

INTERIM SURVEY REPORT:
RECOMMENDATIONS FOR ERGONOMICS INTERVENTIONS
FOR SHIP CONSTRUCTION PROCESSES

at

MARINETTE MARINE CORPORATION SHIPYARD,
Marinette, Wisconsin

REPORT WRITTEN BY:
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Division of Applied Research and Technology
Engineering and Physical Hazards Branch
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PLANT SURVEYED:	Marinette Marine Corporation shipyard, 1600 Ely Street, Marinette, Wisconsin 54143-2434.
SIC CODE:	3731
SURVEY DATE:	May 8-9, 2000
SURVEY CONDUCTED BY:	Stephen D. Hudock, NIOSH Steven J. Wurzelbacher, NIOSH
EMPLOYER REPRESENTATIVES CONTACTED:	Bill Getchell, Safety Director, Marinette Marine
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ABSTRACT

A pre-intervention quantitative risk factor analysis was performed at various shops and locations within Marinette Marine, as a method to identify and quantify ergonomic risk factors that workers may be exposed to in the course of their normal work duties. This survey was conducted as part of a larger project, funded through the Maritech Advanced Shipbuilding Enterprise and the U.S. Navy, to develop projects to enhance the commercial viability of domestic shipyards. The application of exposure assessment techniques provided a quantitative analysis of the risk factors associated with the individual tasks. Based on these analyses, four ergonomic interventions are suggested for Marinette Marine: 1) wheeled, adjustable work stools and knee supports for engine room and lifeboat rack welders, torch cutters, and grinders, 2) a rotating/tilting weld positioner for the tripod assembly welding process 3) worker awareness training in the sheetmetal shop and 4) come-alongs requiring the lowest maximum pull for a given capacity, with capacity appropriate to the shipfitting tasks performed. Of these interventions, it is expected that the wheeled, adjustable work stools/ knee supports and the rotating/ tilting weld positioner will have the most effective impact on reducing musculoskeletal injuries, and therefore they are the most strongly recommended changes. Detailed descriptions of each intervention are provided including cost benefit analysis where appropriate.

I. INTRODUCTION

IA. BACKGROUND FOR CONTROL TECHNOLOGY STUDIES

The National Institute for Occupational Safety and Health (NIOSH) is the primary Federal agency in occupational safety and health research. Located in the Department of Health and Human Services, it was established by the Occupational Safety and Health Act of 1970. This legislation mandated NIOSH to conduct a number of research and education programs separate from the standard setting and enforcement functions carried out by the Occupational Safety and Health Administration (OSHA) in the Department of Labor. An important area of NIOSH research deals with methods for controlling occupational exposures to potential chemical and physical hazards, as well as the engineering aspects of health hazard prevention and control.

Since 1976, NIOSH has conducted a number of assessments of health hazard control technology on the basis of industry, common industrial process, or specific control techniques. Examples of the completed studies include the foundry industry; various chemical manufacturing or processing operations; spray painting; and the recirculation of exhaust air. The objective of each of these studies has been to document and evaluate effective control techniques for potential health hazards in the industry or process of interest, and to create a more general awareness of the need for or availability of an effective system of hazard control measures.

These studies involve a number of steps or phases. Initially, a series of walk-through surveys is conducted to select plants or processes with effective and potentially transferable control concepts or techniques. Next, in-depth surveys are conducted to determine both the control parameters and the effectiveness of these controls. The reports from these in-depth surveys are then used as a basis for preparing technical reports and journal articles on effective hazard control measures. Ultimately, the information from these research activities builds the data base of publicly available information on hazard control techniques for use by health professionals who are responsible for preventing occupational illness and injury.

IB. BACKGROUND FOR THIS STUDY

The background for this study may be found in the previous report no. 229-14a, A Preliminary Survey Report: Pre-Intervention Quantitative Risk Factor Analysis for Ship Construction Processes at Marinette Marine Corporation Shipyard, Marinette, WI by Hudock and Wurzelbacher, 2000.

IC. BACKGROUND FOR THIS SURVEY

The Marinette Marine facility was selected for a number of reasons. It was decided that the project should look at a variety of yards based on product, processes and location. Marinette Marine is one of the U.S. Coast Guard's leading suppliers of large vessels. Marinette Marine

builds two sizes of buoy tenders for the Coast Guard. The Marinette Marine facility is considered to be a medium to small shipyard.

II. PLANT AND PROCESS DESCRIPTION

IIA. INTRODUCTION

Plant Description: The Marinette Marine shipyard is located in Marinette, Wisconsin on the south shore of the Menominee River which separates Wisconsin from the Upper Peninsula of Michigan. The river flows into the northern part of Green Bay which in turn opens onto Lake Michigan. The 60-acre yard includes about 500,000 ft² of enclosed work space including large fabrication shops and enclosed unit erection areas.

Corporate Ties: Marinette Marine is a privately held corporation.

Products: Marinette Marine is under contract to the U.S. Coast Guard to manufacture both 225'-long seagoing buoy tenders and 175'-long coastal buoy tenders. In addition, the shipyard has recently completed lodging barges for the U.S. Navy.

Age of Plant: The facility has been in operation since 1942. The main buildings appear to be no more than twenty years old.

Number of Employees, etc: As of the date of the survey, the Marinette Marine facility employed approximately 650 workers.

IIB. SELECTED PROCESS DESCRIPTIONS

Five specific processes were identified for further analysis. These processes were: engine room wire welding, tripod subassembly wire welding, life boat rack assembly, sheet metal duct assembly, and assembly shipfitting using a come-along. Each of these processes are examined in greater detail below.

IIB1. Engine Room Wire Welding Process

Onboard the vessels under construction, steel structures, whether they are units or subassemblies, must be welded together to form a more complete product. Depending on the location of the work, and the size and training of the individual, the worker may be exposed to constrained and awkward postures. The work may be at or below deck level, on the bulkhead, or over the worker's head. Often one or more other workers are in the vicinity performing their job duties which may or may not be similar to those of the welders.

1. Figure 1 depicts the welding of steel foundation supports onto the deck. Workers either sit or kneel to perform the low work. Note the proximity of the workers.



Figure 1. Engine Room Welding Process

2. When welding is completed, weld splatter and other irregularities must be removed by grinding. Workers kneel on the deck to perform the work. Again note the proximity of the two workers.



Figure 2. Engine Room Grinding Process

IIB2. Tripod Subassembly Wire Welding in Shop Process

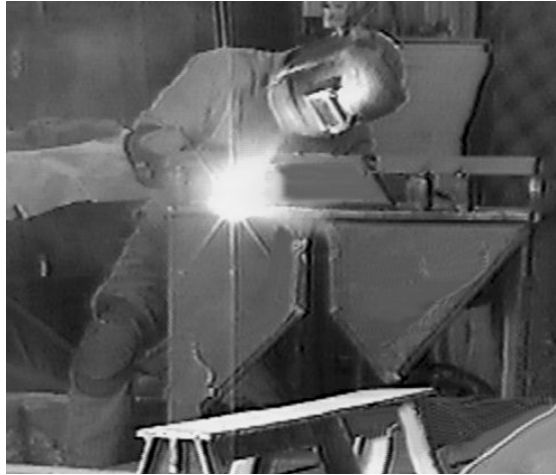


Figure 3. Tripod Welding Task while Seated

Small subassemblies are brought to this location to be welded together or to add additional pieces of steel to the subassembly. A dedicated work station is provided for the worker to perform these tasks. A number of jigs are available to hold the work piece and saw horses and small tables are available to place the work piece on. The worker must perform the job from a variety of postures, including seated (Figure 3), standing bent over the work as shown in Figure 4, or kneeling as shown in Figure 5.



Figure 4. Tripod Welding with Stooped Posture



Figure 5. Tripod Welder Changing Tools

Occasionally, the worker must turn the work piece over or adjust its position so that the worker can weld or grind a particular seam much easier (Figure 6). In addition to welding the seams, the worker also grinds off any primer paint and flux from the weld as shown in Figures 7 and 8.



Figure 6. Tripod Welder Changing Position of Workpiece



Figure 7. Tripod Welder Using Needle Gun while Kneeling



Figure 8. Tripod Welder Using Needle Gun while Standing

If the worker needs to move the subassembly on or off the work station , the worker may rig it to be lifted by one of the hoists available in the shop area (Figure 9). Before removal of the subassembly, the worker will make a final visual inspection of the work piece (Figure 10).



Figure 9. Tripod Welder Attaching Hoist Hook onto Subassembly



Figure 10. Tripod Welder Inspecting Work

IIB3. Life Boat Rack Assembly Process

As each of the current series of vessels nears completion, the upper deck is fitted with lifeboat racks from which the boats can be launched in time of need. The worker is required to perform a number of tasks at or near deck level. The frames are composed of a number of angle irons which are torch cut to exact size (Figure 11) and ground smooth on the edges (Figures 12 and 13).



Figure 11. Lifeboat Rack Worker Torch Cutting



Figure 12. Lifeboat Rack Worker Grinding while Squatting



Figure 13. Lifeboat Rack Worker Grinding while Stooped

The angle irons are then moved into their places on the deck by hand (Figure 14) where they are welded into place on the deck (Figure 15). Adjustment of rack position is occasionally made by sledge hammer, especially if part of the rack has already been welded to the deck (Figure 16).



Figure 14. Lifeboat Rack Worker Moving Workpiece



Figure 15. Lifeboat Rack Worker Welding while Kneeling



Figure 16. Lifeboat Rack Worker Adjusting Workpiece with Sledge Hammer

IIB4. Sheetmetal Assembly in Shop Process

Ventilation ductwork and other sheet metal subassemblies are built on land within the fabrication shops as much as possible. The sheet metal is formed to shape and then fit together in the prescribed size and shape (Figure 17). The worker must move the subassembly around on the fixed height work table to get to necessary work locations (Figure 18). Before completion the

worker must visually inspect the work (Figure 19), making sure it is built to exact specifications (Figure 20) and then sign off on the work before it is passed on to another work area (Figure 21).



Figure 17. Sheet Metal Worker Hammering



Figure 18. Sheet Metal Worker Moving Duct



Figure 19. Sheet Metal Worker Inspecting Duct



Figure 20. Sheet Metal Worker Measuring Duct



Figure 21. Sheet Metal Worker Record Duct Data

IIB5. Assembly Fitter Using Come-along in Shop Process

The shipfitter must torch cut (Figure 22), grind and weld angle iron, steel plate and other materials into place so that subassemblies can be matched and secured exactly in place. The shipfitter uses a variety of tools in the performance of the job (Figure 23) and must be very exact in the task, inspecting it frequently (Figure 24).



Figure 22. Bow Assembly Shipfitter Torch Cutting



Figure 23. Bow Assembly Shipfitter Changing Tools



Figure 24. Bow Assembly Shipfitter Inspecting Setup

Occasionally the two subassemblies being put together do not exactly match. Often the pieces can be forced into place by using come-alongs to maintain force to hold the steel in its proper position (Figures 25 and 26) and then the subassemblies are welded together.



Figure 25. Bow Assembly Shipfitter Adjusting Come-along



Figure 26. Bow Assembly Shipfitter Cranking Come-along

III. ERGONOMIC INTERVENTION COST JUSTIFICATION

The following section has been adapted from the article by Alexander, 1998.

The effectiveness of any ergonomic intervention does not necessarily correlate with the cost of implementing that intervention. The possibility exists for a very effective intervention to be found at a low implementation cost, as well as, the possibility of the opposite. The preferred intervention strategy from a business sense is to implement those interventions with the lowest costs and the highest effectiveness. This point can be illustrated by the value/cost matrix as illustrated in Figure 27.

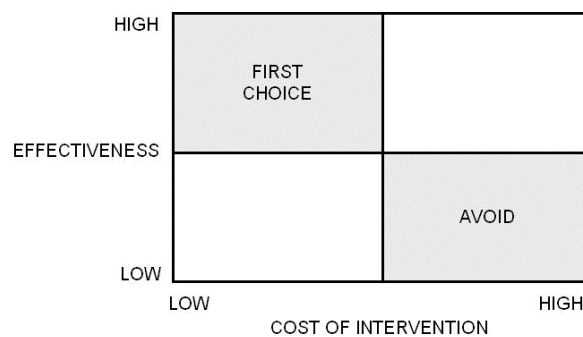


Figure 27: Value Cost Matrix

There are a number of benefits that can be credited to the application of ergonomic interventions in general. These benefits are listed below.

- \$ Avoidance of current expenses and ongoing losses, including:
 - B Workers compensation costs
 - B Overtime for replacement workers
 - B Lost productivity, quality or yields from less skilled workers
 - B Increased training and supervisory time
- \$ Enhanced existing performance
 - B Increased productivity including fewer bottlenecks in production, higher output, fewer missed delivery dates, less overtime, labor reductions, and better line balancing

- B Improved quality including fewer critical operations, more tasks with every operator's control and capacity, and fewer assembly errors
- B Increased operating uptime including faster setups, fewer operating malfunctions, and less operator lag time.
- B Faster maintenance including increased access, faster part replacement, fewer tools needed, more appropriate tools, more power and faster tool speeds.

- \$ Enhanced quality of work life
 - B Less turnover
 - B Less employee dissatisfaction

- \$ Fewer traumatic injuries

- \$ Fewer human errors resulting in lost product or operating incidents

- \$ Reduced design and acquisition costs

In addition to the direct medical costs associated with worker injuries, one must also consider the indirect or hidden costs associated with the primary worker being away from their job. These indirect costs are listed below.

- \$ Costs of replacement workers
 - B Hiring costs for permanent replacements plus training and other costs
 - B Additional costs for temporary workers who may also have lower work skills

- \$ Lower productivity
 - B Fewer units per hour
 - B Lower yields
 - B Damage to material or equipment that would not occur with an experienced worker

- \$ Lower quality
 - B Number of rejects
 - B Amount of rework
 - B Timeliness of product delivery

- \$ Increased supervision
 - B Cost to manage/train a less skilled worker

- \$ Training to develop and maintain job skills
 - B Amount of lost work time
 - B Time of trainer.

Many of these indirect costs are difficult to estimate and can vary widely depending on the severity of the injury involved. The ratio of indirect costs to direct costs has also been found by a number of studies to vary between 5:1 to 1:5, depending on industry (Heinrich, 1931, 1959; Levitt et al, 1981; Andreoni, 1986; Leopold and Leonard, 1987; Klen, 1989; Hinze and Applegate, 1991; Oxenburgh, 1991, 1993). As a conservative estimate, the state of Washington recently decided upon indirect costs of 75 percent of direct workers' compensation incurred costs (WAC 296-62-051, 2000).

Another aspect of ergonomic interventions that must be considered is the cost benefit analysis. If total costs outweigh all benefits received from implementing the intervention, then the intervention is not worth undertaking. One has to determine the associated start-up costs, recurring costs, and salvage costs of the intervention as well as the time value of money (present worth versus future worth) and the company's Minimum Attractive Rate of Return, the interest rate the company is willing to accept for any project of financial undertaking.

IV. CONTROL TECHNOLOGY

The following section presents various ergonomic interventions that are recommended for implementation at Marinette Marine. These recommendations are based on the risk factor analysis that was performed at Marinette in May of 2000 and detailed in a previous NIOSH report (No. 229-14a).

IVA. Possible Interventions for the Engine Room Wire Welding Process and Life Boat Rack Assembly Process



Figure 28. Example of Stool Designed for Prolonged Kneeling Tasks
(photo courtesy of Racatac Products Inc.)



Figure 29. Another example of a commercially available low-slung industrial seat.

Whenever a worker has to kneel or squat for long periods of time to conduct their work, whether it be torch cutting, grinding or welding, it is suggested that adequate stools or benches be provided which allow the worker to sit to lessen the stress on the knees while still enabling the worker to perform the assigned task at or near floor level without additional strain on the lower back. There are a few commercially available seats, such as those depicted in Figures 28 and 29, designed specifically for kneeling and squatting. These seats may be useful for mostly level, non-confined areas of the engine room. Supports (See Figures 30a and 30b) are also commercially available that attach to the back of the calf to prevent over flexion of the knees during squatting postures.



Figures 30a, b. Example of knee support device useful for tasks requiring extended squatting

Suggested approximate work stool characteristics are shown in Table 1. Setup and training time is negligible. Total cost for a crew size supply of stools and knee supports is estimated to be \$4,180.

Table 1: Approximate Work Stool/ Knee Support Characteristics	
Wheeled Work Stool (depicted in Figure 28)	
Weight	8 lbs
Dimensions	19.5 A x 20"
Capacity	300 pounds
Adjustable Seat	vertical travel: 11.5 A to 15.5 A in height horizontal travel: 3 A; tilts
Other Features	7" x 15" tool tray
Price	\$169 per stool * 20 (crew size) = \$3380
Knee Supports	
Price	\$40 pair *20 (crew size) = \$800
Total Price	\$4,180

In identifying benefits of the intervention, one can use the medical and indemnity cost estimates as shown in Table 2 to calculate direct costs.

Table 2: Estimated¹ Shipyard Direct Injury Costs for Musculoskeletal² Injuries (medical + indemnity) by Part of Body

¹ Based on analysis of available participating shipyard compensation data from 1996 - 1998

² Does not include contusions or fractures

Ankle(s)	\$2,390
Arm(s), unspecified	\$7,725
Back	\$6,996
Elbow(s)	\$4,691
Finger(s)	\$735
Hand(s)	\$6,857
Knee(s)	\$7,472
Leg(s), unspecified	\$849
Neck	\$5,961
Shoulder(s)	\$4,960
Wrist(s)	\$3,925
Mean Musculoskeletal Injury Cost = \$5523	

Since the provided Marinette injury logs do not include a narrative describing how the injury occurred, it is difficult to determine exactly how many knee injuries that are recorded were due to prolonged kneeling tasks. However, from 1995 to 1999 Marinette experienced 19 knee injuries to welders and shipfitters. The total estimated medical and indemnity cost of these injuries was \$171,856, based upon the above shipyard industry average costs by part of body injured. If the nineteen injuries can be said to be due to poor postures and contact stress, the average annual estimate direct cost (over the last five years) for musculoskeletal injuries that may be preventable by measures to relieve these postures and stresses is \$34,371. If indirect costs are conservatively assumed to be 75% of the direct costs, the total cost of these injuries per year is \$60,150. It is this amount that can be considered an avoided cost and, therefore, a benefit due to the implementation of the intervention. Assuming the intervention fully eliminates such injuries, a simple benefit to cost ratio would be \$63,089/\$4,180 or 14.4. Since the benefit to cost ratio is greater than one, it is advantageous and cost-effective to implement the proposed intervention. However, it is likely that not all of the knee injuries were due to prolonged kneeling and that the intervention will not eliminate all those injuries due to these postures. Thus, one may estimate that only one-fifth of the estimated annual injury cost is saved each year. It is also possible that the weld stools/ knee supports last only 6 months. Assuming that the shipyard has a minimum attractive rate of return of 20 percent for any project cash outlay, one can still calculate a benefit to cost ratio by utilizing the following equation to determine the present worth of an annual savings:

Equation 1:
$$PW = AS \times \frac{[(1+i)^n - 1]}{i \times (1+i)^n}$$

where PW = present worth
 AS = annual savings
 i = interest rate (ex., 0.20 for 20 percent)
and n = number of years.

Using an annual savings of just \$12,030 (one-fifth of the estimated annual injury cost) at an interest rate of 20 percent over a half year period, the present worth of the proposed savings would be \$5,241. Assuming initial costs of the weld stools/ knee supports are \$4,180 and negligible annual costs, the benefit to cost ratio of implementing this intervention is \$5,241/\$4,180 or 1.25, greater than one, and therefore still economically advantageous.

IVB. Possible Intervention for the Tripod Subassembly Wire Welding in Shop Process

Currently, the worker in the tripod subassembly area must perform the job from a variety of postures, including seated, standing bent over the work, or kneeling. The welder must also occasionally manually reposition the weldment and weld in positions other than flat. Thus, an intervention such as a tilting, rotating weld positioner (such as those depicted in Figures 31 and 32) may offer a solution both to eliminate the risk factor of awkward postures required for the job and to increase the efficiency and quality of the weld job. To use this intervention, a fixture would have to be created to attach the tripod assembly to the positioner table top. The welder would then activate the positioner to move the entire subassembly about two axes into positions where the welder can flat weld and grind without stooping and kneeling.



Figure 31: Example of flat-135 degree type rotating, tilting weld positioner that can tilt the table from the horizontal through the vertical to 45 degrees past the vertical
(photo courtesy of Preston Easton Co.)

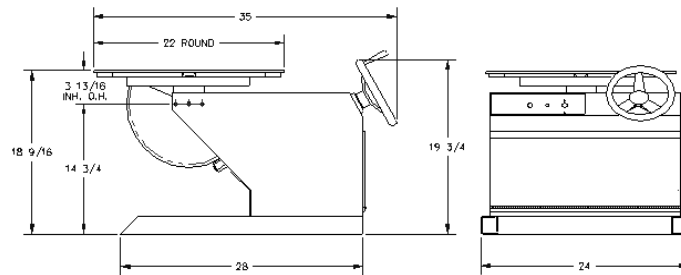


Figure 32: Dimensions of rotating, tilting weld positioner suitable for small subassemblies (drawing courtesy of Preston Easton Co.)

There are many tilting, rotating positioners commercially available but only a few general configurations: flat-135 degree, flat-135 degree with powered elevation, 45 degree to 90 degree, and sky hooks (American Welding Society, 1987). For a small assembly such as the tripod, a flat-135 degree type is probably the best choice since it can tilt the table top from the horizontal through the vertical to 45 degrees past the vertical. The price of such a positioner is driven largely by its capacity, which is based on the rotational and tilt torques required for the weldment. These torques depend on: 1) the combined weight of the weldment and fixture and 2) the center of gravity for the load. The center of gravity of the total load is determined by the distance from the rotational center and distance from the table top. Table 3 and Figure 32 provides estimated specifications and costs for a positioner for the tripod assembly. Actual required table and total price may vary depending on exact torque capacities and fixtures needed.

Table 3: Approximate Rotating/ Tilting Weld Positioner Characteristics	
Weight Capacity	500 lbs
Center of Gravity	4 in
Rotation Speed	.12 to 3.7 RPM
Rotational Torque	2,000 in lbs
Tilt Torque	4,000 in lbs
Table Size	22 in diameter, round
Tilt Range	0 to 135 degrees
Motor	1/4 Horsepower DC
Voltage	115 V 60 Hz Single Phase AC
Table Price	\$3,550
Fixtures, miscellaneous	to be determined
Fixture Price	\$1,000
Total Price	\$4,550

In identifying benefits of the rotating/ tilting weld positioner intervention, one can again use the medical and indemnity cost estimates as shown in Table 2 to calculate direct costs. Since the provided Marinette injury logs do not include a narrative describing how the injury occurred, it is difficult to determine exactly how many back injuries that are recorded were due to the tripod assembly task. However, from 1995 to 1999 Marinette experienced 20 back injuries to welders. The total estimated medical and indemnity cost of these injuries was \$265,848, based upon the shipyard industry average costs by part of body injured in Table 2. The average annual estimate direct cost (over the last five years) for these back injuries is \$53,170. If indirect costs are conservatively assumed to be 75% of the direct costs, the total cost of these back injuries per year is \$93,047. Assuming the weld positioner fully eliminates only one back injury and one-twentieth of the yearly costs, the avoided cost or a benefit due to the intervention would be \$4,652 per year. If the positioner is assumed to last two years and assuming that the shipyard has a minimum attractive rate of return of 20 percent for any project cash outlay, one can calculate a benefit to cost ratio by utilizing the following equation to determine the present worth of an annual savings:

Equation 1:
$$PW = AS \times \frac{[(1+i)^n - 1]}{i \times (1+i)^n}$$

where PW = present worth
 AS = annual savings
 i = interest rate (ex., 0.20 for 20 percent)
and n = number of years.

Using an annual savings of just \$4,652 (one-twentieth of the estimated annual injury cost of back injuries) at an interest rate of 20 percent over a two year period, the present worth of the proposed savings would be \$7,108. Assuming initial costs of the rotating/ tilting weld positioner of \$4,550 and negligible annual costs, the benefit to cost ratio of implementing this intervention is \$7,108/ \$4,550 or 1.56, greater than one, and therefore economically advantageous.

IVC. Possible Interventions for the Sheetmetal Assembly in Shop Process

If feasible, sheetmetal workers should use bench-mount hand brakes, and metal forming presses/ machines rather than hammers, hand seamers, and hand crimpers. For the most part, Marinette sheetmetal workers did have access to these types of machines. Thus, worker awareness training about the ergonomic benefit of these machines may be required.

IVD. Possible Interventions for the Assembly Fitter Using Come-along in Shop Process

The come-along (lever-operated chain or wire rope devices designed for pulling) is a common shipfitting tool that can require the operator to produce pulls up to 100 lbs. The required pull

depends on the brand and load capacity of the come-along and most manufacturers will provide this maximum required pull information. Workers should use the lowest possible capacity puller to do the job and tool personnel should take the tool's required pull into consideration when purchasing new come-alongs. Brands with lower maximum required pulls are generally slightly more expensive for a given capacity and length. A sampling of available come-along characteristics is given in Table 4.

Table 4: Range of Load Capacities and Required Maximum Pulls for Available Come-alongs	
Load Capacity	Range of maximum pull required for available come-alongs
1500- 1650 lbs	45 -68 lbs
3000- 3300 lbs	55- 73 lbs
6000- 6600 lbs	62- 77 lbs

V. CONCLUSIONS AND RECOMMENDATIONS

Five distinct construction processes were examined at Marinette Marine to quantify the musculoskeletal risk factors associated with these processes. The processes included: engine room wire welding, life boat rack assembly, tripod subassembly wire welding, sheetmetal assembly, and assembly fitting using come-along. Based on ergonomic task analyses, four ergonomic interventions are suggested for at Marinette Marine: 1) wheeled, adjustable work stools and knee supports for engine room and lifeboat rack welders, torch cutters, and grinders, 2) a rotating/tilting weld positioner for the tripod assembly welding process 3) worker awareness training in the sheetmetal shop and 4) come-alongs requiring the lowest maximum pull for a given capacity, with capacity appropriate to the shipfitting tasks performed. Of these interventions, it is expected that the wheeled, adjustable work stools/ knee supports and the rotating/ tilting weld positioner will have the most effective impact on reducing musculoskeletal injuries, and therefore they are the most strongly recommended changes.

The implementation of engineered ergonomic interventions has been found to reduce the amount and severity of musculoskeletal disorders within the working population in various industries. However, each of the interventions proposed in this document are to be considered preliminary concepts. Full engineering analyses by the participating shipyard are expected prior to the implementation of any particular suggested intervention concept to determine feasibility, both financially and engineering, as well as to identify potential safety considerations.

VI. REFERENCES

- Alexander, D. C. Strategies for Cost Justifying Ergonomic Improvements. *IIE Solutions*, Institute of Industrial Engineers, Norcross, Georgia, March 1998, 30(3):30-35.
- American Welding Society. Welding Handbook. 1987.
- Andreoni, D. The Costs of Occupational Accidents and Diseases. Geneva: International Labor Office; 1986
- Bureau of Labor Statistics Handbook of Methods, April 1997 web site edition.
- Heinrich, H.W. Industrial Accident Prevention: A Scientific Approach. 4th Edition. New York: Wiley; 1959
- Hinze, J. And Applegate, L.L. Costs of Construction Injuries. *Journal of Construction Engineering and Management*. 1991; 117(3): 537-550.
- Hudock, S. D., S. J. Wurzelbacher, and O. E. Johnston. Preliminary Survey Report: Pre-Intervention Quantitative Risk Factor Analysis for Ship Repair Processes at Todd Pacific Shipyards Corporation, Seattle, WA. DHHS, PHS, CDC, NIOSH, Cincinnati, Ohio, Report # EPHB 229-18a, June 2000.
- Klen, T. Costs of Occupational Accidents in Forestry. *Journal of Safety Research*. 1989; 20(31):31-40.
- Leopold, E. And Leonard, S. Costs of Construction Accidents to Employers. *Journal of Occupational Accidents*. 1987; 8:273-294.
- Levitt, R.E. Improving Construction Safety Performance; 1982 Jan; Report A-3.
- Oxenburgh, M. Increasing Productivity and Profit Through Health and Safety. Australia: CCH International; 1991
- Oxenburgh, M.S. and Guldberg, H.H. The Economic and Health Effects on Introducing a Safe Manual Handling Code of Practice. *International Journal of Industrial Ergonomics*. 1993; 12:241-253.
- Washington State Ergonomics Rule. WAC 296-62-051. (2000)