risk value against an activity

The calculated risk values for the baseline and improved process at individual workstations was used to compare the workers' exposure to risks before and after the implementation of Lean.

The risk value obtained for each activity for baseline and improved process was used to perform paired t-tests to determine if there are any significant differences between the risk scores obtained, for the baseline and improved process of each activity. The t-test analysis was an appropriate tool to compare the means of two groups. The t-test helped us determine, whether the mean risk scores for each activity of two groups (baseline and improved process) are statistically different from each other. The statistical software SPSS-20.0.0 (Statistical Package for the Social Sciences) was used to perform the t-test to calculate the t-value by using the risk values that was obtained for each activity and this t-value was then used to determine the corresponding p-value. Further, the p-value was used to verify if the risk value for each activity for baseline and improved process had significant difference (at 95% significance level). If the obtained p-value was less than 0.05, then the null hypothesis that the Kaizen does not reduce workers' exposure to

risk at each of the three workstations would be rejected. Whereas, if the obtained p-value was greater than 0.05, then we would fail to reject the null hypothesis that the Kaizen does not reduce workers' exposure to risk in each of the three workstations. The result of the t-test served as a base to determine if Kaizen had a significant effect of reducing workers' exposure to risk in each of the three workstations.

Furthermore, a reliability test between the participants' ratings for individual activity was performed. The statistical software SPSS-20.0.0 was used to perform the analysis. The interclass correlation coefficient (ICC) was used to examine the agreement between the participants on the risk values for each activity. Of the five different models available to perform the ICC analysis the two-way random model with measures of consistency was used to determine the ICC value. This model was selected as the best choice because the raters (participants) were selected randomly, and the questions were chosen at random from a pool of possible questions (Shrout and Fleiss 1979). Also, it was predetermined how each judge rated each subject. The ICC values ranges between 0.00 to 1.00. The ICC value is considered to be high if the value is 0.75-1.00, good if the value is 0.60 to 0.74, fair if the value is 0.40 to 0.59, and poor if the value is less than 0.40 (Chicchetti and Sparrow 1981). The goal of calculating the ICC value was to determine the reliability of the risk assessment tool. Moreover, the write-in hazards obtained was used to determine the validity of JSA. If greater number of write-in hazards were provided then lesser would be the validity of the JSA

## CHAPTER 4

### RESULTS

The participants determined the risk values for each of the three workstations: base-framing, sheetrock hanging and painting stations, before and after implementing Lean. Data analysis results from paired t-test and Interclass Correlation Coefficient (ICC) are presented. The paired t-test was performed to determine if there is any significant difference in risk values obtained before and after implementing Lean; whereas, the ICC was performed to determine the reliability of the risk assessment tool.

Initially, the risk values for each of the three workstations were calculated. The average risk values obtained from students' and safety experts' ratings with standard deviation error bars for each of the three workstations are shown in Figure 4 and Figure 5 respectively.

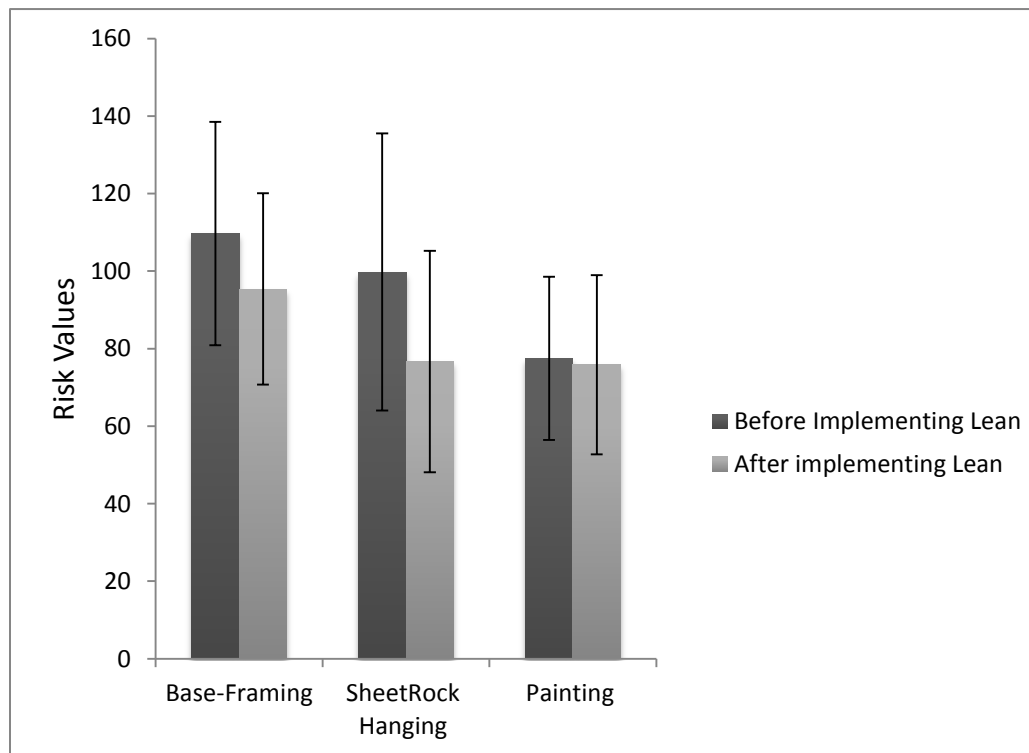


Figure 4: Average risk values as rated by students with standard deviation error bars



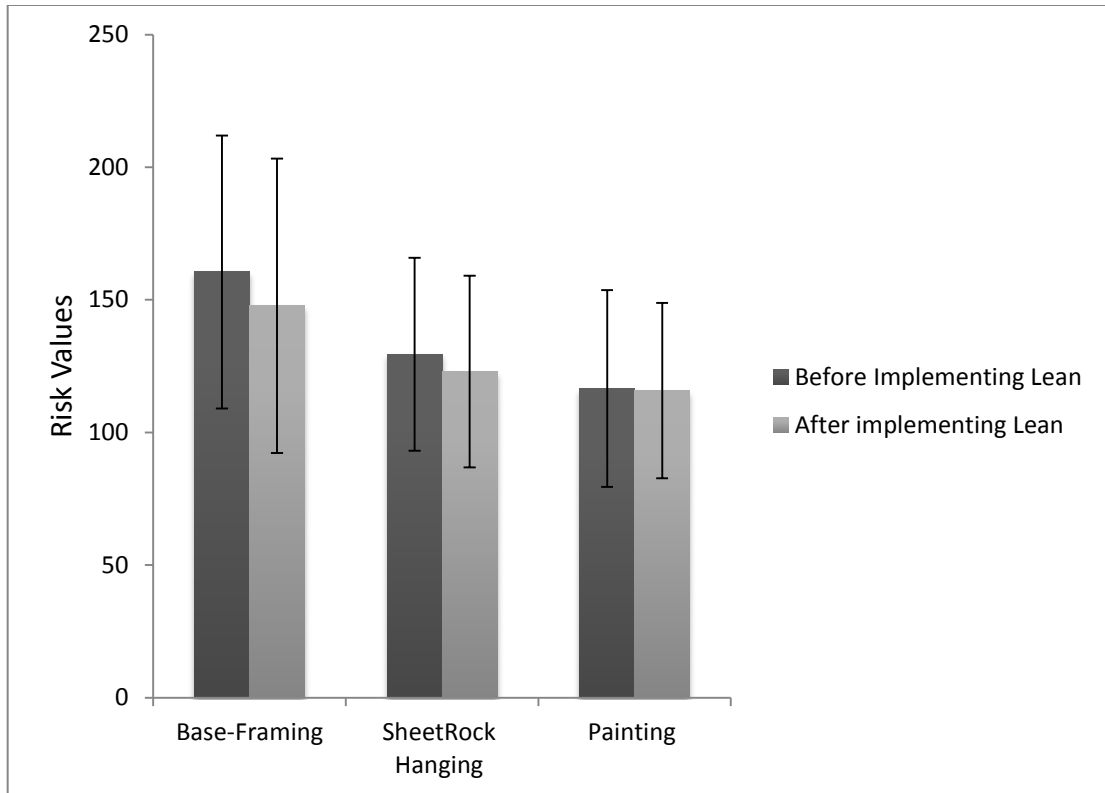


Figure 5: Average risk values as rated by safety experts with standard deviation error bars

A paired t-test was performed using the Statistical Package for the Social Sciences (SPSS 20.0.0) software on the risk values obtained from students' ratings for each of the workstations before and after implementing Lean. The p-values obtained from the paired t-test helped in determining whether Lean reduced the workers' exposure to risk in each of the three workstations. The p-values obtained from the paired t-test for are listed in Table 2. According to students there was a significant reduction in risk values for base-framing station and sheet-rock hanging station. Whereas, according to safety experts significant reduction in risk values was only for base-framing station. ( $\alpha=0.05$ ).

**Table 2:** Paired t-test results for risk values before and after implementing Kaizen

	Stations	P-Values	Before Lean Mean (SD)	After Lean Mean (SD)
Students	Base Framing Station	.001*	109.7 (28.8)*	95.4 (24.7)*
	Sheet Rock Hanging Station	.005*	99.8 (35.7)*	76.7 (28.6)*
	Painting Station	.471	77.5 (21.1)	75.8 (23.1)
Safety Experts	Base Framing Station	.021*	160.5 (51.4)*	147.8 (55.5)*
	Sheet Rock Hanging Station	.097	129.5 (36.4)	123.0 (36.1)
	Painting Station	.753	116.5 (37.1)	115.75 (33.0)

\* Significant difference in the risk values before and after Kaizen ( $\alpha=0.05$ )

For students evaluation the ICC values obtained (0.402 and 0.503) for the base-framing and painting were fair, and the ICC values (0.605) obtained for sheetrock hanging was good. Whereas, for safety experts evaluation the ICC value (0.618 and 0.634) for the base-framing and painting was good, and the ICC values (0.763) obtained for sheetrock hanging was high.

## 4.1 Hypothesis Evaluations

Based on the results the following conclusions were made for each of the hypotheses:

### 4.1.1 Hypothesis 1

$H_{01}$ : Kaizen does not reduce workers' exposure to risk in each of the three workstations.

$H_{11}$ : Kaizen reduces workers' exposure to risk in each of the three workstations.

The p-value obtained for the base-framing station was 0.001 for students and 0.021 for safety experts respectively. The null hypothesis was rejected i.e., As per students and safety experts implementing Lean had a significant effect in improving workers' exposure to risk in the base-framing station.

The p-value obtained for the sheet rock hanging station was 0.005 for students. The null hypothesis was rejected and the alternate hypothesis was accepted i.e., as per students implementing Lean had a significant effect in improving workers exposure to risk in the sheet

rock station. Whereas, the p-value obtained for the sheet rock hanging station was 0.097 for safety experts. The null hypothesis was accepted i.e., as per safety experts Lean did not have significant effect in improving workers exposure to risk in the sheet rock station.

The p-value obtained for the painting station was 0.471 for students and 0.753 for safety experts. The null hypothesis was accepted i.e., As per students and safety experts Lean did not have a significant effect on workers' exposure to risk in the painting station.

Overall, base on the p-values obtained from t-test by students and safety experts at each of the three workstations, we partially reject the null hypothesis i.e., implementing Kaizen occasionally reduced works exposure to risk at each of the three workstations.

#### **4.1.2 Hypothesis 2**

H<sub>02</sub>: The new risk assessment tool is not reliable in measuring the risk at individual workstations.

H<sub>12</sub>: The new risk assessment is reliable in measuring the risk at individual workstations.

The ICC value obtained for the base-framing station was 0.402 (fair) for students and 0.618 (good) for safety experts. Since the ICC ratings for students were fair for base-framing station, the null hypothesis was accepted. i.e., as per students the new risk assessment tool was not reliable in measuring risk at base-framing station. Whereas, the ICC rating for safety experts were good for base-framing station, thus the null hypothesis was rejected in base-framing station i.e., as per safety experts the new risk assessment tool was reliable in measuring risk at base-framing station.

The ICC values obtained for the hanging station was 0.605 (good) for students and 0.763 (high) for safety experts. Since the ICC ratings for student and safety experts were good and high respectively, the null hypothesis was rejected and the alternate hypothesis was accepted in

hanging station i.e., as per students and safety experts the new risk assessment tool was reliable in measuring risk at hanging station.

The ICC value obtained for the painting station was 0.503 (fair) for students and 0.634 (good) for safety experts. Since the ICC rating for students were fair for the painting station, the null hypothesis was accepted in the painting station i.e., as per students the new risk assessment tool was not reliable in measuring risk at painting station. Whereas, the ICC rating for safety experts were good for painting station, thus the null hypothesis was rejected in painting station i.e., as per safety experts the new risk assessment tool was reliable in measuring risk at painting station.

Overall, based on the ICC values obtained from the reliability tests at each of the three workstations, we partially reject the null hypothesis i.e., the new risk assessment tool was reliable in measuring risk at each of the three workstations.

## **CHAPTER 5**

### **DISCUSSION**

The objective of the current research was to determine the impact of Lean through Kaizen on workers' exposure to risk in a modular home building industry. The results of this study showed that there was a significant reduction in the workers' exposure to risk in base-framing and sheet-rock hanging station after implementing Kaizen as per student opinion; whereas, as per safety experts the reduction in risk values were confined to only base-framing station. The reductions in risk values were mainly because the work was made efficient after implementing Lean. Implementing Lean helped in reducing non-value added activities. The workers were aware of their role, the work floors were more organized, materials and tools were setup before the start of work and staged more efficiently, and efficient work methods were adopted at each of the three workstations after implementing Lean. The well-organized workflow, efficient staging of tools and materials, and efficient working methods helped the workers to reduce the risk of injuries caused due to slip and trips, fatigue, muscle strain, and awkward postures. The reduction in risk values after implementing Lean are supported by Nahmens and Ikuma (2009), Saurin and Ferreira (2009), and Wong et al. (2009), who studied the effects of Lean on workers' safety. The degree of impact of Lean also plays an important role in reducing risk.

Five improvements were implemented in the base-framing station:

- 1) Before implementing Lean the workers used concrete blocks to support the base. The workers had to use their hands and legs to align the concrete blocks before placing the base over it. Repositioning the concrete block with hands and legs could cause injuries due to strain on shoulders, back and legs. The concrete blocks were used to support the base-frame before implementing Lean is shown in Figure 6.



Figure 6: Concrete blocks to support base-frame before implementing Lean

After implementing Lean the concrete blocks were replaced by angle irons to support the base on the left side, and casters were built to hold the right side of the base-frame. Eliminating the use of concrete blocks reduced the risk of injuries caused due to strain on back, shoulders and legs. The angle iron used by the workers to support the base-frame after implementing Lean is shown in Figure 7.



Figure 7: Angle iron used to support base-frame after implementing Lean

- 2) Before implementing Lean the workers placed their tools along the pathway when they moved from one place to other. The tools along the pathway had high risk of injuries caused

due to slipping or tripping over the tools. After implementing Lean 2 new toolboxes were built to store tools near the work area. This prevented the workers from placing tools along the pathway, and also reduced the time the workers spent in looking for tools while performing the task. Building two new toolboxes reduced the risk of injuries caused due to slipping or tripping over tools left along the pathway.

- 3) Before implementing Lean the workers had to walk back and forth to the tool crib to get the tools, and to the material staging area to get more materials. Walking back and forth with heavy tools and materials could cause fatigue and thus result in injury. After implementing Lean morning huddles was conducted where the team gather together in a circle to discuss their roles and the plan for the day. The supervisor motivates his team members and discusses the floor plans and assigned roles before the start of work. The workers had their tools and materials close to the work area. This reduced the risk of injuries caused due to fatigue.
- 4) Before implementing Lean workers performed the cutting of rim joist over the staged materials in awkward posture. Performing the cutting operations in awkward postures had potential risk of injuries caused due to strain on back, shoulders, and neck. The worker performing the cutting and drilling operation of rim joist before implementing Lean is shown in Figure 8.



Figure 8: Workers performing the cutting and drilling operation of rim joist before implementing Lean

After implementing Lean sawhorses were built to cut rim joists. Using sawhorses helped the workers to perform the cutting operations in standing postures. The new cutting posture helped in reducing fatigue and strain on back, shoulders and neck while performing the cutting operation. Using the sawhorse also reduced the chance of workers cutting the power cord, and accidentally damaging the materials. The workers performing the cutting and drilling of rim joist after implementing Lean is shown in Figure 9.



Figure 9: Workers performing the cutting and drilling operation of rim joist after implementing Lean

- 5) Before implementing Lean the Oriented Strand Boards (OSB) were staged far away from the working area. The workers had to carry the OSB over a long distance to get it the work area.



Carrying the OSB over a long distance had high risk of injuries caused due to fatigue and strain on back and shoulders. After implementing Lean the OSB were staged closer to the work area. This reduced the risk of injuries caused due to fatigue and strain on back and shoulders. The staging of OSB after implementing Lean is shown in Figure- 10.



Figure 10: Staging of OSB after implementing Lean

Sheet rock hanging station was the second station which implemented Lean. After implementing Kaizen four improvements were implemented in the sheet-rock hanging station:

- 1) Before implementing Lean the sheet-rock panels were staged at three different locations far away from the door of the house. The workers had to carry these heavy sheet-rock panels over a long distance. Carrying the sheet-rock panels over a long distance had high risk of injuries due to fatigue and strain on back and shoulders. The layout displaying the staging of sheet-rock panels before implementing Lean is shown in Figure 11.

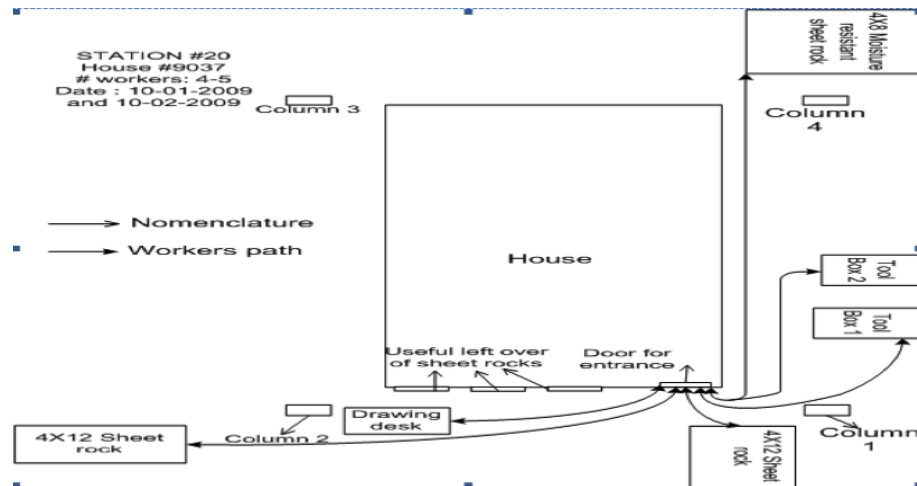


Figure 11: Layout displaying staging of sheet-rock panels before implementing Lean

After implementing Lean the sheet-rocks panels were staged closer to the doors to reduce time for getting the sheet-rock panel to the work area. This reduced the risk of injuries caused due to fatigue and strain on back and shoulders. The layout displaying the staging of sheet-rock panels after implementing Lean is shown in Figure 12.

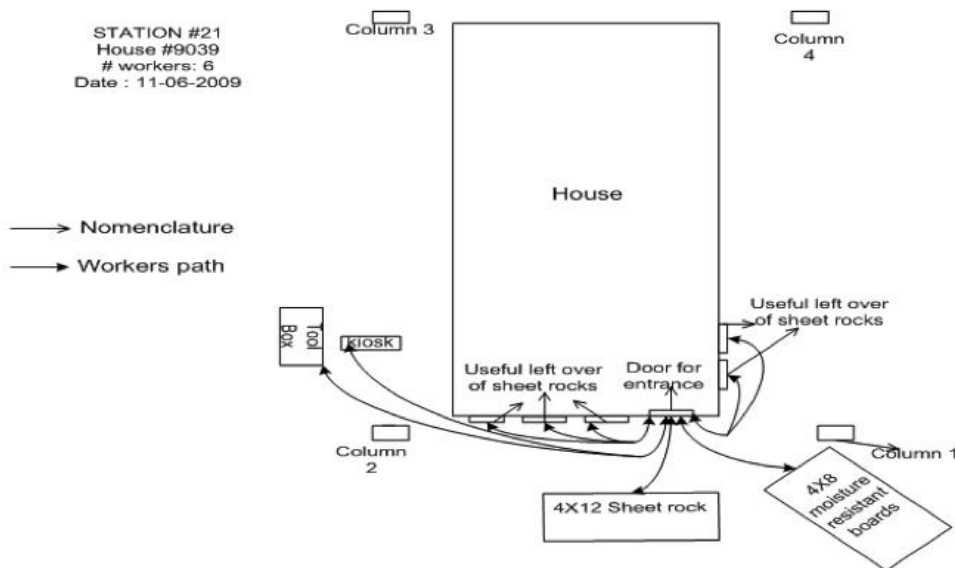


Figure 12: Layout displaying staging of sheet-rock panels after implementing Lean

- 2) Before implementing Lean the sheet-rock panels were staged near the pathway. This had high risk of injuries due to slip and trips. After implementing Lean the sheet-rock panels

were staged away from the pathway to prevent damage by plant traffic and tripping over the materials. This reduced the risk of injuries caused due to slip and trips.

- 3) Before implementing Lean the workers hanged the walls of the entire house followed by the ceilings. Due to this the workers had to carry their sawhorses and tools back and forth in the house. This had high risk of injuries due to fatigue and strain on back and shoulders. The workers performing the hanging operation before implementing Lean is shown in Figure 13.



Figure 13: Workers performing the hanging operation before implementing Lean

After implementing Lean the walls and ceilings were installed simultaneously to reduce the time spent moving the tools from one room to another. This reduced the risk of injuries caused due to fatigue and strain on back and shoulders. The workers performing the hanging operation after implementing Lean is shown in Figure 14.



Figure 14: Workers performing the hanging operation after implementing Lean

- 4) Before implementing Lean the workers walked along the station in search of the supervisor for further instructions. Walking for a longer duration could cause fatigue and thus result in injury. After implementing Lean a Standard Operating Procedure (SOP) were prepared and pasted at the respective workstations to prevent deviations. This reduced the risk of injuries caused due to fatigue.

Painting station was the third station which implemented Lean. After implementing Lean two improvements were suggested in the painting station:

- 1) Before implementing Lean the walls were painted using a roller. Using a roller could cause strain on back and shoulder and thus result in an injury. The workers performing the painting operations before implementing Lean is shown in Figure 15.



Figure 15: Workers performing the painting operation before implementing Lean

After implementing Lean the walls were spray painted instead of rolling. This reduced the risk of injuries caused due to strain on back and shoulders. The workers performing the painting operations after implementing Lean is shown in Figure 16.



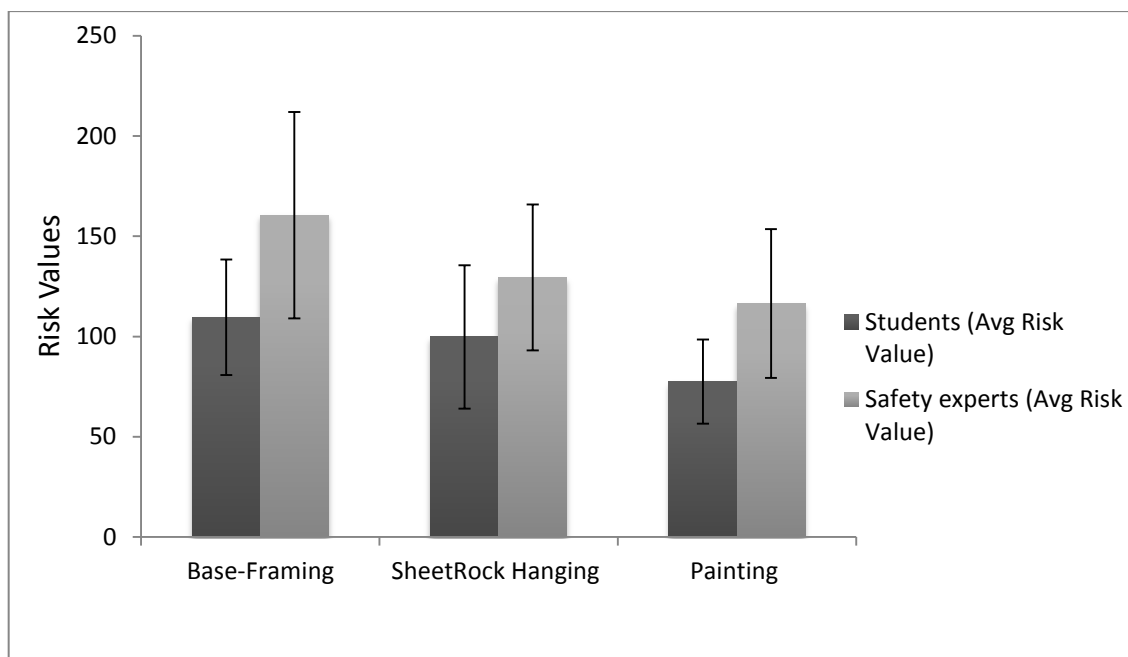
Figure 16: Workers performing the painting operation after implementing Lean

- 2) Before implementing Lean the flooring process was carried simultaneously with the painting process. The workers performing the flooring operations staged their materials and placed their tools along the pathway. Moreover, space constraints were caused while performing the flooring and painting operations simultaneously. The painters were subjected to high risk of injuries caused due to slip and trips over the materials. After implementing Lean the flooring process was carried out only after the completion of the painting process to prevent interference from flooring departments while performing the painting process. This reduced the space constraints, which were caused when the painting and flooring team performed their activities simultaneously. This also reduced the risk of injuries caused due to slipping and tripping over tools and materials placed on pathways.

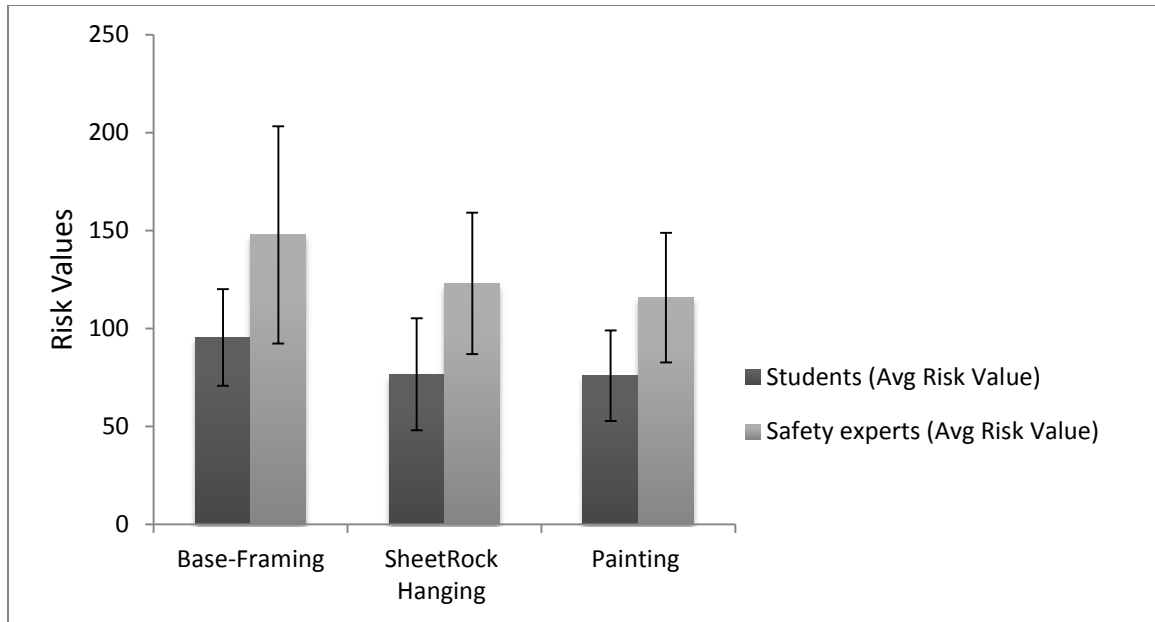
According to students, after implementing Lean, there was a significant reduction in the workers' exposure to risk in base-framing and sheet-rock hanging station; while, evaluation by safety experts showed significant reduction in base-framing station. The degree of success of Lean plays an important role in reducing workers exposure to risk. The degree of success of Kaizen was high in the base-framing and sheet-rock hanging station. The student and safety experts observed five improvements in the base-framing station and four improvements in sheet-rock hanging station. This could be the reason why students and safety experts rated risk values to be lower in base-framing after implementing Lean; whereas, only students rated risk values to be lower in sheet-rock hanging station after implementing Lean. However, both students and safety experts did not observe significant reduction in risk value at painting station after implementing Lean. This could be because of the degree of success of Kaizen was low in painting station. Only two improvements were suggested in the painting station. The participants

may not have found safety to be reduced significantly because of these two improvements in painting station.

Upon comparing the average risk values for base-framing, sheet rock hanging and painting stations, students tended to rate risk lower in comparison to safety experts. Figure 17 and Figure 18 compares' the risk values between students and safety experts at each of the three workstations before and after implementing Lean, respectively. The lower risk rating by students may be because students tend to perceive risk lower in comparison to safety experts. Young adults tend to take more risk in comparison to older adults, and since students were young they could have rated the risk values lower in comparison to safety experts. On the other hand experienced participants tend to rate risk higher in comparison to inexperienced participants. This could be because safety experts have vast experience in evaluating safety and due to this they may tend to rate risk values accurately.



**Figure 17:** Average risk values for students and safety experts before implementing Lean with standard deviation error bars



**Figure 18:** Average risk values for students and safety experts after implementing Lean with standard deviation error bars

To determine the validity of the JSA the questionnaire was provided with an additional row after each task. This row was provided so that the participants could list any new hazards which were not mentioned in the questionnaire. No additional hazards were listed by either by students or safety experts. Since, both students and safety experts did not list any new hazard other than the hazard mentioned in the questionnaire it could be determined that the JSA was valid.

This study also focused on determining the reliability of the new risk assessment tool in determining the risk values at each of the three workstations. As per the rating of students the reliability of the new risk assessment tool in measuring risk was fair for base-framing station, good for sheet-rock hanging station and fair for painting station. The new risk assessment tool was considered reliable only for sheet-rock hanging station. The low reliability in base-framing and painting for students could be because of the limited experience of students in evaluating



safety. Due to the limited experience in evaluating safety the student participants at times could have over rated or under rated a risk value.

However, as per the rating of safety experts the reliability of the new risk assessment tool in measuring risk was good for base-framing station, high for sheet-rock hanging station, and good for painting station. Overall, as per safety experts the new risk assessment tool was reliable and similar tool could be used in other settings to evaluate safety when used by safety experts. The high reliability in each of the three workstations could be because of the greater experience of safety experts in evaluating safety. Due to the vast experience of safety experts in evaluating safety, they will tend to rate risk values more closely and accurately.

Overall the new risk assessment tool could be considered reliable in evaluating safety. In the past safety analyses were usually done either by using self-reported questionnaire, observational video analysis, direct observation or by direct measurement method (Spielholz et al., 2001). According to Reniers et al., (2005) HAZOP (Hazard and operability) study checklists, risk matrix what-if analysis, FTA (Fault Tree Analysis), and safety audits were few popular risk analysis techniques. The use of such methods has certain limitations. The self reported analysis did not capture details such as joint angle and muscle activity, and the direct measurement methods uses tools like electromyography (EMG) and electrogoniometer which interrupted the workers while performing the task, required high cost equipment, and also required larger data collection and assessment time. Direct observation requires the safety analyst to continuously observe worker while he performs work. Such analysis would consume more time. The new risk assessment tool uses pictures in a remote setting to analyze safety. This tool has the advantage of being cheap, systematic, qualitative, and easy to under use. This helps to overcome the

limitations of other methods. The new risk assessment tool could be effectively used in getting multiple ratings with less effort and minimal cost.

## **5.1 Limitations**

The following were potential limitations associated with the study:

1. The outcomes of this study cannot be generalized to the entire modular home building industry; they are restricted to only three workstations (base-framing, sheet rock hanging, and painting) of a modular home manufacturer. This is because the tasks carried out at individual workstations are different and workers are exposed to different hazards at each workstation. Moreover, Lean does not have equal impact on all workstations.
2. This study used extensive photographs and asked participants to rate safety without being in the environment. This does limit the safety observations to only what is shown in the photographs and does not provide information on noise, ambient temperature and humidity, chemical fumes, etc.
3. The questionnaire used in this study had tasks wherein no changes were evident after the implementation of Lean. This would result in recurrent rating of hazards. The participants may have realized the questions were redundant and turned back to copy the ratings.

## **5.2 Prospective Improvements**

The limitations of the study stated above indicate that there is scope for improvement. The power point presentations used in the questionnaire could be replaced by video document showing the posture of workers performing the task before and after implementation of Lean. The advantages of using a video in place of a power point document will allow the participants to better determine the risk of listed hazards and also enable them to consider the external

environmental factors like noise, dust and heat which would otherwise be difficult to understand through pictures.

Secondly, the tasks wherein no changes were evident after the implementation of Lean would result in recurrent rating of hazards. Such instances can be evaded by excluding the relisting of the tasks which are not subjected to any improvements after implementing Lean. Thereby, the participants need not rate the tasks that show no effect upon implementation of lean. This would decrease the time needed to complete the ratings.

Further, the reliability analysis of the data revealed that the safety experts were more reliable compared to the student-raters. This opens up yet another avenue for improvement of the study which could be achieved by increasing the number of safety experts who would rate the hazards. Increasing the number of reliable participants in the study would reduce error in the hypothesis evaluation.

### **5.3 Future Research**

Based on the limitations, a few ideas for future research are suggested.

1. Future studies can be done by increasing the number of participants. This study had a sample size of 12 students and 4 safety experts. Due to the small sample size large variation in risk values were observed. Increasing the sample size would reduce the variation in risk values and reduce the error in statistical hypothesis testing. Future studies with larger sample size could reduce the risk of errors in statistical hypothesis testing due to small sample size. This would more effectively determine whether Lean improves safety in modular home building industry.
2. Research can be done to determine the impact of Lean on workers' exposure to risk in other workstations within the modular home building industry. Moreover, similar studies can be

conducted on other construction and manufacturing industries. This study would help to determine the impact of Lean on workers exposure to risk in other workstations of modular home building industry, construction industries, and manufacturing industries.

3. Research can be done to determine the impact of Kaizen (integrated with safety) on workers' exposure to risk within an industry. This study will help to determine if workers' exposure to risk would reduce significantly if Kaizen had focused on safety.
4. Research can be done by first evaluating risk values using pictorial analysis, and comparing the results of this evaluation using direct observation. This would help to determine which tool would be more effective in measuring risk.

## **5.4 Conclusion**

The results of this study helped in understanding the influence of Lean on workers' exposure to risk in modular homebuilding industries. According to students, the modular home building industry could consider implementing Lean not only to improve productivity, but also to improve safety within the industry. Based on the reliability analysis it was evident that the tool was only reliable for risk rated by safety experts at each of the three workstations. The safety experts were experienced and accurate in rating risk. Thus based on the reliability analysis the finding of safety experts should be supported. The safety experts supported the finding that Lean showed significant reduction in risk values in only the base-framing station. Thus, Kaizen could be occasionally reduce or eliminate specific safety hazards. Furthermore, the risk assessment tool can be effectively used in getting multiple ratings with less effort and minimal cost. Also, construction and manufacturing industries can use this tool to effectively to determine and analyze safety of a work environment within a short period of time.

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**APPENDIX 1**

**CONSENT FORM**

This study is performed as a part of my master's thesis through the department of Construction Management and Industrial Engineering at Louisiana State University, Baton Rouge, LA.

The main aim of this study is to analyze and evaluate the impact of one Lean tool (Kaizen) on workers safety in modular home building industries. The purpose of this survey is to rate the risk values of tasks performed before and after implementation of Lean. You will be given pictures, text, and verbal descriptions of processes carried out at individual workstations (mentioned in the questionnaire) and are asked to rate the probability of occurrence of a particular harm factor and the severity of the harm factor for identified hazard. This process will take about 45 minutes. All the information obtained will be kept confidential. I appreciate you completing the study, although you may stop at any time with no penalty. Participating in this study will contribute to understanding the impact of Kaizen on worker safety in the modular home building industry.

By signing below, you are stating that you have read and understood the purpose of this survey, and that you consent to participate in the survey. This sheet with your signature will be separated from the actual survey to protect your identity. Please take with you the following page with the contact information.

Signature: \_\_\_\_\_

Date: \_\_\_\_\_

Thank you for your participation!

**APPENDIX 2**

**RISK ASSESSMENT TOOL**

Probability

Severity

**Instructions:** Use the pictures provided in the power point presentation, and description given under each step in the questionnaire to understand the process carried out at three individual workstations (base-framing, sheet rock hanging, and painting stations). Based on the understanding of the procedure carried out by workers, rate the probability and severity of workers exposure to injury for the identified hazards, while performing the task. Probability is the possibility of a worker being exposed to the identified hazard while performing the task i.e. remote, occasional, probable and frequent. Remote is the least possibility of occurrence of a hazard while performing the task and frequent is the highest possibility of the occurrence of a hazard while performing the task. Severity is the seriousness of the injury to the worker in case of an accident due to the identified hazard i.e. minor, moderate, serious, catastrophic. Minor being the least severe injury in case of an accident due to the identified hazard and catastrophic being the most severe injury in case of an accident due to the identified hazard. Also, list any additional hazards identified under each task.

### **Risk assessment on base-framing station before implementing Lean tool (Kaizen)**

#### **1. Task 1 (Preparation):**

- a) Materials, equipment and tools required to build the base-frame are brought and placed closer to the workstation.
- b) Workers used their legs to move and position the concrete blocks to support the base-frame.

1) Injury to leg and back while moving the concrete blocks with legs.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
2) List unmentioned hazards.					

#### **2. Task 2 (Rim Joist):**

- a) The LVLs (Laminated Veneer Lumber) are cut of appropriate dimensions with the help of a hand held circular saw (electric powered) over the LVLs, near the material staging area.
- b) Small wooden planks are cut and nailed at the bottom of the LVLs.
- c) The cut LVLs are then moved from the material staging area with the help of a crane, and are placed over the concrete blocks.
- d) The ends of the LVLs are screwed to a fixture (angle iron).
- e) Pieces of LVLs are nailed to each other to form a rim joist.
- f) After forming the rim joist hangers are nailed to the interior side of the rim joist to hold the precut joists firmly in its position when mounted.

1) Eye irritation and respiratory problems while cutting LVLs.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
2) Injury caused due to struck by saw blade while performing the cutting operations.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
3) Injury caused due to pinch points between the materials.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
4) Injury caused due to strain on back and shoulders while performing the cutting operation in awkward postures.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
5) Injury caused due to struck by nails and screws while operating the nail gun and screw gun respectively.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
6) Injury caused while operating high-force tools (electric cutter, screw gun and nail gun).	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
7) Injury caused due to struck by LVLs.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
8) Injury caused due to slipping over saw dust or tripping over materials or tools.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
9) Injury caused due to strain on back and shoulders while installing the hangers in awkward postures.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
10) List any unmentioned hazard.					

### 3. Task 3 (Joist and Blocking):

- Precut joists are carried and placed over the rim joist at appropriate positions.
- Precut joists are inserted into the hangers and are nailed to rim joist to build the frame.
- According to the drawings marking is done at certain parts of the joist to install blockings, and blockings are positioned and nailed to the markings over the joist.

1) Injury caused due to pinch points between the materials.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
2) Injury caused due to struck by nails while operating the nail gun.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
3) Injury caused due to fatigue and strain on back and shoulder while carrying the precut joist (one sheet is carried by two persons).	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
4) Injury caused due strain on back and shoulders while marking and installing the blocking in awkward postures.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
5) Injury caused due to slipping over saw dust or tripping over materials or tools.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
6) Injury caused due to struck by precut LVLs.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
7) Injury caused while operating high-force tool like screw gun.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
8) List any un mentioned hazard.					

#### 4. Task 4 (Gluing):

- a) Upon completion of the blocking a worker glues the top portion of the joist for installing the OSB (Oriented strand board) over the joist.

1) Cancer caused due to direct contact of glue with skin.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
2) Rashes and damage to skin due to direct contact of glue with skin.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
3) Injury caused due to strain on back and shoulders while performing the gluing operation.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
4) Injury caused due to slipping over saw dust or tripping over materials or tools.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
5) List any un mentioned hazard.					

**5. Task 5 (Decking):**

- a) The OSB sheets are placed over the joist.
- b) The OSBs are then nailed over the joist with the help of nail gun.
- c) The same process is carried out over the entire length and width of the frame.

1) Injury caused due to pinch points between the materials.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
2) Injury caused due to struck by nails while operating the nail gun.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
3) Injury caused due strain on back and shoulders while nailing the OSB onto the joist in awkward postures.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
4) Injury caused due to fatigue and strain on back and shoulder while carrying the OSB sheets (one person carried a single board).	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
5) Injury caused due to struck by pre-cut OSBs.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
6) Injury caused due to slipping over saw dust or tripping over materials or tools.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
7) Injury caused while operating high-force tool like screw gun.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
8) List any un mentioned hazard.					

**6. Task 6 (Casters/Wheels):**

- a) Caster wheels are nailed to the base-frame.
- b) A pallet jack is placed below the frame and the floor is to remove the concrete blocks.
- c) The concrete blocks are moved and the base-frame pushed to the next station.

1) Injury caused due to pinch points between the materials and tool.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
2) Injury caused due to struck by screws while operating the screw gun.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
3) Injury caused due strain on back and shoulders while nailing the casters onto the rim joist in awkward postures.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic

4) Injury to leg and back while moving the concrete blocks with legs.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
5) Injury caused due to strain on back and shoulders while pushing the base-frame to the next station.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
6) Injury caused due to slipping over saw dust or tripping over materials or tools.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
7) List any un mentioned hazard.					



## Risk assessment on base-framing station after implementing Lean tool (Kaizen)

### 1. Task 1 (Preparation):

- a) Materials, equipment and tools required to build the base-frame are brought and placed closer to the workstation.
- b) Workers used their legs to move and position the concrete blocks to support the base-frame. In this process the workers had to only move half the number of concrete blocks with their legs because the remaining half were replaced by angle irons to support the base-frame.

1) Fatigue and injury to back and shoulder while lifting and moving the concrete blocks.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
2) List unmentioned hazards.					

### 2. Task 2 (Rim Joist):

- a) The LVLs are cut of appropriate dimensions with the help of an electric cutter, over the saw horse. The saw horse help to improve the workers posture while performing the cutting operations.
- b) Hangers to hold the precut joists are nailed to the LVLs while the material is still positioned over the saw horse. The workers could install the hangers in standing position as compared to the bend posture in baseline process (improvement).
- c) Wooden planks are nailed to the bottom of the LVLs to support the precut joints.
- d) The LVLs which are cut of appropriate dimensions are moved from the saw horse, and are placed over the angle irons with the help of a crane.
- e) The LVLs are nailed to the angle iron.
- f) Pieces of LVLs are nailed to each other to form a rectangle.
- g) Two newly built tool boxes are staged close to the working area (improvement). This helped in preventing the workers from tripping over tools as the workers positioned the tools back into the tool box after using the tool.

1) Eye irritation and respiratory problems while cutting LVLs.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
2) Injury caused due to struck by saw blade while performing the cutting operations.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
3) Injury caused due to pinch points between the materials.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
4) Injury caused due to strain	Probability	Remote	Occasional	Probable	Frequent

on back and shoulders while performing the cutting operation in awkward postures.	Severity	Minor	Moderate	Serious	Catastrophic
5) Injury caused due to struck by nails and screws while operating the nail gun and screw gun respectively.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
6) Injury caused while operating high-force tools (electric cutter, screw gun and nail gun).	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
7) Injury caused due to struck by LVLs.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
8) Injury caused due to slipping over saw dust or tripping over materials or tools.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
9) Injury caused due to strain on back and shoulders while installing the hangers in standing postures.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
10) List any unmentioned hazard.					

3. **Task 3 (Joist and Blocking):** This task is same as the baseline process:

1) Injury caused due to pinch points between the materials.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
2) Injury caused due to struck by nails while operating the nail gun.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
3) Injury caused due to fatigue and strain on back and shoulder while carrying the precut joist (one sheet is carried by two persons).	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
4) Injury caused due strain on back and shoulders while marking and installing the blocking in awkward postures.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
5) Injury caused due to slipping over saw dust or tripping over materials or tools. (Two newly built tool boxes reduces the	Probability	Remote	Occasional	Probable	Frequent

chance of worker tripping over the tools).	Severity	Minor	Moderate	Serious	Catastrophic
6) Injury caused due to struck by precut LVLs.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
7) Injury caused while operating high-force tool like screw gun.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
8) List any un mentioned hazard.					

4. **Task 4 (Gluing):** This task is same as the baseline process:

1) Cancer caused due to direct contact of glue with skin.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
2) Rashes and damage to skin due to direct contact of glue with skin.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
3) Injury caused due to strain on back and shoulders while performing the gluing operation.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
4) Injury caused due to slipping over saw dust or tripping over materials or tools. (Two newly built tool boxes reduces the chance of worker tripping over the tools).	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
5) List any un mentioned hazard.					

5. **Task 5 (Decking):** This task is same as the baseline process:

1) Injury caused due to pinch points between the materials.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
2) Injury caused due to struck by nails while operating the nail gun.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
3) Injury caused due strain on back and shoulders while nailing the OSB onto the joist in awkward postures.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic

4) Injury caused due to fatigue and strain on back and shoulder while carrying the OSB sheets (one person carried a single board).	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
5) Injury caused due to struck by precut OSBs.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
6) Injury caused due to slipping over saw dust or tripping over materials or tools. (Two newly built tool boxes reduces the chance of worker tripping over the tools).	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
7) Injury caused while operating high-force tool like screw gun.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
8) List any unmentioned hazard.					

**Task 6 (Casters/Wheels):** This task is same as the baseline process:

1) Injury caused due to pinch points between the materials and tool.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
2) Injury caused due to struck by screws while operating the screw gun.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
3) Injury caused due strain on back and shoulders while nailing the casters onto the rim joist in awkward postures.	Probability	Remote	Occasional	Probable	Frequent
		Minor	Moderate	Serious	Catastrophic
4) Injury to leg and back while moving the concrete blocks with legs.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
5) Injury caused due to strain on back and shoulders while pushing the base-frame to the next station.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
6) Injury caused due to slipping over saw dust or tripping over materials or tools. (Two newly built tool boxes reduces the chance of worker tripping over the tools).	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic

7) List any un mentioned hazard.	
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### **Risk assessment on sheet rock hanging station before implementing Lean tool (Kaizen)**

#### **1. Task 1 (Preparation (measure, precut, glue)):**

- a) The equipment such as a fan, tools, and raw materials are brought from the previous workstation and placed according to space available around the workstation.
- b) Worker cuts the sheet rock panel using a pocket knife, and glue the sheet rock panel using a glue gun.
- c) The workers did not use any PPE like respiratory mask to prevent inhalation of saw dust and VOC's from glue, safety glasses for eye protection form saw dust, or gloves to prevent hand injuries, while performing the task.

1) Cancer caused due to direct contact of glue with skin.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
2) Health hazards caused due to exposure to inhaling volatile organic components from glue.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
3) Injury to hand while handling sheet rock panels with sharp corners.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
4) Hand injury due to cutting knife.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
5) Fatigue and strain on back and shoulder while lifting the sheet rock panels to cut off appropriate dimensions.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
6) Injury caused due to tripping over materials.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
7) List unmentioned hazards.					

#### **2. Task 2 (Installation of ceiling and walls):**

- a) The cut sheet rock panels were lifted and carried to the work area.
- b) While installing ceilings and walls the sheet rock panels were handed to the hangers standing on the saw-horses, who lifts sheet rock panel overhead, and installs the panel on to the ceiling-rafters and wall-rafters respectively using a screw gun. Also, holes were drilled near electric output on the wall and ceiling panels after installing the panels. The workers did not use any PPE while performing this task.

- c) The workers installed the ceilings of the entire house at once, followed by installation of walls.

1) Eye irritation and respiratory problems while cutting and drilling holes in sheet rock panels.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
2) Injury to hand due to the strike against sharp corners of cut sheet rock panels.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
3) Fatigue and strain on back and shoulder while carrying the sheet rock panel from staging area outside the house to the installation area within the house. The workers lifted the panels with one hand and supported the panel with other hand Weight of a sheet rock panel: approximately 70 pounds (32 kg)).	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
4) Strain on back and shoulder while lifting and holding the sheet rock panels against the roof rafters for installation (approximate time: 2 min).	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
5) Strain on back and shoulders caused due to handling of tools (weight of screw gun: approximately 2.5 pounds (1.1 kg)).	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
6) Hand injury due to cutting knife.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
7) Risk of falling from saw horse.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
8) Injury caused due to falling	Probability	Remote	Occasional	Probable	Frequent

object like tools or sheet rock panels.	Severity	Minor	Moderate	Serious	Catastrophic
9) Injury caused due to struck by screws from screw gun.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
10) List unmentioned hazards					

### 3. Task 3 (Sweep Floor):

- a) Upon completing the above mentioned tasks the worker cleaned up the entire module using a mop and moves the equipment out the working module. The workers did not use any PPE while performing this task. The following hazards were identified while performing the task.

1) Eye irritation caused due to dust while sweeping	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
2) Respiratory problems caused due to dust in air while sweeping the floor.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
3) Awkward posture while sweeping.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
4) Injury caused due to tripping over materials.	Probability	Remote	Occasional	Probable	Frequent
		Minor	Moderate	Serious	Catastrophic
5) List unmentioned hazards.					



## **Risk assessment on sheet rock hanging station after implementing Lean tool (Kaizen)**

1. **Task 1 (Preparation (measure, precut, glue)):** The preparation procedure adopted after implementation of Lean was similar to the base line process.
  - a) The equipment such as a fan, tools, and raw materials are brought from the previous workstation and placed according to space available around the workstation.
  - b) While staging the material care was taken that the materials staged did not obstruct the plant traffic. This was done to prevent the material from getting damaged due to run over on material by plant traffic, and to reduce material waste.
  - c) Worker cuts the sheet rock panel using a pock knife, and glue the sheet rock panel using a glue gun.
  - d) The workers did not use any PPE like respiratory mask to prevent inhalation of saw dust and VOC's from glue, safety glasses for eye protection form saw dust, or gloves to prevent hand injuries, while performing the task.

1) Cancer caused due to direct contact of glue with skin.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
2) Health hazards caused due to exposure to inhaling volatile organic components from glue.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
3) Injury to hand while handling sheet rock panels with sharp corners.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
4) Hand injury due to cutting knife.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
5) Fatigue and strain on back and shoulder while lifting the sheet rock panels to cut off appropriate dimensions.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
6) Injury caused due to tripping over materials.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
7) List unmentioned hazards.					

### **2. Task 2 (Installation of ceiling and walls):**

- a) The cut sheet rock panels were lifted and carried to the work area. After implementing Lean materials were staged closer to the entrance of the house. This helped in reducing the distance travelled by the workers to move the cut sheet rock panel form the staging area to the installation area.



- b) While installing ceilings and walls the sheet rock panels were handed to the hangers standing on the saw-horses, who then lifts sheet rock panel overhead, and installs the panel on to the ceiling-rafters and wall-rafters respectively using a screw gun.
- c) Another improvement in the process included installation of ceiling and walls simultaneously. This helped in reducing walking and tool handling time (moving the saw horse and screw gun). The workstation layout below explains the staging of sheet rock panels before and after implementation of Lean on sheet rock hanging station.

1) Eye irritation and respiratory problems while cutting and drilling holes in sheet rock panels.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
2) Injury to hand due to the strike against sharp corners of cut sheet rock panels.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
3) Fatigue and strain on back and shoulder while carrying the sheet rock panel from staging area outside the house to the installation area within the house. The workers lifted the panels with one hand and supported the panel with other hand (Weight of a sheet rock panel: approximately 70 pounds (32kg)).	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
4) Strain on back and shoulder while lifting and holding the sheet rock panels against the roof rafters for installation (approximate time: 2 min).	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
5) Strain on back and shoulders caused due to handling of tools (weight of screw gun: approximately 2.5 pounds (1.1kg)).	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
6) Hand injury due to cutting	Probability	Remote	Occasional	Probable	Frequent

knife.	Severity	Minor	Moderate	Serious	Catastrophic
7) Risk of falling from saw horse.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
8) Injury caused due to falling object like tools or sheet rock panels.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
9) Injury caused due to struck by screws from screw gun.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
10) List unmentioned hazards.					

### 3. Task 3 (Sweeping of floors):

1) Eye irritation caused due to dust while sweeping.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
2) Respiratory problems caused due to dust in air while sweeping the floor.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
3) Awkward posture while sweeping.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
4) Injury caused due to tripping over materials.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
5) List unmentioned hazards.					

## Painting Station

### 1. Task 1 (Preparation for priming, sanding and texturing):

- a) Equipment such as a fan, lights, tools, air compressor, and raw materials are brought and placed inside the house.
- b) The window trims are masked.
- c) The mud paste is prepared for texturing operation.

1) Strain on back and shoulders while moving heavy equipment into house.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
2) Risk of foot injuries while handling heavy tool.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
3) Injury caused due to tripping over materials.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
4) List unmentioned hazards.					

### 2. Task 2 (Priming, sanding, and texture):

- a) The entire house (inner walls and ceilings) is first primed with the help of a spray gun.
- b) The house is then sanded by using a grinding tool.
- c) The texture is then sprayed using the spray gun over the walls and ceilings.

1) Eye irritation caused due to exposure to mud and primer.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
2) Skin irritation caused due to exposure to mud and primer.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
3) Respiratory problems caused due to exposure to mud and primer.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
4) Heat stress caused due to continuous use of Personal Protective Equipment (PPE).	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
5) Strain on back and shoulders while performing overhead works.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
6) Strain on shoulders while using spray guns and heavy sanding tool (sanding grinder).	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic

7) List unmentioned hazards.	
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### 3. Task 3 (Painting –ceiling):

a) The two coats of paint are sprayed over the ceilings using the spray gun.

1) Prolonged exposure to paint may cause eye irritation, skin irritation, and respiratory problems.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
2) Painting mist when comes into contact with any ignition sources like short circuit, power mishap, etc could lead to fire or explosion.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
3) Heat stress caused due to continuous use of respiratory mask and head socks.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
4) Strain on back and shoulders while performing overhead works.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
5) List unmentioned hazards.					

### 4. Task 4 (Painting - walls 1<sup>st</sup> and 2<sup>nd</sup> coat):

a) The first and the second coat of paint are done with the help of rollers and paint brush.

1) Prolonged exposure to paint may cause eye irritation, skin irritation, and respiratory problems.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
2) Painting mist when comes into contact with any ignition sources like short circuit, power mishap, etc could lead to fire or explosion.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
3) Strain on back and shoulders while performing overhead works.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
4) List unmentioned hazards.					

**4. Task 5 (Putty, caulking, and painting of shoe base, window trims, door trims and door (1<sup>st</sup> and 2<sup>nd</sup> coat)):**

- a) The trims which are fixed by the carpentry department are prepared for painting by applying putty and caulk with the help of spackling knife and caulk gun respectively.
- b) Two coats of paint are applied over the doors and trims.
- c) The doors are painted within the paint booth with the help of spray gun.

1) Prolonged exposure to paint may cause eye irritation, skin irritation, and respiratory problems.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
2) Health hazards caused due to exposure to glue- possible VOC's.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
3) Injury caused due to fire or explosion when painting mist comes in contact with any ignition sources like short circuit, power mishap, etc.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
4) Cancer caused due to exposure to harmful materials in caulk and putty	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
5) Strain on back while performing operations in bending postures.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
6) Strain in shoulder, back and neck muscles while performing work in awkward posture.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
7) List unmentioned hazards.					

## Risk assessment on painting station after implementing Lean tool (Kaizen)

**1. Task 1 (Preparation for priming, sanding and texturing):** This process was same as the baseline process.

1) Strain on back and shoulders while moving heavy equipment into house.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
2) Risk of foot injuries while handling heavy tool.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
3) Injury caused due to tripping over materials.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
4) List unmentioned hazards.					

**2. Task 2 (Priming, sanding, and texture):** This process was same as the baseline process.

1) Eye irritation caused due to exposure to mud and primer.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
2) Skin irritation caused due to exposure to mud and primer.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
3) Respiratory problems caused due to exposure to mud and primer.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
4) Heat stress caused due to continuous use of Personal Protective Equipment (PPE).	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
5) Strain on back and shoulders while performing overhead works.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
6) Strain on shoulders while using spray guns and heavy sanding tool (sanding grinder).	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
7) List unmentioned hazards.					

**3. Task 3 (Painting –ceiling):** This process was same as the baseline process.

1) Prolonged exposure to paint may cause eye irritation, skin irritation, and respiratory problems.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic

2) Painting mist when comes into contact with any ignition sources like short circuit, power mishap, etc could lead to fire or explosion.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
3) Heat stress caused due to continuous use of respiratory mask and head socks.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
4) Strain on back and shoulders while performing overhead works.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
5) List unmentioned hazards					

#### 4. Task 4 (Painting - walls 1<sup>st</sup> and 2<sup>nd</sup> coat):

- a) The first and the second coat of paints are sprayed on the walls with the help of a spray gun instead of a rollers and paint brush.

1) Prolonged exposure to paint may cause eye irritation, skin irritation, and respiratory problems.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
2) Painting mist when comes into contact with any ignition sources like short circuit, power mishap, etc could lead to fire or explosion.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
3) Heat stress caused due to continuous use of Personal Protective Equipment (PPE).	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
4) Strain on back and shoulders while performing overhead work.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
5) List unmentioned hazards					

#### 5. Task 5 (Putty, caulking, and painting of shoe base, window trims, door trims and door (1<sup>st</sup> and 2<sup>nd</sup> coat)): This process was same as the baseline process:

1) Prolonged exposure to paint may cause eye irritation, skin irritation, and respiratory	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic

problems.					
2) Health hazards caused due to exposure to glue- possible VOC's.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
3) Injury caused due to fire or explosion when painting mist comes in contact with any ignition sources like short circuit, power mishap, etc.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
4) Cancer caused due to exposure to harmful materials in caulk and putty	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
5) Strain on back while performing operations in bending postures	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
6) Strain in shoulder, back and neck muscles while performing work in awkward posture.	Probability	Remote	Occasional	Probable	Frequent
	Severity	Minor	Moderate	Serious	Catastrophic
7) List unmentioned hazards					



## **VITA**

Joel James was born in March 1985 in Ribandar-Goa, India. Goa is the smallest state in India and is located to the west of India. He attended his middle school at Red Rosary School and high school at Don Bosco School Goa. He earned his undergraduate degree from Visvesvaraya Technological University- Karnataka in June, 2006. He joined the Department of Construction Management and Industrial Engineering at Louisiana State University in August, 2009. At LSU he worked as a graduate assistant for the Southern Regional Climate Center (Application Developer). He expects to receive his Master of Science in Industrial Engineering in Spring 2012.