REDUCING ERGONOMIC HAZARDS DURING HIGHWAY TUNNEL CONSTRUCTION: A CASE STUDY OF A CEILING PANEL ASSEMBLY OPERATION

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ABSTRACT

During many manual construction activities workers are exposed to ergonomic hazards that may increase their risk for developing a work-related musculoskeletal disorder. An evaluation of the job tasks involved in the ceiling panel assembly operation in the Third Harbor Tunnel of the Central Artery/Tunnel (CA/T) construction project in Boston, Massachusetts was carried out to identify and reduce the ergonomic hazards present in the tasks. Each assembly operation employed ten Iron Workers who each performed one of four job tasks. The researchers divided each job task into activities and evaluated each activity for ergonomic hazards using a systematic ergonomic job analysis. This analysis was used to identify the ergonomically hazardous activities and list the work-related causes of the hazards (e.g. equipment or tool design, work organization). In the analysis, hazards were identified for the trunk, legs, shoulders, hands/wrists and neck. These hazards included: repetitive motions of the wrist and arms, forceful whole body and hand exertions, awkward body postures, and localized contact stresses. The most frequently observed ergonomic hazards were static non-neutral body postures caused by low work heights, heavy pushing of ceiling panels on the assembly line, and forceful repetitive hand movements and contact stresses during bolting activities. Recommendations for the redesign of the assembly line to reduce the hazards were suggested. An operation was later developed at a different location in the tunnel which was identical to the first, with the exception of having several of the recommended design changes. A follow-up evaluation was performed on the redesigned operation and approximately 43% of the previously identified ergonomic hazards had been eliminated or reduced. This study demonstrates how ergonomic hazards can be systematically evaluated and reduced with relatively simple and inexpensive interventions for the prevention of musculoskeletal injuries.

INTRODUCTION

Construction workers show elevated risks of developing work-related musculoskeletal disorders (WMDs) of the back and the upper and lower extremities (Damlund *et al.* 1982;

Burkhart *et al.* 1993; Holstrom *et al.* 1993). Though WMDs are quite common in construction work, little work has been done in the United States to systematically identify the ergonomic hazards for specific construction trades and operations (Schneider and Susi, 1994). Even less work has been devoted to reducing these hazards.

The Central Artery/Tunnel (CA/T) construction project in Boston, MA is currently the largest public works project in the United States. The two main components of the project are: 1) the building of a new underground highway which runs beneath the city and connects freeways from the north and south and 2) the construction of a third tunnel beneath Boston Harbor linking Logan Airport to downtown Boston.

The Construction Occupational Health Project (COHP) at the Department of Work Environment at the University of Massachusetts Lowell is funded by the National Institute for Occupational Safety and Health (NIOSH) through the Center to Protect Workers' Rights as part of a nation-wide research effort to reduce WMDs in the construction industry. The CA/T construction project has served as the site the COHP's efforts to evaluate the ergonomic hazards involved in large scale highway construction projects. As part of this effort, the COHP has evaluated various finishing operations in the recently completed Ted Williams tunnel including wall plastering, wall tiling, ventilation duct panel installation, hand-rail installation, ceiling module assembly and ceiling module installation. These operations are performed by a variety of union trades such as Plasterers, Tile Mechanics and Finishers and Iron Workers.

The contractor responsible for the finishing operations in the tunnel recorded 8 injuries on the Occupational Safety and Health Administration (OSHA) 200 logs, over a six week period. Although this contractor employed many construction trades on this site, only Iron Workers had been injured during this period. Of the eight injuries, six were related to over-exertion of the musculoskeletal system: 2 back strains, 2 shoulder strains and 2 knee or ankle injuries. This prompted the contractor's site safety officer to request the COHP to perform an analysis of this operation which he considered to be ergonomically hazardous, the ceiling module assembly operation. During this operation Iron Workers assembled individual ceiling panels into 10 panel modules which, in a separate operation, were later hung from the tunnel's ceiling.

Researchers conducted the evaluation to 1) summarize some of the ergonomic hazards found in the ceiling module assembly operation and 2) provide recommendations for reducing the hazards in order to prevent future WMDs. One assembly operation was first evaluated and design recommendations to reduce ergonomic hazards were given to the contractor. Later, the contractor developed a similar operation that included many of the design recommendations and the ergonomic hazards for the job tasks were re-evaluated with a similar analysis to determine which of the hazards had been eliminated or reduced.

ANALYSIS

General Ergonomic Analysis Methods

The goal of an ergonomic job analysis is to identify the tasks within a job that increase a worker's exposure to risk factors for work-related musculoskeletal disorders (WMD). The commonly cited risk factors for WMD are:

1. repetitive motions or prolonged activities
2. forceful exertions
3. awkward postures
4. localized contact stresses
5. temperature extremes
6. vibration

The analysis attempts to quantify both the magnitude and duration of these exposures. An understanding of the entire work process is also important so that interventions may be effectively targeted. Therefore, a systematic ergonomic job analysis similar to that described by Keyserling *et al.* (1991) is used in an ergonomic evaluation to identify the hazardous activities and list the work-related causes of these hazards (e.g. equipment or tool design, work organization). The steps involved in the ergonomic evaluation that was employed in this study are listed in Table 1.

The initial steps in the ergonomic evaluation are used to describe the various levels of the overall work process. A taxonomy has been developed to aid in the description of the heavy highway construction process (Buchholz *et al.* 1996). The contents of this taxonomy are based on the "Standard Specifications for Highways and Bridges" used by the Massachusetts Highway Department (1988). The taxonomy is organized hierarchically, with construction projects broken into a series of stages and, on a large construction project, different stages can be underway simultaneously along the length of the site. The primary stages in heavy highway construction are: earthworks, drainage, paving, curbs and edging, fences and walls, and structures. Each stage may be composed of several operations which are processes overseen by a foreman and other on-site supervisors and are completed by at least one crew of workers. Each operation is comprised of job tasks that are performed by an individual worker from a specific trade, which is usually defined jurisdictionally (i.e. construction trades negotiate for the right to perform specific job tasks). Activities are the fundamental acts that are required to complete a job task and are based on work elements (e.g. lift, carry, reach, grasp and move) taken from the time study methodology traditionally employed by industrial engineers (Barnes, 1980). Since the taxonomy allows an analysis to be stratified by construction stage, operation and task, as well as by the trades involved in each operation, it provides the means for achieving a task-based analysis. A comparable taxonomy could be developed for other industries in order to facilitate a similar task-based analysis.

The first step in the evaluation methodology then is to determine the stages and operations that were underway at the site. Workplace organization can have an important impact on the ergonomic hazards, and therefore information about the operation's shift schedule, production demands, the physical layout and material flow is obtained. This information is important for understanding the purpose of the operation of interest, how it is impacted by other operations and how it impacts other operations.

The operation to be studied is described in the second step using observationally-collected information. To aid in this description, a narrative of the operation is obtained from engineers, supervisors and workers on-site. The gathered information includes a description of crew size and structure, a description of the work schedule and pace, and a sketch of the layout of the work area. The operation is then divided into job tasks performed by individual workers. Written documentation of the work (e.g. contract, specifications, industrial engineering methods) may provide additional useful information.

In the third step, each job task is described and further divided into activities, listing the tools, equipment and materials that are used. If possible, the work cycle is defined, i.e. activities are described in the order that they occur. This is often difficult in the construction industry, because much of the work is non-cyclical or the work cycles are long and irregular. However, in large heavy highway construction projects workers often perform the same daily job tasks for an operation which takes weeks or months to complete and some operations are even performed on temporary assembly lines.

Each job task is then analyzed for exposure to the risk factors for WMDs. A checklist is often employed for this purpose. The advantages of a checklist are that it is fast, simple and inexpensive to use. The primary disadvantage is that it gives no detail on the magnitude or duration of the exposure. Direct measurements using a force gauge, stop watch, tape measure or goniometer can be employed to add detail to the analysis. A systematic ergonomic job analysis similar to that described by Keyserling *et al.* (1991) is then used to identify the ergonomically hazardous activities and list the work-related causes of the hazards (e.g. equipment or tool design, work organization). Hazards are identified for the trunk, neck, shoulders, hands/wrists and legs. The important ergonomic risk factors of interest and the guidelines used to identify them are shown in Table 2.

A number of methods are available, if a more detailed analysis is desired. More detail can improve intervention targeting and provide a better measure for evaluation. For example, estimates of the percent of time workers spend in awkward postures or the frequency of wrist posture deviations for activities and tasks can be estimated. Methods for detailed evaluation of posture and motion range from direct observations (e.g. Buchholz *et al.* 1996; Karhu *et al.* 1977) to methods employing videotape (e.g. Armstrong *et al.* 1981; Keyserling 1986) and to electrogoniometers, which are instruments for very detailed posture and motion measurement (e.g. Marras *et al.* 1993). The level of detail in an ergonomic analysis is often determined by logistical considerations, such as time and money.

The fourth step in this process is to design and implement interventions to control the workers' exposure to the identified risk factors. Ideally, this should be a collaborative effort between the ergonomist, workers, management and other stakeholders. The final step of the ergonomic method is to re-evaluate each of the job tasks for ergonomic hazards using the same analysis that was used in the original evaluation, so that comparisons could be made between the pre- and post-intervention operations.

Specific Methods

In this study, three researchers observed the operation for approximately four hours on each of four days over a two week period. Each job task was carefully observed for five to ten work cycles. The cycle of activities was recorded and the time needed to complete a cycle (cycle time) was determined to provide estimates of the frequency of activities throughout the shift. The ergonomic hazards for each activity were identified using a checklist-like approach. In some cases the ergonomic hazards were quantified using direct measurements (e.g. frequency of repetitive hand motions, load weights or forces, exposure duration), but in most cases the hazards were only identified. Equipment and/or work area design problems thought to be cause the hazards were also noted. Still photographs were taken to document the hazards for each job task. Temperature extremes and vibration were not considered a problem because of the relatively mild climate inside the tunnel and only non-vibrating hand tools were used.

Recommendations to improve the design of the operation were given to the Site Safety Officer. Some of these recommendations were incorporated in another assembly line that was later constructed for this operation. One researcher observed the operation on the new assembly line for two hours on three occasions. Again, information about the work area layout, equipment used was collected. The operation was divided into job tasks and each job task was divided into activities. The ergonomic hazards associated with each of the activities were then identified. The hazards were then compared to those of the original operation.

Results of the Initial Ergonomic Evaluation

Stage and Operation

The ceiling module assembly operation that was evaluated was part of the Tunnel Finishing stage of highway construction. Other operations in this stage include: wall plastering, wall tiling, paving, guard rail installation and ceiling module installation. Because attaching individual panels to the tunnel's ceiling would be difficult and time consuming, the contractor decided that it would be more efficient to first assemble groups,of ten panels together before installing them. Therefore, an assembly line that could accommodate a ten panel module was constructed. An over-head monorail system was installed so that panels could be moved along the line. Pallets of panels and steel were delivered to the assembly line, while a large truck having a hydraulic flat bed was used to take the completed modules from the line and position the modules close to the ceiling for installation. The assembly line was located in one of the widest sections of the tunnel to minimize disruption of the other construction operations. When the assembly line was set-up, very little consideration was given to how well the characteristics of the line were suited for the workers assembling the ceiling modules.

The layout of the assembly line for this operation is shown in Figure 1. The work area was approximately 250 feet long and the assembly line was located 16 inches above floor level. Individual ceiling panels were 4 feet by 11.5 feet and weighed approximately 700 pounds. The panels and steel connector beams were moved and lifted onto an assembly line with powered lifts. The lifts were activated with a four button control and virtually eliminated manual lifting of the panels and connecting steel. However, panels and steel were manually adjusted (e.g., pushed or pulled across the rollers) after being placed on the assembly line. A crew of ten Iron Workers

(1 woman and 9 men) participated in the operation. The crew worked a standard eight-hour shift (7 A.M. to 3 P.M.). Job tasks were performed at a moderate, steady pace. The crew did not rotate among the various job tasks.

Job Tasks and Ergonomic Hazards

The operation was divided into 4 job tasks: Panel Sorting, Panel Preparation, Sub-Module Assembly and Module Assembly.

1. *Panel Sorting* - Ceiling panels and beams required for assembly were sorted the with one of the monorail's powered lifts.
2. *Panel Preparation* - Rubber gaskets were glued onto the ceiling panels and the panels were delivered to the sub-module assembly using the powered lift.
3. *Sub-Module Assembly* - Sets of 3 to 4 panels were aligned and connected with steel I-beams and H-beams.
4. *Module Assembly* - Sub-modules were bolted together into one assembled module.

Each assembled module was then connected to another of the monorail's lifts and loaded onto a truck having a hydraulic flat bed. In a separate operation, the module was later delivered to the installation location.

The cycle or sequence of activities for each job task were identified (Table 3). Cycle times for job tasks were variable, but the order in which workers performed the activities during a job task was relatively consistent. Each of the job tasks and the activities for which ergonomic hazards were found are described below. The ergonomic hazards for each of the listed activities and related work area design problems are summarized in Table 4.

1. Panel Sorting

Two Iron Workers sorted the ceiling panels and connecting steel with one of the monorail's lifts (one worker operated the lift, the other guided the panel). The panels were sorted in the order in which they were to be assembled. Each ceiling panel had been tagged with an alphanumeric identification code. The activities in this job task were not considered particularly hazardous.

2. Panel Preparation

Two Iron Workers retrieved individual ceiling panels with another of the monorail's lifts, and stacked them near the assembly line. The Iron Workers glued rubber gaskets onto the ceiling panels and then delivered the panels to the assembly using the powered lift. The panels were lowered onto plywood sheets which protected the panels from being damaged by the rollers and were pushed manually on the rollers to the Sub-Module Assembly. Ergonomic hazards were found for three activities:

a. *Gluing the gasket onto the panel.* The gaskets were carefully aligned and pressed against the glued sub-modules. The work height was at or below waist level (depending on where the panel was located during the Sorting job task) for more than half of the work cycles observed. When the work height was low the workers flexed their trunk more than 45 degrees (often close to 90 degrees) or squatted when pressing the gasket onto the panel in order to view the gaskets. The workers assumed these postures for approximately 2 to 5 minutes each time they glued the gasket onto a panel which was at or below waist height.
b. *Cutting the excess gasket with scissors (Figure 2).* Cutting the excess gasket was also an activity requiring a high degree of precision and therefore the worker again kept the gasket near the eyes. The worker flexed the trunk or squatted while cutting the gasket, although such postures were usually maintained less than one minute.
c. *Pushing the panel down the assembly line.* This was the most physical activity during Panel Preparation. After a panel was placed on the assembly line of rollers it was manually pushed down the assembly line somewhere between 10 and 30 feet. Because the height of the panel when on the assembly line was about 21 inches, the workers were required to flex and/or twist their trunk over 45 degrees while pushing. Workers also

mentioned that it was sometimes difficult to push the panels because the plywood did not roll easily on the rollers.

3. Sub-module Assembly

Sets of 3 to 4 panels were aligned by one or two Iron Workers. Steel beams were aligned with a powered crane lift (not on the monorail) and bolted to the ceiling panels to form a sub-module by two Iron Workers. Ergonomic hazards were found for five activities:

a. *Aligning the panels on rollers (Figure 3).* The workers were required to flex and/or twist their trunks over 45 degrees and often twist their necks while aligning the panels. The weight of the panels placed high forces on the workers' backs and shoulders while pushing the panels.

b. *Gluing the gasket onto the sub-module (Figure 4).* The workers were required to flex their trunks more than 45 degrees or squat when pressing the gasket onto the sub-module The workers assumed these postures for approximately 2 to 5 minutes when pressing the gasket onto the glued panel.

c. *Aligning the steel with the pins (Figure 5).* The steel I beams and H beams each weighed over 200 lb. and the workers were required to push or pull the beams manually to align them. While doing this, the workers had to flex their trunks more than 45 degrees and assume squatting or kneeling postures and remain in these postures for as much as three or four minutes.

d. *Bolting the steel to the panels.* Two beams were attached to each sub-module and each beam was attached with approximately ten bolts. For each bolt, the workers usually had to flex their trunks greater than 45 degrees and/or squat or kneel for up to one minute. During this time, the workers flexed or extended their wrist at least 45 degrees approximately 60 times. Therefore, workers assembling sub-modules deviated their wrists approximately 300 times per sub-module (two workers connected the 10 bolts).

e. *Tightening bolts with the 45 ft.-lb. ratchet.* One worker finished tightening each of the bolts with a ratchet calibrated to 45 ft.-lb. This activity required the worker to jerk the ratchet back to his body during each turn of the bolt. This was done until the bolt had the desired 45 ft.-lb., at which time the ratchet released its resistance (i.e. slipped). The worker often assumed a 3 point crawling (i.e. knees and one hand on panel) or kneeling posture while using the ratchet.

4. *Module Assembly*

Three to four Iron Workers manually pushed the sub-modules 20 to 60 feet. Two to four Iron Workers bolted groups of three sub-modules together into one assembled module. The Ironworker foreman inspected the modules. The assembled panels were then connected to another of the monorail's lifts and positioned on the truck. Ergonomic hazards were found for three activities:

a. *Pushing the sub-module down the assembly line.* The three or four workers who manually pushed the sub-module, weighing between 2500 and 3200 lb., down the assembly line had to flex their trunk and/or twist their trunks greater than 45 degrees. This activity was considered to be the one which required the greatest whole body exertions by the workers. This was done once every 20 to 70 minutes.

b. *Tightening bolts (Figure 6).* The workers were required to bend their trunks greater than 45 degrees while bolting the sub-modules together. Workers were observed flexing their necks greater than 30 degrees during this activity. Twelve bolts were used to connect two sub-modules. While bolting, the workers flexed or extended their wrist at least 45 degrees approximately 60 times. Each bolt took up to one minute to tighten.

c. *Operating the powered winch.* The powered winch, used to move the assembled module beneath the mono-rail's third lift, was located below knee height. Therefore, the worker was required to assume awkward trunk and leg postures while operating the winch. This activity took about one minute to complete.

Summary of Ergonomic Hazards

Some of the most stressful ergonomic hazards included:

1. Non-neutral trunk, neck and leg postures caused by the low work surface heights.
2. Heavy loading and static non-neutral trunk postures during the manual pushing of ceiling panels and sub-modules.
3. Repetitive/forceful wrist deviations during bolting activities.

DESIGN/INTERVENTION

The researchers made several recommendations to improve the design of the assembly operation and increase worker awareness of the ergonomic hazards. These recommendations were first communicated to the site safety representative verbally, and later were included in a brief report to the contractor. In the report, it was recommended that the workers be consulted before any of the interventions were implemented. It was thought that the workers should have control over which of the suggested interventions to accept, and that the workers would have the best understanding as to whether or not the recommendations would disrupt the operation. Most of the recommendations called for changes in the design of the work place because engineering controls have been shown to be more effective than administrative controls or personal protective equipment.

Recommendations for Ceiling Module Assembly

1. *Raise the height of the working surface for panel preparation.* Providing a work surface height of at least 40 inches (i.e. approximately waist height) for the panel gluing activity during panel preparation would reduce the frequency and duration of awkward trunk and leg postures during the panel preparation job task.
2. *Increase the height of the rollers and add stairs.* Increasing the height of the assembly line rollers to approximately 36 inches (i.e. slightly below waist height) would reduce the

frequency and duration of non-neutral trunk and leg postures during the sub-module and module assembly job tasks. Stairs would then need to be installed to allow workers to get on and off of the assembly line.

3. *Possible use of powered ratchets.* Using powered ratchets, calibrated to the 45 foot-pounds of torque that are required in the bolting activities would reduce the frequency of wrist motions during the sub-module and module assembly job tasks and reduce the duration in which workers are in non-neutral trunk postures.
4. *Improve the design of the powered winch.* The powered winch was not always used to move sub-modules for sub-module assembly because the winch was not functioning properly, was not easy to use or was not fast enough. The winch should be raised to about 36 inches from the floor. If feasible, the speed at which the winch pulls the sub-modules should be increased. A back-up winch should be purchased to replace the winch when it is not functioning properly.
5. *Provide ergonomics training.* Providing the workers with basic ergonomics training that explains the importance of maintaining neutral postures while working and of minimizing heavy manual material handling (e.g., pushing of ceiling sub-modules) should increase each worker's ability to recognize ergonomic hazards and may help reduce the risk to musculoskeletal injury caused by hazardous work procedures.

New Design

A similar ceiling module assembly work area was later developed at a different location in the tunnel. Several improvements were made to this work area which reduced some of the ergonomic hazards mentioned above. The improvements included:

1. *Increased Panel Preparation work height (Figure 8).* Panels were raised with the powered lift to over 40 inches from the ground during panel preparation.
2. *Increased assembly line height (Figure 9).* The height of the assembly line was increased and slightly tilted downward from beginning to end so that gravity would assist the workers

when pushing panels and sub-modules. The assembly line heights ranged from approximately 36 inches at the beginning to 18 inches at the end. This was done simply by installing sheets of wood of different heights beneath the assembly line. Stairs were installed so that workers could get on and off of the assembly line.

3. *Fork truck replaced powered winch.* A fork truck replaced the powered winch eliminating the awkward static trunk and leg postures when the winch was operated.
4. *Ergonomics Training.* All of the workers in this operation received a basic 20 minute training session about body mechanics and lifting techniques for reducing stress on the lower back during manual material handling.

TEST & EVALUATION

The effectiveness of an ergonomic intervention may be evaluated by measuring the change in morbidity data (e.g., musculoskeletal injuries rates, absenteeism due to musculoskeletal injuries, prevalence of musculoskeletal symptoms, etc.) or change in ergonomic exposures that follow the intervention. Sometimes, morbidity or exposure data can be compared to that of a similar group of workers that are not introduced to the intervention (a control group).

It is important to understand some of the logistical difficulties that arise when evaluating an intervention. There are a variety of factors which may confound the effect of an intervention. For example, changes in production demands and economic considerations may affect absenteeism, willingness to report symptoms and job turnover. Additionally, when only a small group of workers are affected by an intervention, it may be difficult to show a positive change in morbidity or exposure with conventional scientific methods due to a lack of statistical power. Finally, reductions in injuries or symptoms may not immediately follow an intervention. It is therefore important to select a time interval for the intervention which is short enough to minimize the potential possibility for external changes in the workplace and long enough for the true benefit of the intervention to be observed (e.g., reduction in morbidity or exposure).

In this study, injury data specific to the assembly operations could not be obtained from the contractor (only trade specific information was available). Both injury and symptom data were also thought to be severely limited due to the small sample size. Therefore, a re-assessment of the exposure to ergonomic hazards for each of the tasks was chosen to evaluate the new assembly line. Because of the small number of workers and generally crude measures of exposure, no formal statistical tests were performed. Two important assumptions for this type of analysis are that change in exposure can be measured appropriately and that the exposure is a true predictor of the musculoskeletal health outcome of concern.

The work area layout, job tasks and number of workers performing each job task on the new assembly line were almost identical to those of the original assembly line with the exception of the improvements mentioned above. The sequence of activities within each cycle as well as cycle times were also very similar to the initial operation. Slightly more than 43% of the ergonomic hazards identified during the earlier operation were eliminated or reduced (Table 5). Static non-neutral trunk and leg postures during Panel Preparation were eliminated with the increased work height. The higher assembly line reduced static non-neutral trunk and leg postures during the manual handling of panels. The tilted assembly line helped reduce forces on the trunk and shoulders during manual pushing of the panels. Non-neutral static trunk and leg postures for several activities during Sub-module Assembly were affected very little because workers had to work on top of the panels when aligning and bolting steel. The forceful and repetitive hand motions also remained unchanged during bolting activities. Workers had explained that powered ratchets could not be used because construction design specifications required manual bolting to obtain the desired torque.

CONCLUSION/SUMMARY

Although not all ergonomic hazards were eliminated with the new ceiling module assembly operation, this case study demonstrates how ergonomic hazards can be systematically evaluated and how relatively simple interventions can be used to reduce ergonomic hazards and prevent musculoskeletal injuries from occurring in the future. Interventions such as assembly work heights at or above waist height, locating controls at or above waist height and ergonomics training may be applicable to a variety of assembly operations, including those not on construction sites.

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Table 1. Ergonomic job analysis items.

1. Describe the general process and construction stage.
   a. Identify the contractor for the construction site.
   b. Identify the operations being performed.
2. Describe the operation (# workers, trades involved, locals, machinery, location on site).
   a. Provide a list of the workers (name, description, trade, level, years in trade, injury, symptoms, etc.).
   b. Describe work schedule (shift duration and scheduled breaks).
   c. Describe work pace for each job task (use interviews and observations).
   d. Describe job rotation (if any).
   e. Sketch layout of work area.
3. Describe each job task and break it into activities.
   a. Identify ergonomic risk factors for each body region (back, arms, legs and neck).
   b. Provide a list of tools and equipment.
   c. Identify tasks/activities that need further evaluation.
   d. List possible interventions for reducing hazards.
4. Design and implement ergonomic interventions.
5. Re-evaluate the job tasks after interventions are made.
   a. Identify ergonomic risk factors for each activity of each job task
   b. Identify tasks/activities that need further evaluation.
   c. List possible ideas for reducing hazards.

Table 2. The important ergonomic risk factors and the guidelines used to identify them.

1. repetitive motions
   a. hand/wrist motions repeated once per second[1,2]
   b. sustained static exertions[3]
2. forceful exertions
   a. whole body exertions > 50 lbs. required to lift, push or pull[4]
   b. grip forces > 10 lbs.[1]
3. awkward (non-neutral) postures
   a. trunk flexion > 45 degrees[5]
   b. trunk lateral bending or twist > 20 degrees[5]
   c. neck flexion or twist > 30 degrees[6]
   d. shoulder flexion or abduction > 60 degrees[7]
   e. wrist flexion/extension > 45 degrees[2,8]
   f. wrist radial/ulnar deviation > 20 degrees[2,8]
   g. pinch postures[2,8]
   h. sustained kneeling or squatting[9,10]
4. localized contract stresses[8]
5. temperature extremes
   a. heat[11]
   b. cold[8]
6. vibration
   a. whole-body[12,13]
   b. segmental (hand-arm)[14]

[1] Silverstein *et al.* (1986)
[2] Armstrong *et al.* (1982)
[3] Rohmert (1973)
[4] Waters *et al.* (1993)
[5] Punnett *et al.* (1991)
[6] Kilbom and Persson (1987)
[7] Bjelle *et al.* (1979)
[8] Armstrong (1986)
[9] Thun *et al.* (1987)
[10] Felson *et al.* (1991)
[11] Snook and Ciriello (1974)
[12] Wikstrom *et al.* (1994)
[13] Seidel and Heide (1986)
[14] NIOSH (1989)

Table 3. Job tasks and cycles of activities during ceiling module assembly.

1. Panel Sorting and Stacking (Cycles ranged between 1 and 10 minutes.)

# workers	Major Activities
2	wrap strap around ends of pallet and connect strap to lifting cable
1	operate powered lifter
1	guide load
2	disconnect strap from cable and unwrap strap from ends of pallet

2. Panel Preparation (Cycles ranged between 6 and 25 minutes.)

# workers	Major Activities
1	use powered air-hose to blow screw holes clean of debris
1	screw hooks into 4 corner screw holes
1	wipe edges of panel with rag
1	retrieve bolts, gaskets and glue bottles
2	align gaskets along edges of panel
2	brush glue along panel edges
2	brush glue on gasket
2	**glue gaskets onto panels***
2	**cut excess gasket with scissors***
2	operate powered lift, guide load, place panel onto rollers
2	**push panel down assembly line***
2	take out corner hooks
1	operate powered lift to pick up new ceiling panel
1	perform miscellaneous clean-up (align boards, etc.)
1	screw hooks into new panel

3. Sub-module Assembly (Cycles ranged between 20 and 70 minutes.)

# workers	Major Activities
2	**align 3 or 4 panels on rollers***
2	retrieve clamps
2	clamp together sub-module
2	retrieve rubber gaskets and glue bottles
2	align gaskets
1	retrieve cart of wood, place wood in cart
2	brush glue along sub-module
1	position washers, nuts, bolts near holes
1	**glue gasket onto sub-module***
2	hook lift to I beam
2	operate lift/guide load
1	press gasket onto sub-module
2	push sub-module under I beam
2	**align I beam with pins***
2	**bolt I beam to panels***
1	hook lift to H beam, operate powered lift
1	continue ratchet work
1	**align H beam on pins***
1	**bolt H beam to sub-module***
1	**tighten bolts with 45 ft-lb. ratchet***
2	unhook clamps

4. Module Assembly (Cycles ranged between 60 and 200 minutes.)

# workers	Major Activities
1	**push sub-module 1 down the assembly line***
1	align sub-module 1
1	**push sub-module 2 down the assembly line***
1	align sub-module 2
3	get ratchets, wrenches and bolts
2	put brackets and hardware on I beams and H beams
1	**push sub-module 3 down the assembly line***
1	align sub-module 3
2	**bolt brackets to sub-modules 24 times***
2	tighten down brackets with a 350 ft.-lb. calibrated torque wrench 8 times
1	hook winch to assembled module
1	**operate powered winch to move module***

*** ergonomic hazards**

Table 4. Summary of the ergonomic hazards identified for each job task.

Job Task	Activity	Body Area	Highly Repetitive Motions	High Forces	Static Non-neutral Postures	Contact Stresses	Work Area Design Problems
Panel Preparation	Gluing gasket onto panel	Trunk			√		low work surface
		Legs			√		
	Cutting excess gasket with scissors	Trunk			√		
		Legs			√		low work surface
	Pushing panel down assembly line	Trunk		√	√		winch not accessible or fast enough
Sub-Module Assembly	Aligning the panels on rollers	Trunk		√	√		manual alignment required and work surface is low
		Neck			√		
		Shoulder		√			
	Gluing the gaskets onto the sub-module	Trunk			√		
		neck			√		low work surface
	Aligning the steel with the pin	Trunk		√	√		
		Neck					low work surface
		Legs			√	√	
	Bolting the steel to the panels	Trunk		√	√		low work surface and tighten bolts manually
		Shoulder		√			
		Hand/Wrist	√			√	
		Legs			√	√	
	Tightening the bolts with the 45 lb. ratchet	Trunk		√	√		low work surface and tighten bolts manually
		Shoulder		√			
		Hand/Wrist	√	√		√	
		Legs			√	√	
Module Assembly	Pushing sub-module down assembly line	Trunk		√	√		winch not accessible or fast enough
		Shoulder		√			
	Tightening bolts	Trunk			√		low work surface and tighten bolts manually
		Neck			√		
		Shoulder		√			
		Hand/Wrist	√	√		√	
		Legs			√	√	
	Operating powered winch	Trunk			√		winch low
		Legs			√		

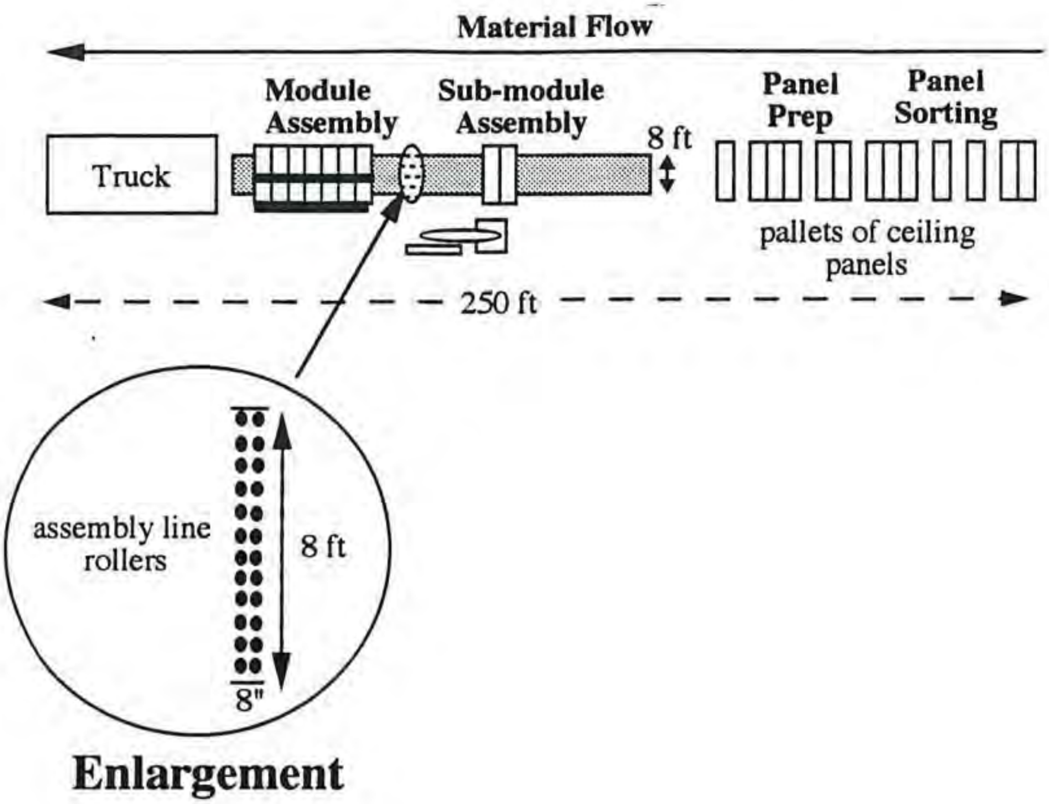
Table 5. Summary of the ergonomic hazards for each job task with the improved design

Job Task	Activity	Body Area	Highly Repetitive Motions	High Forces	Static Non-neutral Postures	Contact Stresses	Work Area Design Improvements
Panel Preparation	Gluing gasket onto panel	Trunk			E/R		height of work surface increased
		Legs			E/R		
	Cutting excess gasket with scissors	Trunk			E/R		height of work surface increased
		Legs			E/R		
	Pushing panel down assembly line	Trunk		E/R	E/R		assembly line height increased and tilted
Sub-module Assembly	Aligning the panels on rollers	Trunk		E/R	E/R		assembly line height increased
		Neck			E/R		
		Shoulder		E/R			
	Gluing the gaskets onto the sub-module	Trunk			E/R		assembly line height increased
		neck			E/R		
	Aligning the steel with the pin	Trunk		√	√		
		Neck					
		Legs			√	√	
	Bolting the steel to the panels	Trunk		√	√		
		Shoulder		√			
		Hand/Wrist	√			√	
		Legs			√	√	
	Tightening the bolts with the 45 lb. ratchet	Trunk		√	√		
		Shoulder		√			
		Hand/Wrist	√	√		√	
		Legs			√	√	
Module Assembly	Pushing sub-module down assembly line	Trunk		E/R	E/R		assembly line height increased and tilted
		Shoulder		E/R			
	Tightening bolts	Trunk			E/R		assembly line height increased and tilted
		Neck			E/R		
		Shoulder		√			
		Hand/Wrist	√	√		√	
		Legs			√	√	
	Operating powered winch	Trunk			E/R		winch not used
		Legs			E/R		

Note: E/R denotes a hazard which was eliminated or reduced in the improved design.

List of Figures

TOP VIEW



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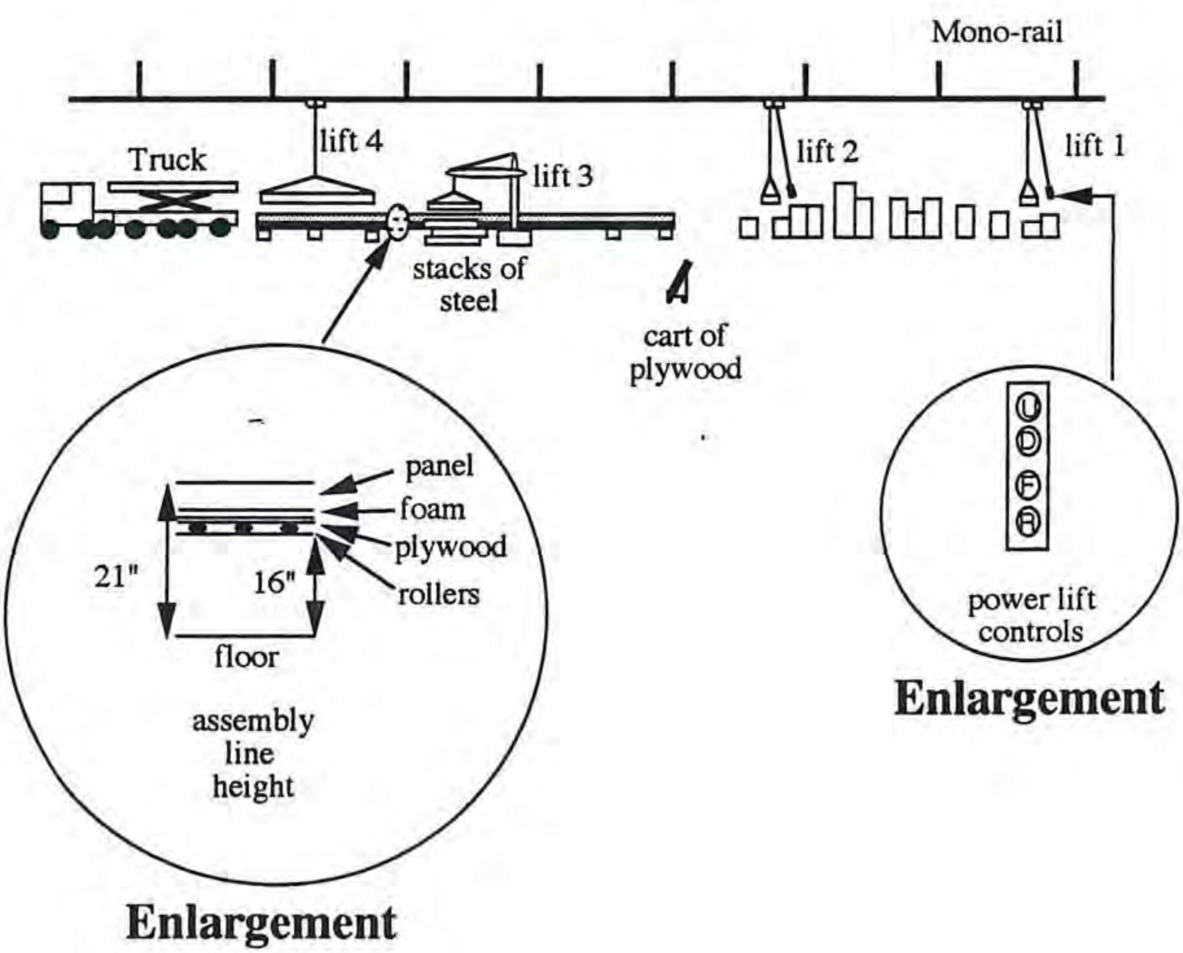

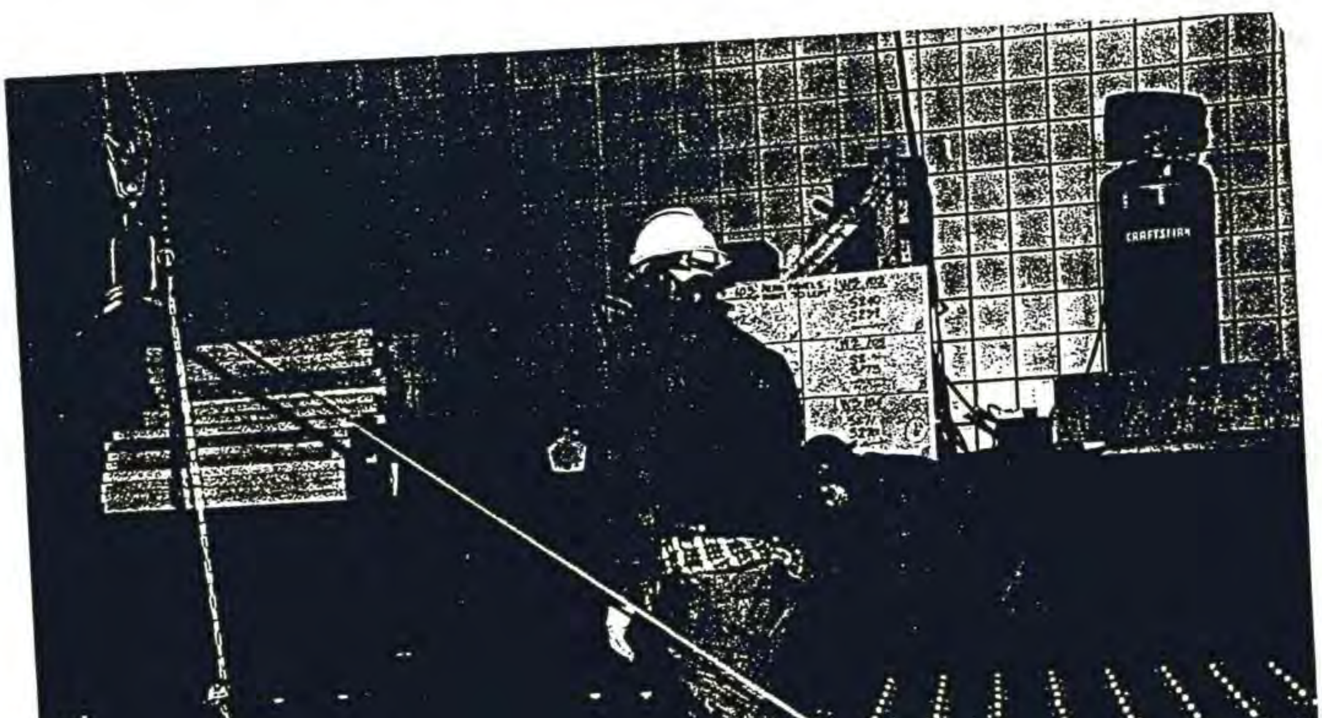
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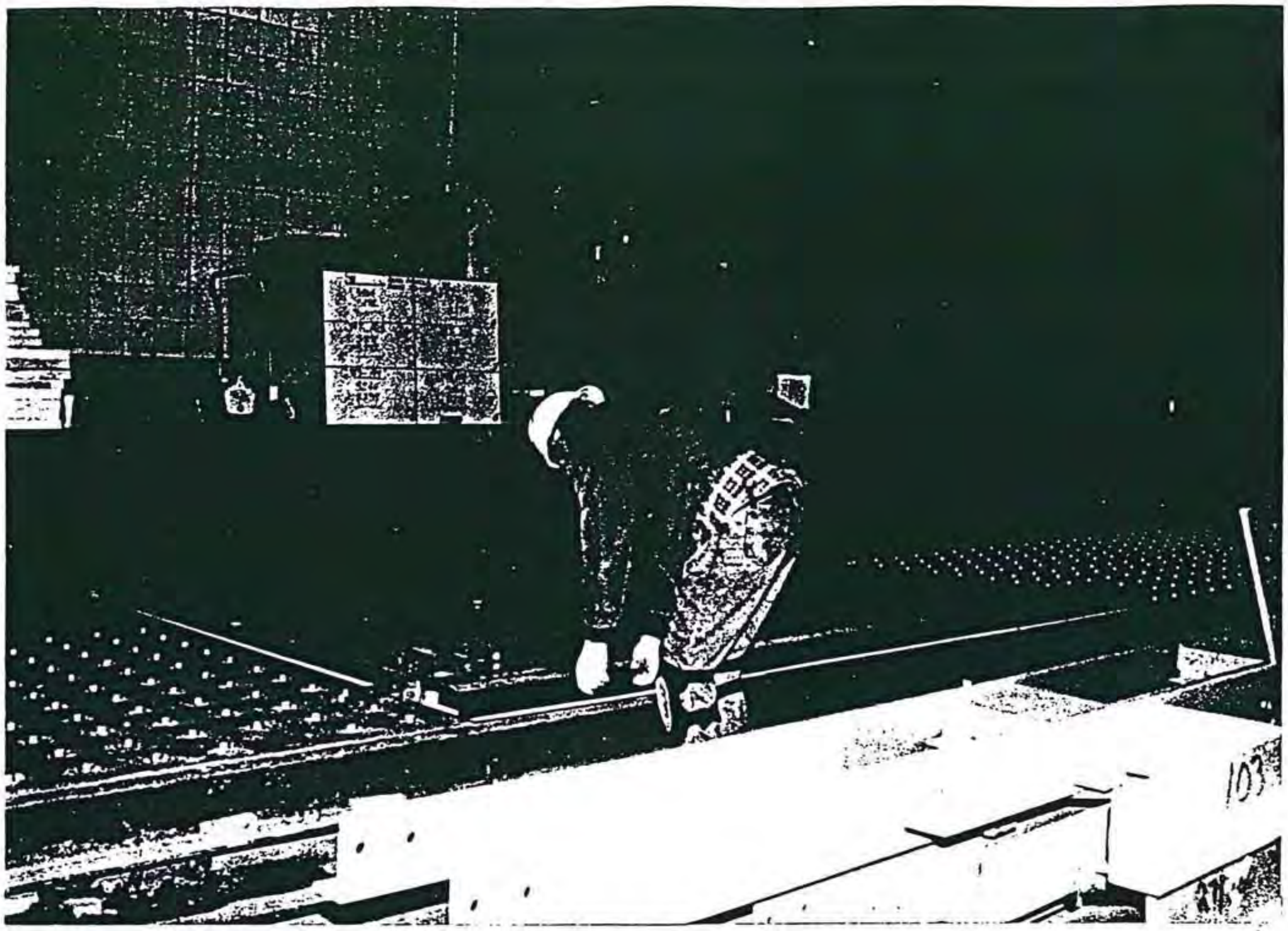
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