Journal of Ship Production, Vol. 17, No. 3, August 2001, pp. 145–150

A Precursor to Ergonomics Best Practices for the Shipyard Industries

Stephen D. Hudock,* Steven J. Wurzelbacher,* Laurence D. Reed,* Thomas R. Hales,* and **Karl V. Siegfried†**

**Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Cincinnati, Ohio. (Mr. Wurzelbacher is now with GARMI, Cincinnati, Ohio.)*
†*MEMIC Safety Services, Portland, Maine*

Many of the job processes being performed today in ship construction, repair and recycling yards do not differ significantly from those same processes as performed fifty years ago. The complexity of vessels may have increased dramatically in the past fifty years but many of the job processes have not kept pace with changes in technology. Due in part to the mismatch of technology between work processes and product design, researchers at the National Institute for Occupational Safety and Health (NIOSH), in collaboration with the National Shipbuilding Research Program Advanced Shipbuilding Enterprise (NSRP ASE) and the Maritime Advisory Committee for Occupational Safety and Health (MACOSH), have conducted a series of ergonomic analyses of work processes at a number of domestic shipyards. These analyses have identified specific work processes within the shipyards that have resulted in numerous, severe, or costly musculoskeletal injuries to the shipyard workforce. The mitigation of the occupational risk factors associated with these processes was the focus of targeted ergonomic interventions.

Background

THE NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH (NIOSH) is the primary Federal agency in occupational safety and health research. Located in the U.S. 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 U.S. Department of Labor. An important area of NIOSH research deals with methods of controlling occupational exposures to potential chemical and physical hazards, as well as the engineering aspects of health hazard prevention and control. Since 1976, the Engineering and Physical Hazards Branch of NIOSH has conducted a number of assessments of health hazard control technology on the basis of industry, common industrial process, or specific control techniques. Included among these assessments are engineering ergonomics intervention studies.

Beginning in 1995, the National Shipbuilding Research Program (NSRP) funded a project looking at the implementation of ergonomics interventions at a domestic ship construction yard as a way to reduce injuries to their workers as well as the associated costs and to improve the productivity for the targeted processes. That project came to the attention of the Maritime Advisory Committee for Occupational Safety and Health (MACOSH), an OSHA advisory committee. MACOSH strongly endorsed the shipyard ergonomics study and encouraged NIOSH to partner with NSRP, in a unique collaboration of industry, labor, trade associations, and government entities. This unqiue partnership resulted in an expansion of the ergonomics intervention project throughout the shipyard industries. In 1997, NIOSH began a project cataloguing ergonomic interventions at several shipyards. In 1998, the U.S. Navy funded, through the NSRP ASE, a number of research projects to improve the commercial viability of domestic shipyards as a way to maintain the trained labor pool. Researchers at NIOSH successfully competed in that project selection process and ex-

---

Manuscript received by JSP Committee July 3, 2001.

8756/1417/01/1703-0145$00.37/0

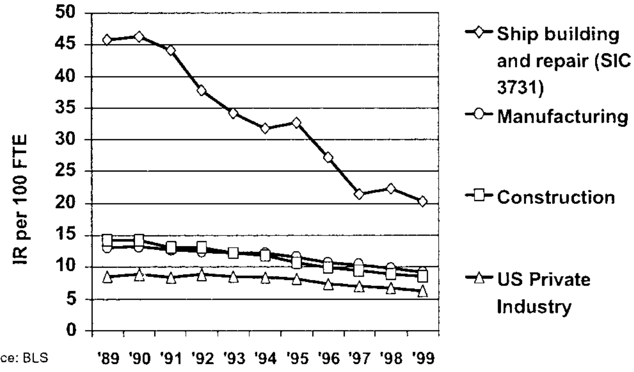
panded the ergonomics intervention project to include new construction, ship repair and ship breaking facilities. In 1999, the NIOSH/NSRP study was expanded to the entire maritime industry by including marine cargo handling operations.

Introduction

The domestic shipbuilding, repair and breaking industries in the United States have historically had much higher injury incidence rates that those of general industry, manufacturing, or construction (Figs. 1 and 2). For 1999, the last year available, the U.S. Bureau of Labor Statistics reported that the shipbuilding and repair sector (SIC 3731) had a recordable injury rate of 20.2 per 100 full-time employees (FTE). By contrast, in 1999 the manufacturing sector reported a rate of 9.2 per 100 FTE, construction reported a rate of 8.6 per 100 FTE, and general industry reported a rate of 6.3 injuries per 100 FTE. When considering lost workday cases, for 1999, shipbuilding and repair had an incidence rate of 10.7 per 100 FTE, compared to manufacturing at 4.6, construction at 4.2, and general industry at 3.0 lost workday cases per 100 FTE. When one considers which part of the worker's body is being injured and resultant lost workdays, shipbuilding and repair was significantly different than the manufacturing sector (Figs. 3, 4, and 5). For injuries to the upper extremity, in 1998, ship building and repair had an injury incidence rate of 80.1 per 10 000 FTE compared to 70 per 10 000 FTE for the manufacturing sector. For back injuries in the same year, ship building and repair had an injury incidence rate of 93.6 per 10 000 FTE, nearly twice the manufacturing rate at 49.4 per 10 000 FTE. For injuries to the lower extremity, ship building and repair had an injury incidence rate of 126 injuries per 10 000 FTE, compared to 40.7 injuries per 10 000 FTE for the manufacturing sector, over three times higher.

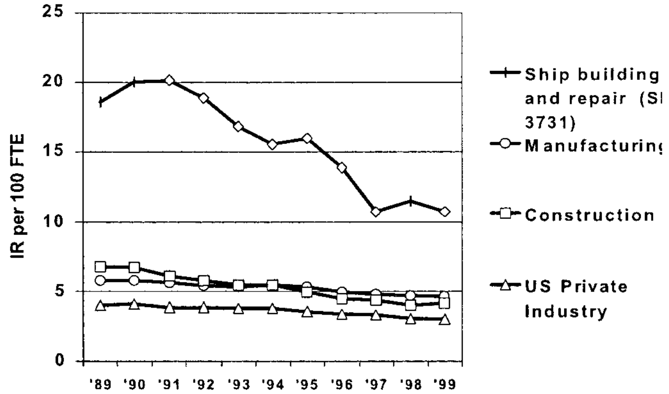
Workers' compensation costs and incidence rates

In an unpublished study of the workers' compensation costs from 1996 to 1998 for a number of domestic shipyards by the authors, the mean workers compensation claim cost for shipyard production workers experiencing a musculoskeletal disorder was approximately $8000. The mean workers compensation claim cost for lower back injuries was approximately $10 000. In an analysis of the blue-collar workforce of the U.S. Navy's Naval Facilities Engineering Command (NAVFAC), which maintains all Navy shore facilities, including the public shipyards, 43% of all recent worker compensation claims were related to ergonomics. It was reported that the average cost of a strain or sprain was approximately $55 000. Back injuries within NAVFAC averaged approximately $25 000. The NAVFAC blue-collar injury incidence rate averaged 11.1 cases/100 FTE. The highest injury incidence rates by occupation were: shipfitting at 18.6/100 FTE, welding at 17.5/100 FTE, painting at 17.2/100 FTE, rigging at 15.7/100 FTE, and pipefitting at 13.9/100 FTE. Obviously, the extent and cost of musculoskeletal injuries within domestic shipyards is a sizeable concern.



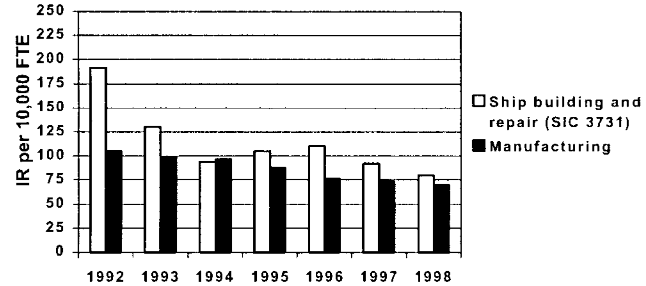
Source: BLS

Fig. 1 Recordable injury rate by industry, 1989–1999



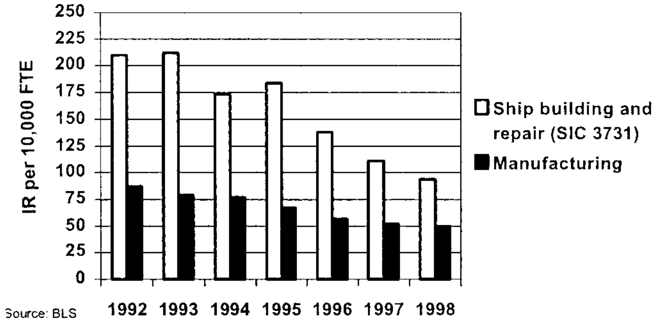
Source: BLS

Fig. 2 Lost workday case rate by industry, 1989–1999



Source: BLS

Fig. 3 Upper extremity incidence rate, 1992–1998

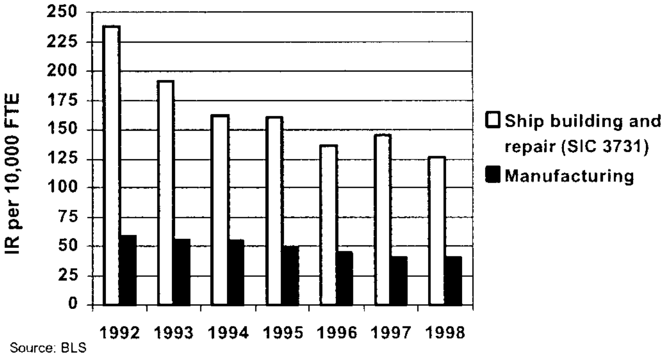


Source: BLS

Fig. 4 Back incidence rate, 1992–1998

Ergonomic intervention cost justification

The effectiveness of any ergonomic intervention does not necessarily correlate with the cost of implementing that intervention.



Source: BLS

Fig. 5 Lower extremity incidence rate, 1992–1998

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 Fig. 6. However, from a public health perspective, all feasible interventions that reduce worker injuries and discomfort are worthwhile.

There are a number of benefits that have been credited to the application of ergonomic interventions in general (Alexander 1998). The avoidance of current expenses and ongoing losses may include workers compensation costs, overtime pay for replacement workers, increased training and supervisory time, schedule impacts, and lost productivity, quality or yields from less skilled workers. Enhanced existing performance may include: (1) increased productivity including fewer bottlenecks in production, higher output, fewer missed delivery dates, less overtime, labor reductions, and better line balancing; (2) improved quality including fewer critical operations, more tasks with every operator's control and capacity, and fewer assembly errors; (3) increased operating uptime including faster setups, fewer operating malfunctions, and less operator lag time; and (4) faster maintenance including increased access, faster parts replacement, fewer tools needed, more appropriate tools, more power and faster tool speeds. An enhanced quality of worklife may result in less turnover and less employee dissatisfaction. Additional benefits may include fewer traumatic injuries, fewer human errors resulting in lost product or operating incidents, and 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. The additional costs of replacement workers include the hiring costs for permanent replacements plus training and other costs, and additional costs for temporary workers who may also have lower work skills than the worker they are replacing. Costs associated with lower productivity include fewer units per hour, lower yields and damage to material or equipment that would not occur with an experienced worker. Costs associated with lower quality include the number of rejects, the amount of rework, and the timeliness of product delivery. Increased supervision costs include the cost to manage and train a less skilled worker. Training costs to develop and maintain job skills include the amount of lost work time and the cost of the time of trainer.

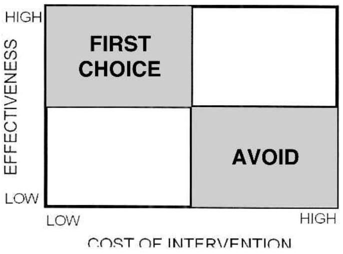


Fig. 6 Value/cost matrix

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 from a strictly business sense, the intervention is not worth undertaking. Again, from a public health perspective, any feasible intervention that reduces worker injuries and discomfort is worthwhile. Regardless, industry 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.

Workplace factors for musculoskeletal disorders

In a review of the scientific literature (NIOSH 1997), NIOSH determined that several workplace factors were directly correlated to the advent of work-related musculoskeletal disorders for the upper extremity and low back. Repetition, excessive force, awkward posture and exposure to hand-arm vibration were all linked in some degree to the onset of upper extremity musculoskeletal disorders. Heavy physical work, lifting and forceful movements, bending and twisting, static work postures and exposure to whole-body vibration were correlated to the onset of low back pain or injury. Additionally, the review identified a number of individual factors including age, gender, smoking, physical activity, strength, and body size that may be associated with the incidence and prevalence of work-related musculoskeletal disorders.

In order to quantify the workplace risks associated with the development of musculoskeletal disorders for specific shipyard processes, it was necessary to compile a number of exposure assessment tools or techniques. The techniques used for the shipyard work processes analyses included (1) the Rapid Upper Limb Assessment (RULA) (McAtamney & Corlett, 1993); (2) the Strain Index (Moore & Garg 1995); (3) a University of Michigan Checklist for Upper Extremity Cumulative Trauma Disorders (Lifshitz & Armstrong 1986); (4) the OVAKO Work Analysis System (OWAS) (Louhevaara & Suurnäkki 1992); (5) a Hazard Evaluation Checklist for Lifting, Carrying, Pushing, or Pulling (Waters & Putz-Anderson 1996); (6) the NIOSH Lifting Equation (Waters et al 1993); (7) the University of Michigan 3D Static Strength Prediction Model (University of Michigan Software 1997); and (8) the PLIBEL method (Kemmlert 1995).

The same exposure assessment techniques are used after ergonomic interventions have been implemented to again quantify the risks associated with how the modified process is executed. A reduction in risk factors suggests that the modified process is less stressful on the worker and should result in a decrease in musculoskeletal complaints, as well as an increase in productivity.

Methodology

Walk-through surveys were conducted at thirteen domestic shipyards to solicit candidate yard participation and to develop qualitative risk factor assessments of the industry. Eight shipyards were selected for participation based on a number of factors including: type of work being performed, type of product, geographic distribution, employment size, willingness to share injury and cost records, and having an interest in developing ergonomic interventions. The injury databases for the selected yards were examined for the years 1994 to 1999 to identify high risk departments, jobs, or processes and to establish a baseline to assess the effectiveness of future intervention efforts. In addition, workers compensation data for the years 1996 to 1998 were collected when possible.

Pre-intervention quantitative risk factor analyses were conducted at the eight participating yards focusing on 52 processes identified as high-risk. A variety of exposure assessment techniques were used where deemed appropriate to the specific process being analyzed. These exposure assessment techniques provided a means to quantify the risk factors associated with how the processes were originally executed.

Ship processes

There are a variety of trades which work within shipyards, each accomplishing very specialized tasks or processes. At times, there are overlaps between trade job functions depending upon the amount of cross-training an individual has, as well as the local labor contract language. Below is a brief summary of tasks performed by the individual trades. Observation of these tasks and quantification of associated risk factors were used to develop the Shipyard Trade Occupational Risk Matrix (STORM) as presented below.

Abrasive blasters—Workers use silica sand, metal shot or slag, or water under high pressure to prepare surfaces prior to painting. Surfaces are cleaned of rust, contaminants and old paint, and the surface is slightly pitted to allow for proper adhesion of the new paint. Workers use a "blasting gun" in a variety of postures to clean the steel pieces, units, or hulls. Often, work is performed from an elevated position, as from a lift truck basket.

Burners/torch cutters—Workers use oxygen-acetylene torches to cut through steel plate decks and hulls in order to make openings in the structure after the ship has been assembled. This is often done to allow the movement of equipment in and out of a vessel, particularly one undergoing repair. Workers often must assume constrained and sustained postures in confined spaces in order to access the correct location for the torch cut.

Electricians—Electricians are responsible for a variety of tasks including the placement and connection of miles of cables of various sizes placed within a ship. Work tasks may include heavy physical labor in pulling cable overhead, below decks, or through transits, or fine motor skills needed to connect cable to their appropriate switches on equipment or control panels.

Grinders/chippers— These workers use a variety of powered hand tools to modify the structure's work surfaces. Angle grinders, die grinders, and needle guns are used to remove welding slag from work surfaces. Deck scrapers remove the textured deck surfaces from outside deck areas. Chipping hammers are used to remove tile from decks and bulkheads. Workers often must assume constrained and sustained postures to complete the work tasks.

Insulators—These workers either install or, in repair, also remove insulation material from the bulkheads and ceilings on vessels. This work may require a fair amount of overhead work, work on ladders, and work with hand tools. Workers may be required to wear protective body suits and respirators if the material being worked with is deemed to be hazardous (e.g., asbestos or manmade vitreous fibers).

Machine operators—Machine operators are responsible for the initial cutting and shaping of individual components through the use of stationary machinery as in the plate and subassembly areas. These tasks may require material handling, lifting and bending by the machine operators.

Material handlers—Most items within a shipyard are handled a number of times from delivery at the shipyard to final installation on the vessel. Items can range from small cut pieces used in subassemblies to large pieces of scrap as obtained during a ship repair or ship scrapping operation. Most items require some manual material handling of the components, although the use of forklifts and pallet jacks will reduce the amount of carrying of material around the shipyard.

Outside machinists—These workers are responsible for the installation and testing of equipment during the preoutfitting and outfitting stages of ship construction and repair. Workers may assume awkward postures in order to complete their job tasks.

Pipefitters—These workers assemble and test piping systems in pipe shops, in blocks or units, or aboard vessels. The work involves a fair amount of material handling and pipe welding, sometimes in awkward postures.

Riggers—Riggers are responsible for the vertical and horizontal movement of material within the shipyard and onto the ships. Riggers work with crane operators to place units and blocks onto the hull under construction and to place heavy equipment into the vessel during the outfitting stage.

Saw operators—Workers using reciprocating saws are becoming a common site in both ship repair and ship scrapping operations. Workers use reciprocating saws to dismantle ancillary equipment attached to bulkheads, ceilings and decks, as well as to cut through those structures to facilitate their removal. The workers may be exposed to high amounts of hand-arm vibration.

Sheetmetal workers—These workers build duct work for heating, ventilation and air conditioning systems either in the shop or on the ship and install the systems in the preoutfitting stage in the blocks or onboard the vessel during outfitting.

Shipfitters—It is the responsibility of the shipfitters to see that each component, subassembly, and assembly perfectly matches that to which it is to be joined. Shipfitters may use a variety of power and hand tools in the completion of their tasks. The workers may also have to work in constrained postures.

Welders—The welders are responsible to join metal components together whether in a panel line, a subassembly area, within a block or onboard a vessel. Constrained and sustained postures can be problem.

Shipyard trade occupational risk matrix (STORM)

Table 1 is a matrix of the affected body parts associated with occupational risk factors and shipyard trades based on an analysis of injury and cost data and quantitative risk factor analysis of

Table 1 Shipyard trade occupational risk matrix (STORM)

TRADE	Sustained Postures	Awkward Postures	Repetition	Vibration	Excessive Force
Abrasive Blasters	(1) Arms (2) Shoulders (3) Back Y	(1) Arms (2) Shoulders (3) Back O	(1) Arms (2) Shoulders Y	(1) Arms (2) Shoulders Y	(1) Arms (2) Shoulders (3) Back R
Burners/ Torch Cutters	(1) Knees (2) Back (3) Neck (4) Shoulders (5) Arms (6) Hand/Wrist O	(1) Knees (2) Back (3) Neck (4) Shoulders (5) Arms (6) Hand/Wrist R	G	G	G
Electricians	(1) Back Y	(1) Back (2) Knees (3) Hand/Wrist O	(3) Hand/Wrist (5) Arms O	G	(1) Back (3) Hand/Wrist (4) Shoulders (5) Arms R
Grinders/ Chippers	(1) Back (2) Knees (3) Arms (4) Shoulders (6) Neck O	(1) Back (2) Knees (3) Arms (4) Shoulders (5) Hand/Wrist (6) Neck R	(3) Arms (4) Shoulders (5) Hand/Wrist Y	(3) Arms (4) Shoulders (5) Hand/Wrist R	(3) Arms (4) Shoulders (5) Hand/Wrist R
Insulators	(2) Shoulders (3) Neck (4) Back Y	(1) Hand/Wrist (2) Shoulders (3) Neck (4) Back R	(1) Hand/Wrist (2) Shoulders Y	G	(1) Hand/Wrist (2) Shoulders R
Machine Operator	(1) Back (2) Neck Y	(1) Back (2) Neck O	(1) Back (3) Shoulders (4) Hand/Wrist Y	G	(1) Back (3) Shoulders R
Material Handlers	G	(1) Back (2) Shoulders (3) Arms R	(1) Back (2) Shoulders (3) Arms O	G	(1) Back (2) Shoulders (3) Arms R
Outside Machinists	(1) Back (2) Neck Y	(1) Back (2) Neck O	(3) Shoulders (4) Hand/Wrist Y	(3) Shoulders (4) Hand/Wrist Y	(1) Back (3) Shoulders R
Pipefitters	G	(1) Back (2) Knees (3) Arms (4) Neck O	(3) Arms (5) Hand/Wrist Y	(3) Arms (5) Hand/Wrist Y	(1) Back (3) Arms (5) Hand/Wrist R
Riggers	G	(1) Shoulders (2) Back (3) Knees O	(1) Shoulders (4) Hand/Wrist Y	G	(1) Shoulders (2) Back R
Saw Operators	G	(1) Hand/Wrist (2) Arms (3) Shoulders (4) Back O	G	(1) Hand/Wrist (2) Arms (3) Shoulders R	(1) Hand/Wrist (2) Arms (3) Shoulders (4) Back R
Sheetmetal Workers	G	(1) Back (2) Neck (3) Knees O	(4) Arms (5) Hand/Wrist Y	(4) Arms (5) Hand/Wrist Y	(1) Back (4) Arms (5) Hand/Wrist R
Shipfitters	G	(1) Back (2) Knees (3) Neck (4) Hand/Wrist (5) Arms (6) Shoulders R	(1) Back (4) Hand/Wrist (5) Arms (6) Shoulders Y	(4) Hand/Wrist (5) Arms Y	(1) Back (4) Hand/Wrist (5) Arms (6) Shoulders R
Welders	(1) Knees (2) Back (3) Neck (4) Shoulders (5) Arms (6) Hand/Wrist R	(1) Knees (2) Back (3) Neck (4) Shoulders (5) Arms (6) Hand/Wrist R	(6) Hand/Wrist Y	(5) Arms (6) Hand/Wrist Y	(2) Back (6) Hand/Wrist Y

targeted shipyard work processes. The numbers represent the rank order of importance for injury to that body part based on incidence and cost, given the occupational risk factors observed for work processes performed by that specific trade. The color code (R = red, O = orange, Y = yellow, and G = green) represents the importance of that occupational risk factor in the development of musculoskeletal injuries for that trade. Red is the most important, followed by orange, then yellow. A "green" cell would mean that the particular occupational risk factor is not a strong factor in the development of musculoskeletal injuries for that trade.

Interventions

For each of the eight shipyard study sites, NIOSH has prepared detailed pre- and post-intervention reports that quantify the effectiveness of the intervention studies at each yard. Examples of intervention studies to date include the installation of a lift table in a pit behind a shear machine in a plate shop to minimize manual material handling, the introduction of "ergonomically-designed" wire welding whips to a crew of welders, the use of a bin tilter in a scrapping operation to assist in manual material handling, the installation of a nozzle mount in a water blasting operation to eliminate the need of the worker to hold the waterjet "gun," the conduct of power-tool (e.g., grinders) vibration analysis, the implementation of a motorized cable pulling system, the distribution of kneepads and mobile worker stools for those tasks requiring extensive kneeling, and the delivery of ergonomics awareness training for supervisors and employees.

Conclusions

The primary product for this project will be a set of ergonomics best practices guidelines for the shipyard industries. (A separate best practices guideline will be created for the marine cargo handling industries.) These guidelines will be prepared from a compilation of findings from the in-depth survey reports and from existing interventions at shipyards already documented. NIOSH has developed a website (www.cdc.gov/niosh/ergship/ergship.html) that highlights the study results to date. NIOSH will also partner with labor, industry, trade associations, and government agencies to conduct workshops to disseminate effective interventions. It is anticipated that the interventions from this study will be broadly implemented within the shipyard industries, and will result in significant decreases in worker injury and compensation costs, as well as improved process productivity and quality. This study has also been used by NIOSH as a model to develop ergonomic solutions for the construction industry.

References

Alexander, D. C. 1998 Strategies for cost justifying ergonomic improvements. *IIE Solutions,* Institute of Industrial Engineers, Norcross, Ga., March, **30,** 3, 30–35.

NIOSH 1997 *Musculoskeletal Disorders and Workplace Factors: A Critical Review of Epidemiologic Evidence for Work-Related Musculoskeletal Disorders of the Neck, Upper Extremity, and Low Back.* B. P. Bernard, Ed., U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, NIOSH, Cincinnati, Ohio, NIOSH Publication Number 97-141, July.

Kemmlert, K. 1995 A method assigned for the identification of ergonomic hazards—PLIBEL. *Applied Ergonomics,* **26,** 3, 199–211.

Lifshitz, Y. and Armstrong, T. 1986 A design checklist for control and prediction of cumulative trauma disorders in hand intensive manual jobs. *Proceedings,* 30th Annual Meeting of Human Factors Society, 837–841.

Louhevaara, V. and Suurnäkki, T. 1992 OWAS: a method for the evaluation of postural load during work. Training Publication No. 11, Institute of Occupational Health, Helsinki.

McAtamney, L. and Corlett, E. N. 1993 RULA: a survey method for the investigation of work-related upper limb disorders, *Applied Ergonomics,* **24,** 2, 91–99.

Moore, J. S. and Garg, A. 1995 The strain index: a proposed method to analyze jobs for risk of distal upper extremity disorders. *American Industrial Hygiene Association Journal,* **56,** 443–458.

University of Michigan Software 1977 3D static strength prediction program version 4.0, 3003 State St., #2071, Ann Arbor, Mich. 48109-1280, Copyright 1997 The Regents of The University of Michigan.

Waters, T. R., Putz-Anderson, V., Garg, A., and Fine, L. J. 1993 Revised NIOSH equation for the design and evaluation of manual lifting tasks. *Ergonomics,* **36,** 7, 749–776.

Waters, T. R. and Putz-Anderson, V. 1996 *Manual Materials Handling, Ch. on Occupational Ergonomics: Theory and Applications,* A. Bhattacharya and J. D. McGlothlin, Eds., Marcel Dekker, Inc., New York, 329–349.