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A case study of an ergonomic evaluation for a shop floor facility

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ABSTRACT

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The aim of this paper is to discuss and recommend solutions for the ergonomic hazards present in a shop floor type of manufacturing facility. This type of study is important since the ergonomic issues that concern the shop floor worker are different than those faced by the assembly line worker. The shop floor employee for the most part enjoys work satisfaction, task variety, and is able to control his own work pace. From an ergonomic standpoint, this is the preferred work environment.

The focus of this paper is a case study. This study is a one-day ergonomic assessment of a plastic manufacturing facility located in New Jersey. The ergonomic hazards found in this facility provided valuable information for developing guidelines that can be applied in most shop floor facilities. Among these guidelines is the implementation of a program that includes joint participation from management and workers for hazard evaluation.

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by
Ivan Siguencia

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APPROVAL PAGE

A CASE STUDY OF AN ERGONOMIC EVALUATION FOR A SHOP FLOOR FACILITY

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This thesis is dedicated to my parents, Miguel Siguencia and Elvia Larreategui
and also to T., and Jr.

Esta tesis esta dedicada a mis queridos padres, Miguel Siguencia y Elvia Larreategui
y tambien a T., y Junior.

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CHAPTER 1

INTRODUCTION

1.1 Evolution of the Factory System

The factory system has evolved considerably throughout time. The early history starts with the discovery of pottery works found in ancient Rome and Greece. Glassware and bronze ware were manufactured in the Roman Empire. In the Middle Ages, silk factories and textile factories were established in Syria and throughout Europe.

The Renaissance introduced new factors in the development of the factory system. The advance of science, new trade routes to the Far East and contact with the New World enormously influenced industrialization. Funk and Wagnalls New World Encyclopedia indicates, "Although heavy machinery, operated by waterpower in some places, was used in a few establishments, the industrial process were generally carried on by means of hand labor and simple tools. In contrast to modern mechanization plants with assembly lines, the factories were merely large workshops where each laborer functioned independently." These large workshops, also called shop floors, relied on the skills of the workers to manufacture a complete product.

The domestic system was eventually replaced by the factory system, as the primary method of production in modern economies, when the British textile industry was transformed due to a series of inventions and thus gave way to the Industrial Revolution. The next important contribution to the factory system was the development of the idea of using interchangeable parts by the American inventor Eli Whitney. This new breakthrough led to the production of firearms by assembly line methods. Funk and

Wagnalls explain, "Interchangeable parts, with which Whitney began experimenting in 1798, eventually made it possible to produce firearms by assembly line techniques, rather than custom work, and to repair them quickly with pre-made parts." Therefore, American factories began to incorporate the features of mass production and standardization of parts by the mid nineteenth century.

Biggs (1996) indicates that the effort to introduce these new methods culminated in what she calls the "rational factory" with Henry Ford's motor company and his River Rouge plant. The application of assembly line techniques to automobile production completely revolutionized industry. Today, alterations of this system can be observed throughout the world. Each alteration has its unique characteristics according to the culture and history of the region it occupies. Although most factories exhibit an assembly line layout, there are still many smaller companies that have kept with the shop floor layout tradition. This type of layout is still necessary since their will always be demand for certain type of manufactured goods that can only be produced efficiently in a shop floor layout.

1.2 The Introduction of State and Federal Regulation

Factory inspections by state agencies had their origins in England in the early nineteenth century. This was in response to public outcry against working conditions for working women and children. Factory regulations thus spread to many other industrialized nations. Funk and Wagnalls indicate, "These codes provide for restriction on child labor and hours of work, regulation of sanitary conditions, installations of safety devices and the enforcement of safety standards, medical supervision, adequate ventilation, the elimination of sweatshops, and the establishment of minimum wages."

In the United States, the federal and state governments are responsible for the regulation of safety and health standards. This is done through the Occupational Safety and Health Administration (OSHA), Public Employees Occupational Safety and Health (PEOSH), and numerous OSHA approved state plans. OSHA was established in 1970 as an agency of the U.S. Department of Labor.

Ergonomics is a current issue for OSHA and although the ergonomics standard was shut down by congress in early 2001, efforts were still being made within the agency to rewrite this much needed standard. The effort of OSHA was further derailed after the unfortunate incidents of September 11, 2001. Presently, there is no clear initiative by OSHA to undertake the development of an ergonomic standard; instead the agency has created a non-mandatory ergonomic guideline that falls under the umbrella of the general duty clause. Regardless of the current socio-political situation, ergonomics hazards are issues that affect workers throughout our nation and it's to our best interest to have the Federal Government regulate it through a comprehensive mandatory standard.

1.3 History of Ergonomics

The term ergonomics comes from two Greek words. Ergon, which means work, and nomos, which means natural laws. Thus, ergonomics may be defined as a disciplined concerned with the application of natural laws governing human work (Mital, 1995). There are, of course, other definitions that can be used to describe ergonomics. Singleton

(1972) defines ergonomics as the technology of work design. Chapanis (1995) defines ergonomics with the following:

- Ergonomics and human factors use knowledge of human abilities and limitations
- To the design of systems, organizations, jobs, machines, tools, and consumer products
- For safe, efficient, and comfortable human use.

Despite diverse definitions, the goal of ergonomics is to fit the task to the human in order to eliminate or minimize ergonomics hazards and consequently enhancing the effectiveness of human interaction with the work environment. Mital (1995) lists the following aims of ergonomics:

- Eliminating or minimizing injuries, strains and sprains
- Minimizing fatigue and overexertion
- Minimizing absenteeism and labor turnover
- Improving quality and quantity of output
- Minimizing lost time and costs associated with injuries and accidents
- Maximizing safety, efficiency, comfort and productivity, etc.

It is also important to separate the meaning of ergonomics from that of human factors. Mital (1995) explains, " Even though the terms ergonomics and human factors are generally considered synonymous, many prefer to make a distinction. These individuals associate the term human factors with the behavioral aspects of human performance and the term ergonomics with the quantitative and/or health and safety aspects of humans at work in occupational and non-occupational settings."

Wojciech Jastrzebowski used the word ergonomics for the first time in a Polish newspaper in 1857 (Karwowski, 1991). The development of human factors and ergonomics goes hand in hand with the development of technology and thus has its beginnings with the industrial revolution of the late 1800s and early 1900s (Sanders and McCormick, 1993). Ergonomics as a profession has its beginnings during World War II. Konz and Johnson (2000) write, "During World War II, research was conducted to maximize human performance in military applications."

After World War II, the U.S. Air Force and U.S. Navy established engineering psychology laboratories. Concurrently, the first civilian company was created to perform engineering psychology contract work. Up until the 1960s, ergonomics was mainly concentrated in the military. In the 1980's and 90's human factors saw rapid growth thanks to the computer industry and unfortunate disasters around the world like Chernobyl in the former Soviet Union and the Union Carbide disaster in Bhopal, India (Sanders and McCormick, 1993).

During the 1980s and 1990s, the computer revolution made the term ergonomics popular with the public since phrases like "ergonomic keyboard" or "ergonomic mouse" become popular slogans for computer marketing. It wasn't until OSHA's attempt to regulate ergonomics that it focused the national spotlight in a science that recognizes ergonomic risk factors and recommends proper interventions to minimize or eliminate it's adverse health effects. This attempt to regulate ergonomics is currently a controversial issue and still causes heated debates within industry, the medical field, and workers everywhere. Today, human factors and ergonomics are widely thought, and applied in a broad variety of companies.

1.4 Current Limitations of Ergonomics

Ergonomic investigations and epidemiological studies conducted thus far have concentrated on the association between occupational risk factors and the development of musculoskeletal disorders in the back, neck, shoulders, and arms (Winkel and Westgaard, 1992; Kilbom, 1994). Also, the prevelance of work-related musculoskeletal problems of the lower extremity is not as frequently reported as those of the upper-body (Li and Buckle, 1999).

Constrained working postures are one of the most important risk factors associated with various occupational musculoskeletal disorders (Hunting et al., 1980; Westgaard and Aaras, 1984), but these risk factors are not the only factors of concern. Force, frequency, and duration are also believed to be important (Kilbom, 1994; Winkel and Mathiassen, 1994). Therefore, when evaluating occupational risk factors, all factors should be considered and measured. Here is where the problem resides, little is known about the relative importance of each risk factor (Li and Buckle, 1999). As a consequence, there is no agreement on how different exposure variables can collaborate to provide a specific dose (Hagberg, 1988).

The "biological injury mechanism" involved in cumulative trauma disorders is poorly understood. The "injury mechanism" is likely to be multicasual. New risk factors can unintentionally be introduced when ergonomics interventions are implemented against known risk factors (Westgaard and Winkel, 1997). In some instances, there has been argument over the actual relationship between CTD and risk factors. This viewpoint argues that cumulative trauma disorders are only common to a certain population of the workforce. This particular population is characterized by either smaller or larger anthropometrical features or is of lesser physical strength (Nathan, et al., 1992a; Nathan, et al., 1992b; Rempel, 1992). Furthermore, others believe that muscle inactivity following an injury will cause the worker to have increase susceptibility to subsequent injury (Fordyce, et al., 1986). Other views even argue that the root source of CTDs is often psychological and that physical interventions have little effects (Flor and Turk, 1984; Hocking, 1987) and thus creating doubts about the usefulness of ergonomic interventions (Winkel and Westgaard, 1996). In a Swedish study it was observed that improved dentists' workstations facilitating better work postures did not lead to a reduction in disorders (Winkel and Westgaard, 1996).

In 1997, the National Institute of Occupational Safety and Health (NIOSH) gathered a review of numerous epidemiological studies. The purpose was to show a casual relationship between risk factors and CTD (NIOSH, 1997(b)). This evaluation shows that for a considerable amount of CTD there is significant evidence to suggest a direct relationship with risk factors.

CHAPTER 2

LITERATURE REVIEW

2.1 Ergonomic Hazards

Ergonomics hazards are workplace conditions and physical stressors that cause a risk of injury or illness to the worker's musculoskeletal system (NIOSH, 1995). Of specific interest are those hazards that pose a cumulative effect on the workers and which are called cumulative trauma disorders (CTD) or work-related musculoskeletal disorders (WMSDs). They are also known as repetitive strain injury (RSI) in Canada and the United Kingdom and cervicobrachial syndrome or occupational cervicobrachial disorder in Japan and Sweden. Yassi (1997) gives the following list of disorders commonly attributed to repetitive strain injury:

Tendon related disorders:

- Tendonitis
- Tenosynovitis
- Peritendonitis
- Gangilion cyst
- Epicondylitis (lateral or medial)

Peripheral-nerve entrapment:

- Carpal tunnel syndrome
- Guyon tunnel syndrome
- Radial tunnel syndrome
- Pronator teres syndrome

- Cubital tunnel syndrome

Neurovascular/vascular disorders:

- Hand-arm vibration syndrome (raynaud's syndrome)
- Ulnar-artery thrombosis

Muscular disorders:

- Focal dystonia
- Fibromyositis
- Tension-neck syndrome
- Myositis
- Myalgia

Joint/joint-capsule disorders:

- Osteoarthritis
- Bursitis
- Synovitis
- Adhesive capsulitis

Also, NIOSH (1997) defines the term musculoskeletal disorders as describing:

- Disorders of the muscles, nerves, tendons, ligaments, joints, cartilage, or spinal discs
- Disorders that are not typically the result of any instantaneous or acute event (such as a slip, trip, or fall) but reflect a more gradual or chronic development (nevertheless, acute events such as slips and trips are very common causes of musculoskeletal problems such as low back pain)

- Disorders diagnosed by a medical history, physical examination, or other medical tests that can range in severity from mild and intermittent to debilitating and chronic
- Disorders with several distinct features (such as carpal tunnel syndrome) as well as disorders defined primarily by the location of the pain (i.e., low back pain)

The ergonomic risk factors that can lead to CTD include: repetitive and forceful motions, static muscle load, mechanical stress, vibration, temperatures extreme, and awkward postures (Yassi, 1997). There are also psychosocial and physical factors to consider. These include cognitive and emotional stress relating to work task, social relationships, individual psychological factors, administrative concerns, lighting, noise and indoor climate (Westgaard and Winkel, 1997). The previously mention factors present a musculoskeletal hazard independently of mechanical exposure (Bongers et al., 1993; Vasseljen and Westgaard, 1996). In a landmark study (Bigos et al., 1991) it was argued that, in addition to prior back problems, work perceptions and some psychosocial responses were the only factors linked with reporting low back pain during a 4 year follow-up period.

Organizational factors may also increase the risk of CTD's. These factors include: excessive work rates, duration of work, externally paced work, inadequate work breaks or rest periods, monotonous work, and job insecurity (NIOSH, 1995; Chatterjee, 1987; Gerr, Letx and Landrigan, 1991). Also, if two or more risk factors are present then the risk for CTD increases significantly (Silverstein, Fine and Armstrong, 1986).

Individual risk factors could also contribute to the occurrence of CTDs. For example, obesity can contribute significantly to the occurrence of CTDs (Nathan et al., 1992b). Athletic activity and hobbies have also been associated with these disorders. Athletic activities such as racket sports have been associated with the development of tendinitis, tenosynovitis, degenerative joint disease, and peripheral nerve entrapments. Knitting, sewing, or the playing of musical instruments as hobbies, have also been associated to these disorders (Armstrong and Chaffin, 1979). The table below summarizes the different types of ergonomics risk factors:

Table 2.1 Ergonomic Risk Factors

Risk Factors	Examples	Author/s
Mechanical Hazards	Repetitive motions Static muscle load Awkward postures Mechanical stress Vibration Temperature extreme	Yassi, 1997
Psychosocial and Physical	Cognitive stress Social relationships Psychological factors Administrative concerns Lighting Noise	Westgaard and Winkel, 1997 Bongers et al., 1993 Vasseljen and Westgaard, 1996
Organizational Factors	Excessive work rates Duration of work Externally paced work Inadequate work breaks Monotonous jobs Job insecurity	NIOSH, 1995 Chatterjee, 1987 Gerr, Letx and Landrigan, 1991
Individual Risk Factors	Obesity	Nathan et al., 1992b
Athletic Activities/Hobbies	Racket sports Knitting and sewing Musical instruments	Armstrong and Chaffin, 1979

It is important to point out that repetitious work activities can inflict cumulative trauma on several body parts simultaneously. Rempel, Harrison and Barnhart (1992) explains, "For example, a worker sitting at a poorly designed computer workstation may experience pain in the shoulders, neck, upper back, and low back as well as in the wrists. Indeed a large proportion of workers with carpal tunnel syndrome have other repetitive strain injuries." Yassi (1997) lists and explains different tests that can be used by health care professionals in evaluating repetitive strain injuries:

- Finkelstein's test: Ulnar deviation of the hand with the thumb flexed against the palm and fingers flexed over the thumb; a positive response consists of pain at the radial styloid due to stretching of the abductor pollicis brevis and extensor pollicis.
- Phalen's test: Flexing of both wrists 90 degrees with the dorsal aspects of the hands held together for 60 seconds; a positive response is pain or tingling in the median nerve distribution, especially digits 2 and 3.
- Tinel's test of the median nerve: Tapping of the median nerve as it passes through the carpal tunnel; a positive response consists of pain and tingling in the median nerve distribution.
- Tinel's test of the ulnar nerve: Tapping the ulnar nerve as it passes through Guyon's canal; a positive response consists of pain or tingling in the ulnar nerve distribution (digits 4 or 5).
- Cozen's test: Resistance to wrist extension and radial deviation while the forearm is pronated; a positive response consists of pain at the lateral (or medial) epicondyle.

- Spurling's test: Compression on the top of the head with the neck at 20 degrees extension; a positive response consists of pain radiating down the arm.
- Adson's manoeuvre: Hyperextension of the shoulder with chin thrust forward; a positive response consists of a weakened pulse, pain, and numbness.

Yassi (1997) lists the following ergonomics interventions according to each type of risk factor:

Repetitiveness:

- Use mechanical aids.
- Enlarge work content by adding more diverse activities.
- Automate certain tasks.
- Rotate workers.
- Increase rest allowance.
- Spread work uniformly across work shift.
- Restructure jobs.

Force/mechanical stress:

- Decrease the weight of tools/containers and parts.
- Increase friction between handles and hand.
- Optimize size and shape of handles.
- Improve mechanical advantage.
- Select gloves to minimize effects on performance.
- Balance hand held tools and containers.
- Use torque control devices.
- Enlarge corners and edges.

- Use pads and cushions.

Posture:

- Locate work to reduce awkward posture.
- Alter position of tool to avoid bending of wrist.
- Move part closer to worker.
- Move worker to reduce awkward postures.
- Select tool design for workstation.

Vibration:

- Select tools with minimum vibration.
- Select processes to minimize surface and edge finishing.
- Use mechanical assistance.
- Use isolation for tools that operate above resonance point.
- Provide damping for tools that operate at resonance point.
- Adjust tool speed to avoid resonance.

Psychological stresses:

- Enlarge workers' task duties.
- Allow more worker control over pattern of work.
- Provide micro work pauses.
- Minimize paced work.
- Eliminate blind electronic monitoring.

The above lists are general guidelines for ergonomics interventions. The shop floor layout reduces the number of ergonomics concerns and/or risk factors compared to assembly line work. These specific ergonomics hazards and proper interventions will be discussed later in this paper.

2.2 Impact on Industry

There has been a considerable increase of CTD in the last few decades. In the United States, the number of reported upper-extremity disorders has tripled between 1986 and 1993 (Bureau of Labour Statistics, 1993). A similar trend is seen in other industrialized nations. Hagberg et al., (1995) indicates, "Work-related musculoskeletal disorders constitute a major problem in many industrialized countries." CTD's accounted in the United States for over 60% of all occupational illnesses in 1990 (Bureau of Labour Statistics, 1994). Part of this increase is attributed to better recognition and reporting (Brogmus, Sorock and Webster, 1996). Also, of considerable importance, is the fact that work in a stressful and highly competitive global economy tends to be highly paced and repetitious (Putz-Anderson, 1988; Guidotti, 1992; Yassi, 1997).

The economic burden CTD cause employers is enormous. In the United States it is estimated that the cost of compensation exceeds $20 billion per year (Bureau of Labour Statistics, 1993). These types of disorders are also more expensive than disorders of similar pathology caused from acute trauma (Yassi, 1997). Further, in Industries like newspaper publishing, automobile manufacturing, and meatpacking, CTD have become not only a health issue but also a productive issue. This is due to the fact that in these industries work related CTD represent a high percentage of the work force (Bureau of National Affairs, 1991).

Besides the direct costs caused by CTD, there are also many more indirect costs. Indirect cost includes high absenteeism, high employee turnover, low employee morale, and a decrease in work efficiency and quality (Carson, 1993). Therefore, it is to the benefit of the employer as well as the employee to setup ergonomic interventions aimed to early detection and prevention of CTD's. There is also a general agreement that early intervention and diagnosis improves prognosis (NIOSH, 1995; Rempel, Harrison and Barnhart, 1992).

2.3 Ergonomic Control Methods

There are three main types of ergonomic control methods. These are listed below in the desired order of implementation:

- Engineering Controls
- Administrative Controls
- Personal Protective Equipment

Selection of the appropriate control will depend on the nature of the ergonomic hazard and the feasibility of implementing it in that particular work setting. The Occupational Safety and Health Administration (OSHA) defines each as follows:

Engineering controls: Are physical changes to a job that reduce MSD hazards. Additionally, NOSH (1997a) gives the following engineering control strategies to reduce ergonomic risk factors:

- Changing the way materials, parts, and products can be transported, for example; using mechanical assist devices to relieve heavy load lifting and carrying tasks or using handles or slotted hand holes in packages requiring manual handling.

- Changing the process or product to reduce worker exposure to risk factors; examples include maintaining the fit of plastic molds to reduce the need for manual removal of flashing, or using easy-connect electrical terminals to reduce manual forces.
- Modifying containers and parts presentation, such as height-adjustable material bins.
- Changing workstations layout, which might include using height-adjustable workbenches or locating tools and materials within short reaching distances.
- Changing the way parts, tools, and materials are to be manipulated; examples include using fixtures (clamps, vise-grips, etc.) to hold work pieces to relieve the need for awkward hand and arm positions or suspending tools to reduce weight and allow easier access.
- Changing tool designs; for example, pistol handle grips for knives to reduce wrist bending postures required by straight-handle knives or squeeze-grip-actuated screwdrivers to replace finger-trigger-actuated screwdrivers.
- Changes in materials and fasteners (for example, lighter-weight packaging materials to reduce lifting loads).
- Changing assembly access and sequence (e.g., removing physical and visual obstructions when assembling components to reduce awkward postures or static exertions).

Administrative controls: Are changes in the way that work in a job is assigned or schedule that reduce the magnitude, frequency or duration of exposure to ergonomic risk factors. Furthermore, NIOSH (1997a) gives the following examples of administrative control strategies for reducing ergonomics risk factors:

- Reducing shift length or curtailing the amount of overtime.
- Rotating workers through several jobs with different physical demands to reduce the stress on limbs and body regions.
- Scheduling more breaks to allow for rest and recovery.
- Broadening or varying the job content to offset certain risk factors (e.g., repetitive motions, static and awkward postures).
- Adjusting the work pace to relieve repetitive motion risks and give the worker more control of the work process.
- Training in the recognition of ergonomics risk factors and instruction in work practices that can ease the task demands or burden.

As the last bullet indicates, training is an important part of administrative controls. Also, training is a valued investment in a workforce that tends to have a low turnover, as is the case with the shop floor. It was pointed out in a study, that learning the correct working technique from the start reduced sick leaves among assembly workers (Parenmark et al., 1993).

Personal protective equipment (PPE): Are equipment employees' wear that provide a protective barrier between the employee and the hazard. PPE should be used as the last line of defense since it could only protect the employee to a certain degree while leaving the hazard intact. Some types of PPE will give a false sense of security to the worker. A clear example of this is the use of back belts as the sole protection for back injury. The National Institute of Occupational Safety and Health (1994), based on a review of scientific literature, concluded that insufficient evidence exists to prove the effectiveness of back belts to prevent back injuries. Some studies advocate the use of PPE to reduce the occurrence of back injuries. In particular, a large nationwide retail hardware store claims that the use of back belts reduced injury rates substantially (Knill, 1997). Additionally, in fall protection, the use of the common body belt as part of a personal fall arrest system has proven to cause serious injuries. OSHA prohibits the use of body belts for fall protection since 1998 since the forces generated in a fall and the use of body belts can cause substantial injury to the employee. The use of a full body harness with a shock-absorbing lanyard is the current standard in fall protection.

Engineering controls are preferred over administrative control since the former focuses on system redesign. Personal protective equipment (PPE) is the last alternative. In occasions, engineering and administrative controls cannot be used to reduce the exposure or potential exposure to an ergonomics hazard. In these circumstances the use of PPE becomes necessary but special attention should be given to the fact that these control measures are only temporary and should be substituted by engineering or administrative controls as soon as possible. It is also of vital importance that if PPE's are used then employees must be adequately trained on how to properly wear them, and management must establish procedures for enforcement. The table below shows examples for each control method.

Table 2.2 Examples of Each Control Method

Engineering Controls	Administrative Controls	Personal Protective Equipment
Redesign of: - Workstations - Tools - Facilities - Materials - Equipment & Processes	- Employee rotation - Job task enlargement - Alternative tasks - Employer-authorized changes in work pace - Training	- Personal fall arrest system - Vibration-reduction gloves - Carpet layers knee pads - Wrists splints

CHAPTER 3

RESEARCH OBJECTIVES, PROCEDURES, AND METHODOLOGY

3.1 Objective

The objective of this research is to develop an ergonomic program that will focus specifically to a shop floor facility. This objective is accomplished through analysis performed in a case study at a plastic manufacturing facility. From the case study, specific guidelines are obtained that will help reduce ergonomic disorders. These guidelines are particular to the characteristics of the facility involved in the case study.

In order for these specific guidelines to be useful to other shop floor facilities, this paper will further analyze the main differences of the shop floor compared to an assembly line type of layout. Finally, general ergonomic guidelines that benefit facilities with a shop floor layout are developed.

3.2 Research Procedures

The following are the procedures followed in this research paper:

- An in-depth literature review was performed on ergonomics. Among the areas reviewed were ergonomic hazards, its impact on industry, assembly line characteristics, shop floor characteristics, and ergonomic control measures.
- A case study was performed at a plastic manufacturing facility. The ergonomic analysis was performed on several workstations of concern. Recommendations were given on how to eliminate or reduce many of the risk factors found to be of concern.

- In order to properly evaluate the case study workstations and/or work tasks, different methods were utilized. Among the methods used were RULA and the 3D static strength prediction program, both performed by using computer software. More information of the methodology used will be discussed latter in this chapter.
- From the information obtained through literature review and the analysis of the case study, comprehensive guidelines are given for implementing an ergonomic program specific to a shop floor facility.

3.3 Case Study Methodology

The main methodology used for the case study is the observational method. The advantages of using this technique includes:

- The work tasks were not designed for the purpose of the investigation but represented the real conditions under which the employees worked.
- There was little interference with the tasks that the workers performed. Therefore, the pace and work practices of the employees were a good representation of the actual working conditions.
- Data was collected using videotape, sound level meter, measuring devices, informal interviews, and observation.

To complement the analysis of certain postures found in the case study, computer software was used to perform a qualitative and quantitative analysis of the postures. Next, the Rapid Upper Limb Assessment (RULA) technique and the 3D static strength prediction program are discussed.

3.4 RULA

RULA is an excellent tool for evaluating the exposure to risk factors for the upper extremities (McAtamney and Corlett, 1993). The factors of consideration used in this technique are: posture, frequency, and force. Based on the previous factors, a risk index is derived. The risk index represents a qualitative approach for rating job tasks. Since it's a qualitative measure it should be used with caution and not as an exact measurement. The steps in calculating the RULA risk index are:

- Determination of the posture scores. The score depends on the distance the limbs move from the neutral axis and approaches the natural limits for movement.
- The frequency scores are calculated by identifying the number of repetitions per minute required for the task.
- After the previous mentioned factors are considered and a scores given, a grand score is given for that particular job or work task.

The RULA computer output for different postures considered in this paper can be seen in Appendix A.

3.5 Three-Dimensional Static Strength Prediction Program (3D SSPP)

The University of Michigan Center for Ergonomics developed this program based on over 25 years of research regarding the biomechanical and static strength capabilities of the employee in relation to the physical demands of the work environment (The University of Michigan 3D SSPP, 1998).

The software is most useful in the analysis of slow movements in manual material handling since the biomechanical computations assume that the effects of acceleration and momentum are negligible. In the case study, one posture of concern that met the above requirements was analyzed using the 3D SSPP software. The task involved is described in the next chapter and the computer output can be seen in Appendix B.

CHAPTER 4

CASE STUDY

4.1 Introduction

The case study was a one-day ergonomics assessment of a plastic manufacturing facility located in New Jersey on February, 2001. This facility manufactures polymer-based products. Specifically, specialty hoses are manufactured for fluid systems. The demand of these hoses occupies a particular niche in the market. Therefore, production is low if compared to an assembly line type of facility. The facility layout is setup in stations that flow from the receiving/shipping area through different process shops. It is in these shops that workers, machines, tools, and material come together to craft the final product. It is this interaction that is of interest and which this case study is based upon.

The majority of the employees at the shop floor is skilled, and enjoys a certain degree of work variety. Consequently, the ergonomics concerns and solutions are somewhat different from those commonly attributed to facilities using assembly lines. Primarily, the worker has the opportunity to execute several tasks or components instead of constantly performing a single routine. The latter one has a major concern of a cumulative physical burden due to its repetitiveness throughout a work shift. On the other hand, since workers at the shop floor are skilled they will tend to stay in their jobs for a longer time frame. In this case, ergonomics risk factors could pose a greater chronic threat. This point will be further discussed in the Conclusions and Recommendations chapter.

The main ergonomics risk factor observed in the shop floor deals with awkward postures. These poor postures can be detected when employees lifted heavy containers or performs tasks at their worktables. Lifting issues can be solved by the use of proper material handling devices in conjunction with correct lifting techniques. Worktable tasks that require the employee to take on an awkward posture can also be improved. The first alternative should always look into system redesign. This can be applied to the worktable, vise, fixture or any equipment so as to improve employee posture. Other ergonomic risk factors were identified and recommendations given in this report.

In the office area, the concerns revolve mainly on a good Video Display Terminal (VDT) setup. The changes recommended deal mainly with modifications to their present setup. These include adjustment necessaries to improve employee posture when typing and/or viewing the computer screen. Other visible opportunities for ergonomic improvements are also advocated in this case study.

Training is an essential tool that can be used in the shop floor and office areas. Employees should be trained on how to identify ergonomics risk factors and how to properly avoid them and report them to management. Training is a good investment since the shop floor workforce is already skilled and will tend to have a low turnover. Further, management should also be trained on recognizing these risk factors and how to effectively control them. Training and ergonomics awareness is especially important in these types of facilities since having a full time safety professional might not be cost effective.

The overall work environment at this facility from an ergonomics point of view is acceptable. The changes recommended in this case study would help to reduce ergonomics problem and improve the work quality, safety, and job satisfaction of the entire workforce.

4.2 Demographics

The composition of the workforce is diverse. There are young as well as older employees. The ethnic distribution is also diverse since there are Caucasians, Hispanic, and African American employees. Regarding sex, the overwhelming majority of workers on the shop floor are male.

These employees are moderate to highly skilled in the tasks that they perform. An employee will usually stay in a particular station during most of his employment but there are several cases where employees are trained in two or more workstations.

4.3 Current Practices

The work environment at this plastic manufacturing facility is different from those found at other manufacturing companies. At a time when most manufacturing is performed in assembly line layouts, a shop floor arrangement offers a distinct work environment. This design without a doubt requires diverse knowledge and skills from its employees. Therefore, employees enjoy a variety of work activities as oppose to typical monotonous assembly line tasks. For this reason, from an ergonomics perspective, the workshop layout is preferred over the assembly line. The workers perform their jobs at their own pace while utilizing different areas of the body since different job elements are involved. Although the employees have an acceptable work environment they are lacking knowledge and awareness of ergonomics risk factors. This lack of knowledge was evident since workers were seen performing their tasks with improper postures.

Additionally, correct material handling procedures seems to be lacking. Employees where seen lifting and moving heavy containers with poor lifting postures and no lifting aids. This poor work practice is a risk factor for potential back injury.

4.4 Constraints

It is imperative to mention several constraints present in this case study. There was insufficient time for the consultants to explain the purpose and objectives of the study to the employees. It is natural that the behavior of the employees will change to a certain degree when there are outside observers present. Thus, certain type of actions that the employees normally perform in their tasks may have not been observed. Another constraint is the fact that this ergonomic evaluation was done in a one-day period. Some operations may have been missed, and a busy work pace was also excluded. Consequently, results from this ergonomic assessment should not be treated as equivalent to a detailed job analysis for ergonomics improvement.

4.5 Flow of Analysis

The ergonomic evaluation in this case study will flow from workstation to workstation while providing recommendations for ergonomic control measures in each. Following the evaluation of the shop floor, an ergonomics evaluation of the office area is included. To obtain and measure certain risk factors, the use of different equipment was necessary. This procedure will be further discussed in Methods. Also, a detailed analysis of ergonomics risk factors and control measures will be given in Chapter 6 of this paper. Finally, Chapter 7 will discuss general ergonomics considerations that can be applied in a shop floor facility.

As a final word, the pictures shown in this report are meant to facilitate data analyses rather than fault a particular employee for his or hers work practices. We are also appreciative that employees were very cooperative in allowing us to take pictures while they were performing their jobs.

4.6 Methods

In order to perform the ergonomics evaluation, the following method was followed:

Procedure:

- Meeting with the Operations Manager
- A plant tour guided by the Operations Manager
- Plant walk through
- Station-by-Station ergonomics analysis according to the following steps:
  - Observation
  - Informal interviews
  - Measurements

Tools:

In order to quantify certain risk factors, measurements were taken using the following tools:

- Tape measure
- Video recording

- Still images
- Sound level meter

4.7 Risk Factors and Recommendations

Station-to-station evaluation:

Teflon (Pig Tail):

The crimper (Finn Power) machine is used to clamp fittings on the hose. The employee performs this task by holding the hose in between the machine as it is clamped. This procedure forces the employee to work in an awkward posture (as seen in Figure 4.1). A mirror was provided with the machine but made the task harder since detail observation of the hose as it is being clamped is difficult. An analog version of this machine provided easier view of the controls and access in holding the hose.

This posture has an ergonomics risk factor since both arms are constantly extended causing a static load to the shoulders, and the back is also slightly bended. Static work will lead to rapid muscle fatigue since its work durations are measured in seconds (Eastman Kodak Company, 1986). Static work impairs venous return, which is the amount of blood returning to the right side of the heart every minute. Therefore, the heart has to beat faster to compensate for the limited amount of blood it can empty into the aorta per beat (Eastman Kodak Company, 1986). The table below shows the maximum amount of time that a muscle can sustain a given percentage of its maximum strength (Eastman Kodak Company, 1986).

Table 4.1 Percent of Maximum Static Strength and Maximum Endurance Time

Source: Eastman Kodak Company (1986)

Percent of Maximum Static Strength	Maximum Endurance Time (Seconds)
100	6
75	21
50	60
25	204
15	>240

It is recommended that an alternative position for the crimper be found. The machine can be rotated 180 degrees so as to allow the employee easier access to the controls and hose during the operation. A rapid upper limb assessment model (RULA) was utilized to analyze this posture. Information on the posture of the employee and frequency of task is used to obtain an overall score that rates the job according to action levels. The results were obtained using the ERGO 2000 Software, and they indicate the need for further investigation. Also, general guidelines that have the goal of reducing static effort are given on a latter section of this paper.

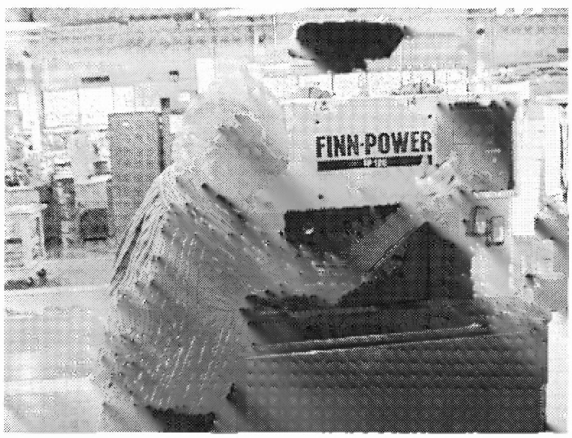


Figure 4.1 Employee Using the Crimper.

Another piece of equipment used by the same employee requires him to constantly swing a handle (see Figure 4.2).

The handle is low force but high repetition. It also positions the arm of the employee in an awkward posture causing stress to the shoulder, elbow and wrist. This is especially of concern in periods of high production to meet increased demands. This risk factor can lead to disorders called repetitive-motion disorders and its effects range from joint inflammation, muscle soreness, to nerve entrapment (Eastman Kodak Company, 1986). Of specific concern to this task is Bursitis. It is a common shoulder and elbow complaints associated with repetitive tasks as in working above chest height or with forward extended reaches (Eastman Kodak Company, 1986).

It is suggested to redesign the handle by reducing its size and/or changing its direction of motion.

Figure 4.2 Employee Swinging the Handle.

In another task, a fixture used to hold the fittings are constantly taken apart each time a fitting is placed.

This constant action from the employee causes unnecessary stress to his hands, wrists and fingers. This task can also be characterized as repetitive since this procedure is repeated continuously.

A solution to this concern is to connect the two halves of the fixture leaving one side open. This will minimize the motions required to re-construct the fixture. The connection could be made with a strong adhesive tape.

Whip Valve:

In this station, the employee uses a combination of an Allan wrench and power wrench to insert several hex screws. When interviewed, the worker explained that he used the power tool to insert the hex screws to a determined positioned. Afterwards, he finished the insertion using the Allan wrench with a determined torque (see Figure 4.3).

Figure 4.3 Employee Using an Allan Wrench to Insert Screws.

This task causes the worker much wrist and elbow movement combined with the repetitive nature of the task. The Rapid Upper Limb Assessment (RULA) model was applied to this posture; the results indicate that changes are required soon. Specifically, of concern are the wrists position and its repetitive movement, and the posture of the neck. Eastman Kodak Company (1986) gives the following general guidelines for hand tool design used in repetitive tasks:

- Design handles that make use of the maximum strength capability of the hand by featuring a power or oblique grip involving the palm. Avoid pinch grip requirements. Make handle diameters as close as possible to 3.75 cm (1.5 in.) and the span on double-handled tools from 5 to 6.25 cm (2 to 2.5 in.).

- Make handles long enough (about 10 cm or 4 in.) to avoid applying repeated pressure to the base of the thumb, as when using a putty knife or a paint scraper.
- Orient the tool handle so it does not have to be used with the wrist deviated markedly in either the ulnar or radial directions.
- Design tools to reduce the need to exert a sustained force on a cold and hard surface. Properly textured handles increase the feeling of control on a powered tool; handle material with low thermal conductivity may also be desirable for some tasks.
- Reduce the vibration from a powered hand tool, such as an electric drill as far as this is practical.

Using a power Allan wrench with torque and variable speed control can minimize these risk factors. Of concern in the use of small hand held power tools is the exposure of workers to repetitive forces necessary to hold the tool, engage the bit and resist the torque reaction forces (Pheasant and O'Neill 1975, Radwin et al. 1989, Cederqvist and Lindberg 1993). Also, repetitive exertion of force may be linked with fatigue and chronic muscle, tendon and nerve disorders (Hagberg et al. 1995). As mention further on in this paper, a torque arm attachment can partly absorb this inertia (Neelam, 1994). Furthermore, the power tool can be suspended in order to reduce its weight. Another observation is the constant use of the employee's left hand as a fixture in holding the part. A fixture with flexible and rapid adjustability will eliminate this problem.

Plastic Welding:

In this station, plastic welding was performed on parts. A tall employee was seen performing this task as seen in Figure 4.4.

The manner in which the work area is setup required him to constantly bend his back, neck, and deviate his wrists from the natural posture. Of particular concern is the stress on the neck caused by this poor posture. The neck is subjected to the continuous load produced by the weight of the head. It was also mentioned that a shorter employee also had difficulty in adjusting to this particular worktable.

Each worktable should be adjustable to the necessities of short and tall employees. The purpose behind this feature is to allow the employees to perform their tasks with a posture that closely approximates his/her natural stance. The vise could also be improved by designing it according to the type of parts that it will be used for. For example, the parts in this case are plastic and consequently of lightweight. These features should be considered when designing or choosing an appropriate vise.

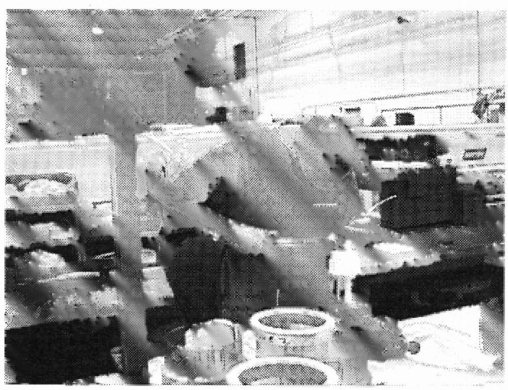


Figure 4.4 Employee Bending His Neck when Performing Task.

The RULA model was also applied to the posture exhibited by this employee. The results obtained indicate that investigation and changes are required soon (see Appendix A). The neck posture and position of the wrists are of immediate concern. Table 4.3 summarizes the RULA results.

Manual Handling:

Manual material handling is performed throughout the facility. Of specific interest to this ergonomics evaluation is the manual material handling of hose containers. It was observed that employees moved heavy hose containers. The lifting required the employee to bend his back in a potentially hazardous manner (see Figure 4.5a).

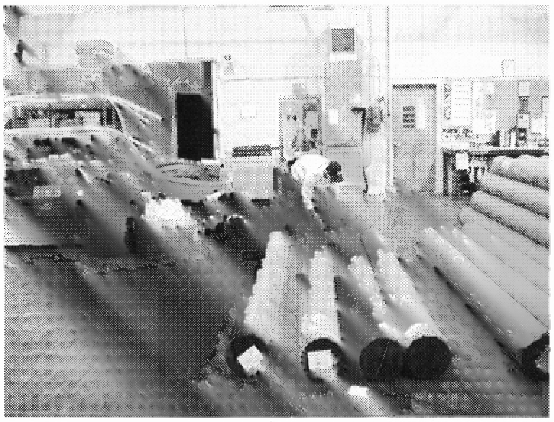


Figure 4.5a Employee Positions Himself to Move the Hose Containers.

In other instances, the employee is required to remove or stack these containers in shelves (Figure 4.5b).

Several factors influence the load placed on the spine during the performance of lifting and carrying objects (Lindh, 1980).

- The position of the load relative to the center of the spine.
- The degree of flexion or rotation of the spine.
- The characteristics of the object: size, shape weight, and density.

General Recommendations:

It is recommended that all worktables exhibit certain requisites. First, there should be adjustable so as to adapt to different workers height. Also, sharp edges (see Figure 4.6a) causes contact stress that could lead to injuries. It is also one of the risk factor to ergonomics problems. In this case the employees rest their forearms on the edges while performing their jobs. Therefore, it's advisable for all table edges to be smooth and round, or use durable rubber for padding.

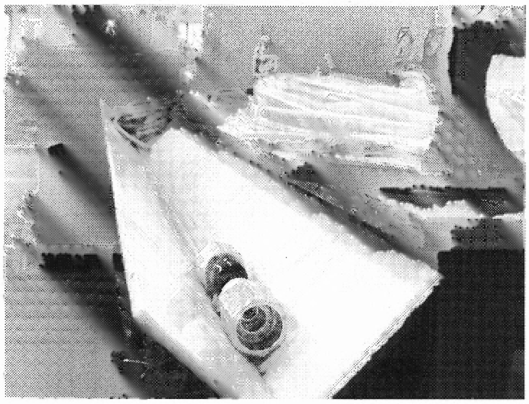


Figure 4.6a Sharp Edges Causes Contact Stress.

Seating should be provided for almost all workstations. Even if it's not used constantly, the employees should have them available. This will enormously reduce the stress on the feet and legs caused by standing the whole shift. The chairs should have back support, and could be of different models. For example, a stand stool model is suitable for employees whose jobs require frequent changes in position. Also, a stand stool used with a correct posture could be preferred over sitting since standing erect have lower relative compressive forces at the third intervertebral lumbar disc (L3) (Eastman Kodak Company, 1986).

In some areas it was noticed that material was positioned all over the work area (see Figure 4.6b). This can lead to trips, falls, contusion, abrasion, and sprain ankles with

There are several ways to implement these recommendations. First, installing rollers could reduce the force required to push in or pull out the containers. These rollers should have a locking mechanism to prevent the containers from accidentally slipping out. Also, methods for providing a good grip of the container should be considered. Finally, proper lifting techniques should be taught to all employees engaged in these tasks. For example, Figure 4.5a shows the awkward posture used to handle the container. Proper lifting techniques would require the employee to bend his knees and maintain his back as straight as possible in order to avoid possible injury. Konz and Johnson (2000) give the following guidelines for occasional lifting:

Select Individual:

1. Select strong people based on tests

Teach technique:

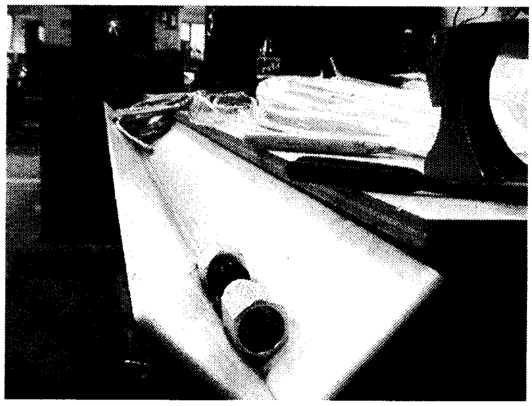
2. Bend the knees
3. Don't slip or jerk
4. Don't twist during the move

Design the job:

5. Use machines
6. Move small weights often
7. Get a good grip
8. Put a compact load in a convenient container
9. Keep the load close to the body
10. Work at knuckle height

General Recommendations:

It is recommended that all worktables exhibit certain requisites. First, there should be adjustable so as to adapt to different workers height. Also, sharp edges (see Figure 4.6a) causes contact stress that could lead to injuries. It is also one of the risk factor to ergonomics problems. In this case the employees rest their forearms on the edges while performing their jobs. Therefore, it's advisable for all table edges to be smooth and round, or use durable rubber for padding.



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Seating should be provided for almost all workstations. Even if it's not used constantly, the employees should have them available. This will enormously reduce the stress on the feet and legs caused by standing the whole shift. The chairs should have back support, and could be of different models. For example, a stand stool model is suitable for employees whose jobs require frequent changes in position. Also, a stand stool used with a correct posture could be preferred over sitting since standing erect have lower relative compressive forces at the third intervertebral lumbar disc (L3) (Eastman Kodak Company, 1986).

In some areas it was noticed that material was positioned all over the work area (see Figure 4.6b). This can lead to trips, falls, contusion, abrasion, and sprain ankles with potentially harmful consequences. A good housekeeping practice will increase workers safety and also work efficiency. The importance of good housekeeping is best explained by the following statements (Laitinien et al., 1997), "Good order is linked to many production aspects, such as reduction of work, equipment and material costs, savings of production times, better production quality and better company image. It also means a better working environment, better safety and better fire prevention. Thus industrial housekeeping is a concrete area, which both the management and the employees would like to improve."

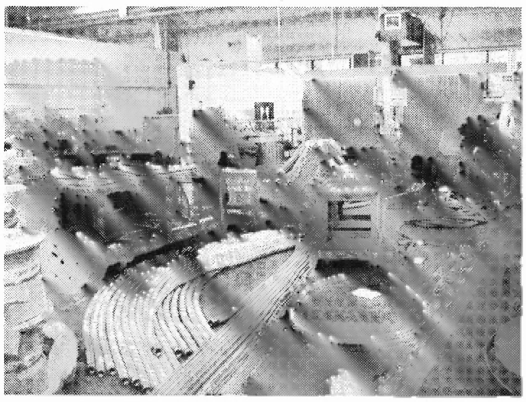


Figure 4.6b Good Housekeeping can Increase Workers' Safety.

Noise at the Quality Control Unit:

The purpose of ergonomics is to improve the overall work environment and fit the task to the worker. There are factors that although not directly related to musculoskeletal disorder still pose a significant safety issue. Noise is one of these factors since its excessive incidence can lead to employee error and safety concerns and is also considered a physical risk factor by some authors as indicated in Table 2.1. The shop floor as a whole reveals a considerable levels of noise. This noise level will fluctuate according to the type of operation performed by the employee.

In particular, the quality control station shows the highest level of noise. In this station the employee performs quality inspections by testing the hoses for water leaks. After the test is performed, the hose is dried out by means of pressurized air. The measurements taken during this process indicated levels of 86 to 98 dB. These levels varied according to the position where the noise was measured. In the area where the two workers are located and where they perform most of their daily tasks the noise level is the highest.

Noise is covered under OSHA's 29 CFR 1910.95. OSHA defines an unsafe noise level as continuous noise exposure above 90 dB on an eight-hour time-weighted average (TWA). Also, an 85 dB action level is required in the standard. With lower noise exposure levels there could be a reduction in worker performance and cause a hearing threshold shift. Irle et al. (1998) indicates, "But it is scientifically proven that noise exposure – even if they do not exceed the above mentioned rating level – are often annoying, disturbing, and performance-reducing, and furthermore, they cause considerable hearing threshold shifts." Also in agreement is Kryter (1985) who explains that at an exposure level over 65 dBA people will increase their hearing loss faster than it would from age alone.

The issue of threshold shift has been a current one with OSHA. The new recordkeeping standard that came into effect January 2002 was originally set to keep track of employee's threshold shifts of at least 10 dB. Opposition from various sectors has delayed the implementation of this particular section until 2003. It would be interesting to observe the final consensus between OSHA and industry on what constitutes a significant threshold shift.

Noise can have diverse effects on the workers. Konz and Johnson (2000) indicate that "Noise reduces comfort because the workers must increase their concentration; this tends to increase fatigue." Kjellberg (1990) indicates that there is no evidence that productivity is lower when the employee works under high-level noise unless he is also working at maximum mental capacity. Hartley, Boultwood and Dunne (1987) suggest that a 95-dBA-noise level helps when following written instructions and hurts when following pictorial instructions.

From the present evaluation, it is not conclusive whether OSHA's action level is met since the noise is intermittent and noise levels were not recorded for the entire shift, but implementation and enforcement of a hearing protection plan is highly recommended. A more detailed noise evaluation could establish the actual TWA noise exposure. A sign indicating the use of ear protection was seen but only one of the workers was observed wearing hearing protection.

Engineering and Administrative controls should be applied to reduce the noise levels but if these are not feasible then a strictly enforced personal protective equipment program should be established. Thus, the employees should be trained in hearing protection awareness and required to wear personal protective equipment.

The tables in the following page summarize some of the findings. Table 4.2 recapitulates the risk factors/safety-concerns station-by-station. Table 4.3 shows the RULA results for the tasks previously discussed.

Table 4.2 Summary of Risk Factors/Safety Issues Found at the Shop Floor

	Awkward Posture	Contact Stress	Repetitive Work	Noise	Housekeeping
Quality Control				X	
Teflon (Pig Tail)	X	X	X		
Whip Valve	X	X	X		
Plastic Welding	X	X			
Manual Handling	X				
All areas				X	X

Table 4.3 Summary of RULA Results

TASK	RULA Grand score	Action Necessary	Area of immediate concern
Clamping operation on the crimper	4	Further investigation is needed.	Neck and trunk posture.
Whip valve	6	Investigation and changes are required soon.	Wrist and neck posture.
Plastic welding	6	Investigation and changes are required soon.	Neck posture.

Office Ergonomics:

In order to perform an ergonomic evaluation of the office area a few of the VDT workstations were observed. This will suffice for an adequate evaluation since most of the VDT workstations have similar configurations. The amount of usage of a VDT workstation dictates the stage of ergonomics interventions that should be incorporated. Thus, an employee that performs intense computer usage should have a higher level of ergonomics design into his/her workstation than an employee that performs light usage. A full ergonomic VDT design should consider the following:

Keyboard:

The prevalence of musculoskeletal disorders amongst keyboard users has been reported to be as high as 81% (Kamwendo et al., 1991). There are several recognized hazards associated with keyboard use. These include duration of time between rest breaks and duration of computer use (Bergqvist et al., 1995; Smith and Carayon, 1996). The height of the keyboard is a physical factor that affects work posture (Hunting et al., 1981; Bergqvist et al., 1995). Also, several authors have reported that age and gender have an effect on symptom prevalence (Knave et al., 1985; Rossignol et al., 1987; Stock, 1991; Hales and Bernard, 1996).

A keyboard drawer should be installed underneath the desk whenever possible. This will allow a more natural posture of the hands when typing. It will also give more table space between the monitor and the keyboard. Furthermore, adapting one of these keyboard drawers is possible in the majority of desks as shown by Figure 4.7.

Figure 4.7 A Keyboard Drawer can Easily be Installed on this Desk.

Mouse:

Computer mouse usage accounts for up to two-thirds of computer operation time, depending on the software used and the task performed (Karlqvist et al., 1994). It is recommended that a trackball (see Figure 4.8) or touch pad be used instead of the conventional mouse for intensive computer use. The concern lies in the physical cost of repetitive mouse usage and wrist posture since it has been suggested that mouse use may be related to musculoskeletal discomfort and injury (Pascarelli and Kella, 1993). Of specific concern are the working postures of wrist extension and ulnar deviation (Karlqvist et al., 1994; Fernstrom and Ericson, 1997; Cook and Kothiyal, 1998; Burgess-Limerick et al., 1999).

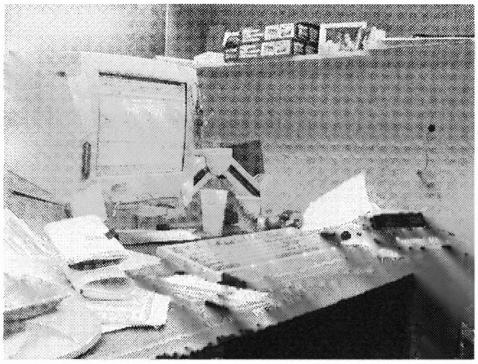


Figure 4.8 Poor Monitor Positioning.

Telephone:

Some employees require the constant use of the phone and computer in concert. This leads to an awkward posture of the neck as the employee juggles with the phone while typing on the computer. Using a hands free phone set can easily solve this problem. Another but less desirable alternative would be the use of a shoulder rest as seen in the figure below.

Figure 4.9 Phone with Shoulder Rest.

Desks:

Most of the desks observed have sharp edges (see Figure 4.10). This can aggravate the tendons and blood vessels of the forearm. Therefore, desk with round or padded edges are highly recommended. What's more, there are commercially available solutions for padding the sharp edges.

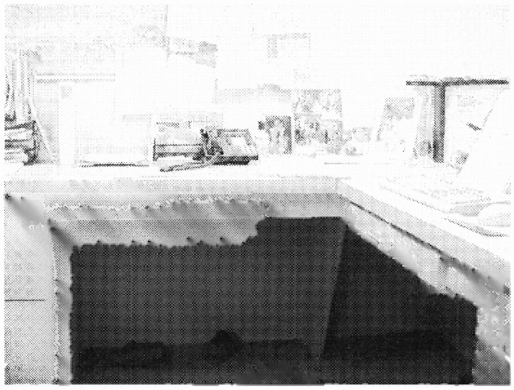


Figure 4.10 Sharp Edges on the Desk Should be Avoided.

Chairs:

The chairs observed were good. They had lumbar support and height adjustability. Some of the issues are that for taller or shorter workers the lumber support would not correctly be used since it is not adjustable. Shorter employees may also experience contact stress in the inner side of the thigh due to the seat depth. Special attention has to be given to the short and tall employee population.

Another issue of concern is the physical effects of prolonged sitting. Prolonged sitting may lead to swelling of the lower extremities, especially in constrained postures (Winkel, 1981; Stranden et al., 1986). A solution to this problem is to have office chairs, which permits variations in seat angle. Deursen et al., (2000) writes, "A locked seat mechanism does not prevent activation of the vein pump mechanism, but the indications are that office chairs which permit variations in seat angle per se stimulate movement of the legs. This, in turn, activates the vein pump and counteracts formation of local oedema in seated working postures."

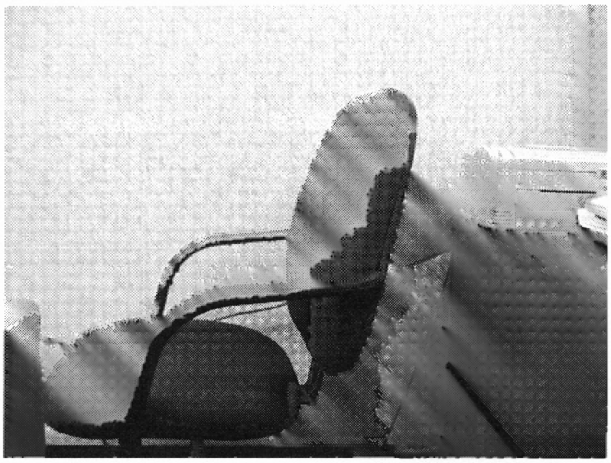


Figure 4.11 Chairs Should Exhibit Adjustability Features.

Monitor:

The monitor should be positioned so as to reduce the need for the employee to look up. The ideal position has the view of the monitor at a small angle below the horizontal line of sight. Some authors have argued that monitors should be located at least 15 degrees below horizontal eye level (Ankrum and Nemeth, 1995). These same authors also indicate that adopting postures involving relatively extended head or neck for prolonged periods is likely to lead to discomfort. Therefore, lowering the monitor increases the range of comfortable head and neck postures that can be adopted while allowing gaze angles that are comfortable for the visual system (Ankrum and Nemeth, 1995).

Monitor stands or support arms should be used with caution since they tend to elevate the monitors significantly. The monitor swivel stand, in this case study, that originally came with the monitor can be removed to reduce the monitor height (see Figure 4.9).

Other recommendations deal with the general layout of the office furniture. The furniture should not only consider the space available but also the physical limitations of the worker. For example, positioning the cabinet seen in Figure 4.12 will make it difficult for shorter employees to use.

Figure 4.12 Furniture Positioning Should Consider User.

CHAPTER 5

ANALYSIS OF RESULTS

5.1 Case Study Results

This ergonomic evaluation served as a preliminary assessment of potential risk factors. Wherever a risk factor was found, recommendations where given. These suggestions can be applied immediately and with low cost to the employer. Further ergonomic analysis can be performed in order to detail specific concerns or issues.

The first step in any ergonomics program is training. Presently, it was observed a lack of education on the part of workers and managers on ergonomics risk factor recognition and control. Employees are skilled in performing their tasks and have consequently established work priorities. These priorities are based on high work efficiency, and minimization of the energy consumption needed in performing a task. Therefore, a very minimum use of personal protective equipment like hearing protection and gloves was seen throughout the evaluation. More to the point, the employees weren't aware of ergonomics problems as exemplified in the work postures used in several workstations. Thus, employees need to be educated about ergonomics problems and how to avoid the risk of MSDs.

Managers and supervisors need also to receive ergonomics training immediately. This training will educate them in recognizing risk factors and taking appropriate measure in controlling them.

This paper will further discuss ergonomics interventions that can be implemented in any shop floor layout type of facility.

5.2 Usefulness of the Case Study Results

The results obtained in the case study are particular to one facility. Nevertheless, shop floor facilities share many of the characteristics that make them different from the assembly line facility. Thus, the understanding and analysis of the results obtained are of great importance if general guidelines are recommended for the shop floor. This paper will further discuss the characteristics of the assembly line and the shop floor. From this discussion, an ergonomic program for the shop floor is recommended based largely on the results obtained from the case study.

CHAPTER 6

COMPARISON OF THE SHOP FLOOR AND ASSEMBLY LINE FACILITIES

6.1 Characteristics of the Assembly Line Facility

Assembly work, most people would agree, tends to be fast paced, short cycled, and monotonous. Furthermore, workers have little opportunity in decision-making, work planning, or work content (Pack and Buck, 1992). Bullinger, Rally and Schipfer (1997) explain: "In addition to the resulting monotony on the psychological side, the physical demands lacks the variation in position and type of movement necessary for good health." Therefore, an employee performing his daily work duties at an assembly line could suffer a high physical cost due to the high repetition and the inability to rest those muscle groups.

6.2 Shop Floor Characteristics

In contrast, a shop floor layout has its own unique characteristics. Although it can conserves some of the characteristics of assembly line work, like its high repetition and short cycle time, usually such tasks are not performed during the entire 8-hour workday. The employee has the opportunity in planning his workday according to the tasks that need to be performed. So, it is not unusual for the employee to perform diverse tasks as the workday progresses. For such work setup to be successful the employee needs to be skilled. Additionally, these factors contribute to employee work enrichment and satisfaction.

6.3 Differences Between the Shop Floor and the Assembly Line Facility

The contrast between both work systems is apparent. The psychological stressors present in assembly line work are not as pronounced is the shop floor. Many of the physical stressors are quite different in both systems. Mainly, the high repetitiveness and posture constraints prevalent in assembly lines are less pronounced on the shop floor. From an ergonomics perspective, it is desirable for the employee to work in such an environment. Desirable but not ideal since many of the risk factors are still present and the potential for multiple risk factors affecting the employee should be considered. For example, since the employee would perform different work task during the workday, he can also be exposed to various risk factors as different work tasks are performed.

The advantage over assembly line work lies in the fact that the employee would have the opportunity to rest the affected muscle group when the work task is changed. Yassi (1997) explains: "The focus of treatment of most repetitive strain injury is to rest the part with symptoms and to reduce soft-tissue inflammation. The most effective means of resting the affected part is to reduce or eliminate exposure to the ergonomic hazards associated with the disorder." Thus, if the employee were subjected to different risk factors as the work task changed, the periods away from certain risk factors would serve as a rest breaks for that particular body area. Therefore, an inadvertent control measure is present when employees rest worked muscle groups. There are also negative features of working in the shop floor. Besides the potential for multiple risk factors exposure, there is also the important consideration of workforce shortage. The shop floor worker is highly skilled and therefore the pool of candidates that can fill his position is small. In case of labor shortage, other employees within the shop floor would have to fill the absentee employee position causing greater physical stress to them. This is another reason why management should protect its workers from ergonomic hazards.

6.4 Control Measures for the Shop Floor

In order to recommend guidelines for an ergonomic program at a shop floor facility, there is the need first to describe the type of risk factors and body area affected by these factors. From this information, further steps can be taken on creating a program that will consider the unique characteristics of the shop floor facility.

6.4.1 Body Area Affected

The control measures that can be implemented will differ according to the body limb affected. In the shop floor, as in the assembly line, there are specific muscles, ligaments, nerves and tendons that can be affected by cumulative trauma. These areas of interest are:

- Hand and wrist
- Upper limb: shoulder, neck and elbow, and
- Back

Hand and wrist: The main areas in which engineering solutions can be applied are: repetition and duration, joint deviation, and force (Konz and Johnson, 2000). Repetition has a greater influence over the occurrence of carpal tunnel syndrome than force does (Armstrong et al, 1985). Therefore, the objective is to reduce the overall use of the joints during a lifetime of work (Konz and Johnson, 2000). On the shop floor, many times, the risk factor of repetition is of greater concern than force is. For example, in the case study, it was observed that an employee performed a continuous lowering of a handle of insignificant force (see Figure 5.2). Another example seen in the case study was the employee using the Allan wrench to insert screws at a specific torque (see Figure 4.3). In both of these cases the ergonomics interventions are simple and straightforward. In the first case, a solution is to use a foot-operated control or change the direction of the handle as mentioned in the case study. In the second case, the use of a power Allan wrench with torque and variable speed was recommended. Also, there are other ergonomics issues that should be considered when implementing these ergonomics interventions. The idea is not to introduce new ergonomics hazards when implementing control methods. In general, tools should be designed so as to reduce the potential for repetitive-motion disorders. The Eastman Kodak Company (1986) gives excellent guidelines for hand tool design as described previously in the case study.

Joint deviation is another important factor of concern when dealing with ergonomics on the shop floor. The aim is to keep the wrist in the neutral position. Many times, the operator will have to work on specific tasks that require hand deviations. The use of proper fixtures is one of the solutions that can minimize this problem. The fixture has to be able to adjust properly to the piece being worked on and also regulated to the specific needs of the employee. Another ergonomics solution for joint deviation is the use of proper tools. On the shop floor many employees will utilize several tools during the workday since their jobs require them to work at various tasks. Thus, it is greatly desired to use tools with a proper design in order to minimize potential hand injury. In addition to the Eastman Kodak Company (1986) design guidelines presented earlier in this paper, Helander (1995) presents the following guidelines for hand-tool design:

For precision grip:

- Grip between thumb and finger.
- Grip thickness 8 to 13 mm
- Grip length minimum 100 mm
- Tool weight maximum 1.75 kg.
- Trigger activated by distal phalanges of finger(s) with fast-release locking mechanism.

For power grip:

- Grip with entire hand.
- Grip thickness 50-60 mm.
- Grip length minimum 125 mm.
- Grip force maximum 100 m.
- Grip shape non-cylindrical; preferably triangular with 110 mm periphery.
- Tool weight maximum 2.3 kg, preferably about 1.2 kg.
- Trigger activated by thumb with locking mechanism.

General guidelines:

- Grip surface smooth, slightly compressible and non-conductive.
- Avoid vibration, particularly in the range of 50 to 100 Hz.
- Design handles for use by either hand.
- Keep the wrist straight in handshake orientation.
- Tool weight balanced about the grip axis.
- Eliminate pinching hazards.

Finally, force is also a concern in the shop floor although not to such a large extent compared to the assembly line since in the latter there is a greater frequency. A situation where force can be present is when an employee will use a tool, especially a power tool that can exert an unwanted weight on the hand and wrist. The tool can be suspended and balanced thus considerably reducing its weight. Also, in the case of a power tool with torque control there is an unwanted inertia present when the tool automatically shuts off at a preset torque. The inertia will be absorbed in the operators' hand (Konz and Johnson, 2000). A torque arm attachment can partly absorb this inertia (Neelam, 1994). Gloves can also reduce the force required to grip an object. The downside to gloves is that control of the object is reduced, thus a greater force needs to be exerted if the same control is desired (Konz and Johnson, 2000).

Upper limb: Shoulder, neck and elbow: Shoulder pain is one of the most common in clinical frequency second only too low back and neck pain (Sommerich et al., 1993). According to Konz and Johnson (2000) the disorders can be related to:

1. tendons

- rotator cuff tendinitis
- calcific tendinitis
- bicipital tendinitis
- tendon tear
- bursitis

2. muscular shoulder pain
3. nerve-related disorder (suprascapular nerve)
4. neurovascular disorder (thoracic outlet syndrome)

The job tasks that are specifically at risk for these disorders in the shop floor, as seen in the case study, are assembly workers, welders, and workers who perform their tasks on certain machines that require the arms to be extended and raised. It is known that work at shoulder height compared to work below shoulder height increased the risk of rotator cuff tendinitis by 1100% (Hagberg and Wegman, 1987). As with the guidelines given for hand and wrist, engineering solutions can also be applied to repetition and duration, joint deviation, and force.

Repetition in the shop floor layout will be quite different than the assembly line. In the former, repetition is an issue mainly when the employees use hand tools. This use will not only affect hand and wrist but also the elbow. Repeated use of the elbow requires repeated lower arm movement leading to considerable energy expenditure (Konz and Johnson, 2000). The primary ergonomics concern is when frequent use is accompanied by extreme deviations or considerable force (Konz and Johnson, 2000).

Duration is a risk factor of importance mainly in static work. It was observed in the case study that employees engaged in postures that caused a static stress on the shoulders. Eastman Kodak Company (1986) explains that: " In the design of jobs, reducing the static component of any task can prevent local muscle fatigue from limiting productivity." The following guidelines given from Eastman Kodak Company (1986) for workplace and job design have the goal of reducing static effort:

- Avoid the placement of displays so that rigid location of the head or eyes is required to monitor the output.
- Avoid reaches or lifts above 127 cm (50 in.).

- Avoid forward reaches more than 50 cm (20 in.) in front of the body when standing or 38 cm (15 in.) in front of the body when sitting.
- Design standing workplaces to avoid stretching or stooping.
- Provide seating or supports for leaning for people who must work on their feet much of the day. Provide adequate foot support at seated workplaces.
- Reduce force requirements on controls that have to be operated rapidly (>10 times per minute) or held for periods in excess of 30 seconds.
- Design foot pedals to reduce the need to keep a constant pressure on the pedal during an assembly operation.
- Provide rest breaks within highly repetitive tasks.
- Provide aids such as carrier bags or carts for carrying tasks taking more than one minute and involving objects weighing more than 7 kg.
- Use jigs and fixtures to reduce the requirement for holding in assembly tasks.
- Whenever possible, provide handles or handholds on objects to be lifted or carried.

Another problem observed in the case study are postures that have the potential to cause neck disorders (Figure 4.4). The neutral positions for the neck is facing forward and slightly bend downward at an angle of 10-15 degrees (Konz and Johnson, 2000). Neck flexion of over 20 degrees is a risk factor that will cause neck disorders in electronic assembly (Kilbom et al., 1986). A solution to these types of problems is to have an adjustable worktable and/or seat that can be easily adapted to the physical characteristics of diverse employees.

Neck disorders can also arise in the office area of the shop floor. Office workers that hold the phone between their head and shoulder are at risk for a sore neck and possible future complications. Solutions to these problems are simple and reliable. A headset could completely eliminate the need for this type of poor postures. Video display terminals (VDT) should also be positioned correctly in order to avoid neck disorders. VDT and document holders should be positioned so the gaze is down and ahead rather than horizontal and to the side (Konz and Johnson, 2000). Poor posture is a problem that can affect multiple areas of the body. Van Wely (1970) gives the following table for work postures and related complaints:

Table 6.1 Postured Used and Related Physical Complaint

Source: Van Wely (1970).

Posture	Complaint
- Standing.	- Feet, lower back.
- Sitting without lower back support.	- Lower back.
- Sitting without back support.	- Central back.
- Sitting without proper foot support.	- Knees, legs, lower back.
- Sitting with elbows on a high surface.	- Upper back, lower neck.
- Unsupported arms.	- Shoulders, upper arms.
- Head bent back.	- Neck.
- Trunk bent forward.	- Lower back, central back.
- Cramped position.	- Muscles involved.
- Joint in extreme position.	- Joints involved.

Force is a risk factor that will primarily be present in the weight of certain tools. This unwanted weight will cause a static load on the shoulder. Suspending the tools with balancers can reduce this weight considerably. Other issues that deal with force can also be present on the shop floor. When carts filled with the product are taken from one area to another the employee needs to exert a force in order to push the cart. It is recommended that push or pull be performed below the shoulder and above the hip. This is the range in which the muscles are the strongest (Konz and Johnson, 2000). In office settings where the employee usually won't work with heavy tools, just the weight of their arm is about 4.9% of body weight (Konz and Johnson, 2000). It is recommended that office employees use armrest when performing such activities as using a mouse.

Back: Back pain is the number one employee complaint. Khalil (1991) gives the following statistics:

- On any given day, 6,500,000 people in the United States are in bed with back pain.
- 75,000,000 Americans have back pain problems.
- In industrialized societies, 80% of working adults will develop back pain during their career.
- In the United States, only colds cause more physician visits than back pain. An estimated 50% of all chiropractor visits are due to low back symptoms.

Additionally, Snook (1991) presents a hierarchy of low back problems:

1. Low-back pain.
2. Low-back impairment, which is reduced ability to perform various musculoskeletal activities. About 11% of U.S. working population.
3. Low-back disability that is defined as time lost from the job or assignment to restricted duty. About 2% of workers are affected with this disability each year.
4. Low-Back compensation, which is economical reimbursement for medical cost and lost wages.

Khalil (1991) also gave the following risk factors for low-back pain:

- Individual risk factors, for example: weight, physique, age, gender, and flexibility.

- Psychological factors, for example: depression, anxiety, and job dissatisfaction.
- Task demand factors, for example: posture, speed, repetition, twisting, prolonged sitting and standing.
- Environmental factors, for example: workplace design, slippery floors, distractions, and bulky containers.

Back problems in a shop floor layout will deal primarily with material handling and sitting/standing postures. In the case study it was observed that employees continuously moved large containers from one area of the shop floor to the other. This work task is nearly inevitable and will almost always be present in any shop floor. Eastman Kodak Company (1986) lists the following guidelines for improving manual material handling:

- Provide ways to adjust the materials to be handled so that less lifting and more sliding can be done. For example, provide a levelator or scissors table to adjust the height of the load.
- Provide good handholds on containers or objects to be handled.
- Rotate people to a lighter job after one or two hours in a constant handling task.
- Provide carts and handling aids to support the weight of objects that have to be carried more than a few feet.
- Provide tools to help in applying forces with the hand.
- Provide space for in-process inventory in production line operations so time pressure does not drive the handler.

The actions required for manual material handling are carrying and lifting. Lifting, unlike carrying, requires a certain degree of forward rotation of the trunk

(Eastman Kodak Company, 1986). The high incidence of back problems during lifting is due to the stresses placed on back muscles, ligaments and intervertebral discs (Eastman Kodak Company, 1986). A solution is to train the employee in lifting techniques. Eastman Kodak Company (1986) explains the benefit of certain lifting techniques. They indicate that when a person lifts with the back straight and knees bent (squat position) part of the load passes between the knees an thus minimizes the lever arm. Also, "Moving the object closer to the center of gravity of the body reduces the forward-bending moment and results in less stress on the back and shoulder muscles." A summary of Mital et al., (1993) recommendations are given below:

- Two hands are better than one.
- Force capability goes down as it is exerted more often.
- Females are weaker than males – especially in pushing.
- Push at waist level rather than shoulder or knee level.
- Pull at knee level rather than waist or shoulder level.

Also, Konz and Johnson (2000) give the following guidelines for carrying:

- Minimize the moment arm of the load versus the spine.
- Carry large loads occasionally rather than light loads often. However, this minimization of energy cost increases stress on the back and thus may lead to back pain.

Office employees and other employees who perform their work task seated also experience back pain. Disc compression forces are higher when sitting than when standing erect. If the sitting posture used by the employee is poor then the disc compression forces could be higher than even those measured when standing with a flexed trunk (Eastman Kodak Company, 1986). The body mass responsible for this is the torso since it creates a forward-bending moment around the fifth lumbar/first sacral (L5/S1) vertebrate (Eastman Kodak Company, 1986). Thus, it is recommended that a backward inclination of the seat and/or lumbar support be used since it will reduce the forward-bending moment and disc pressure (Eastman Kodak Company, 1986). It is also important to point out that the seat needs to exhibit adjustability features since the body dimensions are so variable. It will be ineffective to have an excellent ergonomic seat with lumbar support for an employee whose height will make this feature useless. Depending on the type of task, either sitting or standing can be chosen in order to properly perform the task. Helander (1995) presents the following guidelines:

- If there is frequent handling and lifting of heavy objects, it is preferable to stand up. However, sit standing may be an option.
- For packaging, or other tasks where objects must be moved vertically below the elbow height, it is preferable to stand or sit-stand. A sitting posture will not be feasible since the hands are reaching downwards and the table cannot be put at a sufficiently low level without interfering with the operator's legs.
- If the task requires extended reaching it is sometimes preferable to stand or sit-stand, as the operator can reach further.
- Light assembly with repetitive movements is a common task in industry, and sitting is preferable. A table is necessary to organize part bins, fixtures and incorporate work aides and supports to relieve local body fatigue due to repetitive movements.

- For fine manipulation and precision tasks, the operator usually wants to support the underarms. Sitting is definitely preferred.
- Visual inspection and monitoring is best done sitting. The sitting work posture makes it possible to focus one's attention better than if standing.
- If the work task involves a variety of subtasks and also frequent moving around, it may be preferable to sit-stand, since the operator does not then have to get in and out of the chair.

6.4.2 Implementing a Health and Safety Program for the Shop Floor

The administrative and managerial characteristics of the shop floor are different than those present at the assembly line. Facilities with a shop floor layout tend to be smaller in size compared to assembly line facilities. Also, as mentioned numerous times in this paper, employees tend to be highly skilled and have better control over their work pace and work tasks. This is in agreement with a case study done by Laitinen et al., (1997) the author mentions, "The personnel of the workshop had thorough knowledge and skills in the special field of the workshop, which was the repairing of freight wagons."

Laitinen et al., (1997) case study was carried out in a metal workshop of the Finnish state railway company. Teams were organized which included members of management as well as employees. The author explains, "Every team designed and realized many technical innovations. Some of them both improved the ergonomics of the work and made it easier to maintain good order. Carts for hand tools, new stands for lifting devices, and new racks/transport crates for components were manufactured. The workers also built themselves new rest rooms. In some areas the workers changed the layout, and built new more ergonomic working areas." The table below summarizes the changes obtained in this case study (Laitinen et al., 1997).

Table 6.2 Technical Innovations Designed by the Teams
Source: Laitinen et al., (1997).

Innovation	Number of equipments	Effects on working conditions
Carts for personal hand tools	70	Easier to keep own tools in order and in good condition, easy to move tools to different work stations
Racks/transport crates for three different heavy components (buffer, function valve, fastening)	3x10	More ergonomic lifting posture, easier to keep good order
Stands for lifting devices	Many	Easier to keep good order
Pneumatic pushing device to move the wagons in the hall	5	Eliminated heavy manual pushing
Lifting table for installing components under the wagon	5	Eliminated heavy manual lifting tasks (hands above the shoulder)
Pneumatic device to remove the floor plate bolts of wagons	1	Eliminated heavy manual hammering in a bad position
Pneumatic device to remove and fasten the nuts of the wheels	1	Eliminated bent working postures
Lubrication table for components	10	Easier to keep good order, eliminated bent working postures
Hoisting bridge to lift for working high	2	Eliminated the (hazardous) use of ladders
Special lifting devices for buffer	1	Eliminated heavy manual handling
Rest rooms for use during pause time	10	More silent and cozy environment

The author further indicates that as a result of these technical innovations, "The percentage of sick leaves decreased from 12.8% in 1991 to 9.9% of the total working hours in 1994. The decrease was gradual and it seemed to follow the gradual expanding of the development project."

The author argues that the key for success when implementing ergonomics control measures is ownership or participatory ergonomics when applying work place improvements. He mentions, "A process, in which the workers themselves participate into developing their workstations, enhances the ownership of workplace improvements and thus the likelihood of implementing ergonomics successfully." Participatory ergonomics is best introduced through small group activities. Thus, an important feature in a successful ergonomic program in the shop floor is the interaction between management and employees through the implementation of small teams to evaluate and implement ergonomic control measures on the shop floor.

Some of the risk factors present at the assembly line are also present on the shop floor but less pronounced for the reasons mentioned above. In particular the mechanical risk factors will be present in both work settings. The psychosocial and physical factors will also be present in both work settings with the exception of cognitive stress that will tend to affect the shop floor worker to a higher degree. When considering the organizational factors, a marked difference can be observed between the assembly line and the shop floor. This is particularly true if the employee on the shop floor enjoys work enrichment and a certain degree of empowerment by scheduling his workday according to his pace and physical limitations. Individual risk factors and athletic activities and/or hobbies are a constant in both work settings and will not be discussed further since these are factors that cannot be controlled in the work environment. The table below summarizes the risk factors present in the assembly line versus the shop floor. The ergonomic risk factors are classified as High, Medium, or Low.

Table 6.3 Risk Factors in the Assembly Line vs. the Shop Floor

Ergonomic Risk Factors	Assembly Line	Shop Floor
Mechanical Hazards:		
- Repetitive motion	High	Low
- Static muscle load	Medium	Medium
- Awkward postures	High	High
- Mechanical stress	High	High
- Vibration	High	Low
- Temperature extremes	Medium	Low
Psychosocial and Physical:		
- Cognitive stress	Low	Medium
- Social relationships	Low	Medium
- Psychological factors	Low	Medium
- Administrative concerns	High	Medium
- Lighting	Medium	Medium
- Noise	High	Medium
Organizational Factors:		
- Excessive work rates	High	Low
- Duration of work	High	Low
- Externally paced work	High	Low
- Inadequate work breaks	High	Low
- Monotonous jobs	High	Low
- Job insecurity	High	Low

As Table 6.3 indicates, there are two main issues that should be considered when comparing ergonomics risk factors from the assembly line to the shop floor. First, most risk factors are present in both work settings and this is particularly true of mechanical factors. The key with this issue is that although risk factors are present in both layouts it is the degree of its presence that differs. For example, if an awkward posture is present in the assembly line there is a good possibility that this risk factor will continue to be present for the whole period of employment of that particular employee. In the shop floor, the awkward posture seen will not be present the entire shift since the employee will perform several tasks throughout the day. The downside of this benefit is that new ergonomic concerns can be introduced when the shop floor employee changes job task. Thus, the shop floor employee could be subject to two or more mechanical risk factors throughout his workday butt to a lesser degree than the assembly line worker. The second issue that separates the assembly line worker with the shop floor employee is the organizational factors. Assembly lines can be highly paced work environments with little opportunities to recover those muscles involved in the work task. The assembly line also offers little job satisfaction to the employee since it creates a monotonous work environment with little opportunity for job empowerment. Further, the assembly line worker is not a highly skilled employee and thus can be easily replaced. Job insecurity will affect the assembly line worker to a much higher degree. Any safety and health program tailored to the needs of the workshop worker will definitely need to consider these two issues in order to be successful.

So far, this section has discussed the benefits of participatory ergonomics and the main differences between the assembly line and the shop floor worker regarding ergonomic stressors. Tasks that teams should perform during participatory ergonomic include recommendations for work area redesign. There is research showing that ergonomic modifications of jobs and workstations ease risk factors (Wick, 1987). Kadefors et al., (1996) show that an analysis of two similar tasks in the automotive industry with ergonomic different work methods demonstrated a clear difference in postural and musculoskeletal strain for the benefit of ergonomic. Also, several studies show that ergonomic modifications have positive short-term effects on productivity and quality (Helander and Burri, 1995; Nagamachi, 1995; Wick, 1987). Long-term results from ergonomic interventions are also beneficial. According to one study, an ergonomic intervention helped reduce absenteeism due to musculoskeletal problems substantially in a 17 year long before-after study (Aaras, 1994).

The following steps for ergonomic success in a shop floor work setting are recommended:

1- The use of participatory ergonomics through the use of small teams that includes members of management and workers.

2- These teams will evaluate and recommend changes to the workstations. Changes will focus on technical modifications through the use of engineering controls.

3- Monitoring the control measures and feedback from the workers themselves is also necessary.

4- This process continuously receives feedback and loops according to the necessities of the shop floor.

The above recommendations should be an important feature of the safety and health program for the shop floor. A successful Safety and Health program will need to have the following features:

- Management training and commitment to safety and health.
- Employee training and participation.
- Hazard recognition, evaluation, and control.
- Medical program.
- Program monitoring and evaluation.

Management training and commitment to safety and health: The size and production capabilities of the shop floor facility is smaller than the assembly line; hence most facilities of this type would not be able to afford a full time safety professional. Therefore, this responsibility has to fall onto the managers and floor supervisors. They will need to be properly trained in safety and health including hazard recognition and henceforth train workers of potential risk factors. If it's not economically feasible to train management then other solutions should be found. A good alternative is for several shop floor type facilities to network and use the services of a single consultant. The consultant in this case will be responsible to evaluate different facilities belonging to the participating companies. From an ergonomic standpoint, managers and supervisors will need to be able to recognize risk factors on the shop floor. Training of management personnel will not suffice if there is no serious support and commitment from company corporate officers. So, a forthright safety and health philosophy has to trickle down from upper management. Once there is commitment from above, lower management and floor supervisors have to continually insure that company policy is being followed. The National Safety Council (2001) gives the following objectives for a good occupational health program:

- Promote health and protect employees against hazards in their work environment.
- Facilitate placement and ensure that individuals are assigned work that matches physical and mental capabilities and that they can perform with an acceptable degree of efficiency without endangering their own health and safety or that of their fellow employees.
- Promote adequate health care and rehabilitation of employees injured on the job.

- Monitor the work environment for hazards and abate them.
- Encourage workers to maintain their personal health.

It will be the obligation of managers and supervisors to promote company policy and to seek active participation from all employees. NIOSH (1997) lists the following responsibilities for employers:

- Providing education and training to employees regarding the recognition of the symptoms and signs of work-related musculoskeletal disorders and the employers' procedures for reporting them.
- Encouraging employees' early reporting of symptoms and prompt evaluation by an appropriate health care provider.
- Giving health care providers to become familiar with jobs and jobs task.
- Modifying jobs or accommodating employees whom have functional limitations secondary to work-related musculoskeletal disorders as determined by a health care provider.
- Ensuring, to the extent permitted by law, employee privacy and confidentiality regarding medical conditions identified during an assessment.

The privacy issue mentioned above is now a current practice under OSHA's new recordkeeping standard.

Employee training and participation: As mentioned before, shop floor employees will tend to be skilled and have some control over their job pace and work content. These employees will feel very comfortable with their work practices since it is an acquired skill that most likely took many years to learn. Hence, shop floor employees are highly confident of their work procedures and will have a tendency to resist changes. Any training program in order to be successful has to take this fact into consideration.

To initiate an employee-training program, all employees have to be trained in safety and health hazard recognition. For ergonomics hazards, employees should be trained in risk factors recognition, ergonomics awareness, CTD symptoms recognition, and proper reporting procedures. It's always a good investment to train employees in safety and health especially in industries that have a low turnover rate like the shop floor will tend to have. NIOSH (1997) enumerates the following objectives for ergonomics awareness training:

- Recognize workplace risk factors for musculoskeletal disorders and understand general methods for controlling them.
- Identify the signs and symptoms of musculoskeletal disorders that may result from exposure to such risk factors, and be familiar with the company's health care procedures.
- Know the process the employer is using to address and control risk factors; the employee's role in the process, and ways employees can actively participate.
- Know the procedures for reporting risk factors and musculoskeletal disorders, including the names of designated persons who should receive the reports.

After this initial training is performed, further training will be needed to refresh acquired knowledge and also when certain conditions arise. The National Safety Council (1992) gives the conditions under which a safety-training (refresher) program is needed:

1- For all new or reassigned (transferred) employees.

5- When new equipment or processes are introduced.

6- Whenever procedures are revised or updated.

7- When new information is available or required.

8- When employee performance needs improvement or to provide employee growth.

9- When employee interest in safety and efficiency needs a boost.

Additionally, The National Safety Council (1992) also provides a list of red flags that will indicate or alert when training is needed.

1- Proportionately higher accidents or injury rates than other companies that do the same type of work.

2- Increasing accidents rates and/or insurance rates.

3- High employee turnover.

4- Excessive waste and/or scrap materials from operations.

5- Recent company expansion or procedural changes.

6- Increased or high levels of sick days.

7- Changing regulatory requirements.

8- Need to upgrade or update employees' knowledge and/or responsibilities.

9- Poor job satisfaction.

A properly trained employee also has certain responsibilities. NIOSH (1997) lists the following responsibilities for employees:

- Employees should follow applicable workplace safety and health rules.
- Employees should follow work practices procedures related to their jobs.
- Employees should report early signs and symptoms of work-related musculoskeletal disorders.

Employee responsibilities have limited practical use since OSHA and most Workers Compensation programs have a no-fault policy concerning employees. In the case of OSHA, employee misbehavior is difficult to use as a defense against citation. In any case, the above list can be used as a reference and company policy can incorporate employee responsibilities among its rules and regulations. An incremental enforcement policy would also be necessary if strong responsibilities were placed on the employees and thus allowing the company to defend itself from an OSHA citation by alleging employee misconduct. These types of policy should not overlook the primary objective of any safety and health program; making the work place safe and free of any recognized hazards.

Training has its limitations and problems. Helander (1995) lists the following issues and concerns regarding training in manual lifting:

- There is usually a limited time effect of training. During the immediate time following training, trainees have a sense of enthusiasm and relevance. After a few weeks the information sinks back and is perceived as secondary to many other problems. People tend to revert to previous habits if training is not reinforced.
- One of the problems in teaching correct lifting techniques is the lack of feedback from the body itself while lifting. There are no nerve endings in the discs, which means the lifter is not aware of differences of disc pressure due to lifting technique. The trainee must then rely on feedback from the training instructor, peers and managers.
- Emergency situations that lead to back injury are difficult for an individual to control. As with other accidents, several different things occur simultaneously.

The individual must make quick decisions, and body movements cannot be controlled. The situation is quite different from planned, deliberate lifting that can be controlled. Therefore, if job requirements are basically stressful, behavior modification through training may not be successful. It is better to design safe jobs, where manual handling is less frequent.

Hazard recognition, evaluation and control: So far, it has been recommended that managers and workers be trained in hazard recognition. Once a potential hazard or ergonomics risk factor has been found, the job and/or job procedure has to be evaluated in order to properly determine the risk involved and ways to eliminate or reduce it through system redesign. In this step, active employee participation will be needed since these are skilled jobs that are understood best by the employees performing them. Thus, control measures will work best if both managers and employees participate in the hazard analysis process, as is the case with participatory ergonomics. Hazard analysis is a feature that is particularly important in shop floor layouts. The National Safety Council (1992) gives the following benefits for hazard analysis:

1- To identify hazardous conditions and potential accidents.
2- To provide information with which effective control measures can be established.
3- To determine the level of knowledge and skill as well as the physical requirements workers need to execute specific shop tasks.
4- To discover and eliminate unsafe procedures, techniques, motions, positions and actions.

In order for hazard recognition, evaluation and control to work properly there has to be a mutual feeling of trust between labor and management. This is a more difficult objective to achieve than it seems at first glance. There are several factors that could influence or affect the desired cooperation. Among these factors are the presence of organized labor, labor-management relations, and current collective bargaining efforts.

Medical program: In MSD there is specific physical sign and symptoms that the employee and health care professional need to be aware of. The Occupational Safety and Health Administration (OSHA) give the following definitions and examples for MSD signs and symptoms:

MSD signs: Are objective physical findings that an employee may de developing an MSD. Examples of MSD signs are:

1- Decrease range of motion;
2- Deformity;
3- Decrease grip strength; and
4- Loss of muscle function.

MSD symptoms: Are physical indications that an employee may be developing an MSD. Examples of MSD symptoms are:

1- Pain;
2- Numbness;
3- Tingling;
4- Burning;
5- Cramping; and
6- Stiffness.

The health care professional will have to evaluate the employee and decide if work restriction or transfer will be necessary. All the policies and procedures concerning health care need to be readily available to all employees. Any temporary work restrictions should guarantee the employee salary and benefits. This will not only help the employee in a time of need but also demonstrate that company policy is serious about protecting employees, thus boosting morale and work satisfaction.

According to the National Safety Council (1992), medical monitoring can include "health and work histories, physical examinations, X rays, blood and urine tests, pulmonary function tests, and vision and hearing tests. The aim of such monitoring is to find evidence of exposure early enough to identify especially susceptible workers and to detect any damage before it becomes irreversible." Additionally, NIOSH (1997) gives the following list of responsibilities for the health care provider:

- Acquire experience and training in the evaluation of work-related musculoskeletal disorders (WMSDs).
- Seek information and review materials regarding employee job activities.
- Ensure employee privacy and confidentiality to the fullest extent permitted by law.
- Evaluate symptomatic employees including:
    - Medical histories with a complete description of symptoms.
    - Descriptions of work activities as reported by the employees.
    - Physical examinations appropriate to the presenting symptoms and histories.
    - Initial assessment or diagnoses.
    - Opinions as to whether occupational risk factors caused, contributed to, or exacerbated the conditions.

- Examinations to follow up symptomatic employees and document symptom improvements or resolutions.

A good working relation between the employer and the health care professional is key if medical program is to succeed. The better the health care professional is familiar with the employees work tasks the better a treatment program can be tailored to that particular employee. Thus, it is a good idea for the health care professional to visit the shop floor and familiarize himself with the work tasks performed by the workers. This relationship is possible in the shop floor primarily because of its smaller size.

Program monitoring and evaluation: Once the safety and health program including any control measures are in place it will be necessary to monitor them. The main purpose is to perform a preliminary evaluation and verify that the program and/or changes made are actually working. If the ergonomics problems persist then further analysis can take place and other control measures implemented.

Managerial interaction with the employees in this process is necessary to properly evaluate the control measures. Also, the overall safety and health program needs to be evaluated to assure that the program as a whole is working properly and meeting the safety and health goals set by management. The Occupational Safety and Health Administration gives the following guidelines for program evaluation.

- Consult with your employees in the program, or a sample of those employees, and their representatives about the effectiveness of the program and any problems with the program.
- Review the elements of the program to ensure they are functioning effectively.
- Determine whether MSD hazards are being identified and addressed.

- Determine whether the program is achieving positive results, as demonstrated by such indicators as reductions in the number and severity of MSDs, increase in the number of problem jobs in which MSD hazards have been controlled, reductions in the number of jobs posing MSD hazards to employees, or any other measure that demonstrates program effectiveness.
- You must also evaluate your program, or a relevant part of it, when you have reason to believe that the program is not functioning properly.
- If your evaluation reveals deficiencies in your program, you must promptly correct the deficiencies.

All the parts of a good safety and health care program have to come together in perfect order for the program to function properly and achieve its objectives. It is the opinion expressed in this paper that a safety and health program is easier to implement in the shop floor than the assembly line. The following further explains this point:

- The shop floor is smaller in size and thus, a safety and health program will be easier to implement and manage.
- Shop floor workers are skilled and enjoy job satisfaction. These two attributes make these types of employees eager to conserve their jobs. Therefore, following safety and health regulations and/or being aware of ergonomics risk factors is an attitude that will lead to job security.
- Many of the social-economical issues present at the assembly line workforce like a transitory workforce, language barrier and cultural differences makes it difficult to successfully manage a safety and health program. These employees want to finish their days meeting work quotas and not necessarily worrying about safety

and health. These employees will tend to view their present work situation as temporary and therefore do not see the need for actively participating in the safety and health program. In larger assembly line facilities, it is the duty of the safety and health professional to make sure that the safety guidelines are followed and not necessarily that of the employees.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

Ergonomic hazards are an important issue that affects employees at their place of work throughout this nation and the world. In the United States and other industrialized nations, ergonomics related problems are extremely costly and affect a wide variety of workers. It can affect workers on the shop floor, assembly line, office areas, and many other types of work.

The ergonomics risk factors that of concern are: awkward postures, repetitive work, contact stress, and force. The consequences of these risk factors being present for a long period of time (weeks and months) can lead to cumulative trauma disorders or CTDs, as they are known. Examples of CTD are: tendonitis, carpal tunnel syndrome, hand-arm vibration and bursitis.

The shop floor facility exhibits certain unique characteristics that separate it from the assembly line. The shop floor employee is a skilled worker that has some control over his work pace and work content. The skilled employee usually will have the advantage of performing his task at a comfortable pace. Also, the employee generally will have several job tasks to perform. Thus, his workday enjoys a certain degree of work enrichment. These are the characteristics that must be considered when setting up a safety and health program that includes ergonomics. Another point to consider in shop floor facilities is the fact that employees will enjoy a certain level of job security since they are skilled workers and thus will tend to stay in the jobs for a longer period than assembly line workers. This issue is of concern since the ergonomic risk factors that can affect the shop floor employee could be present for the duration of his or hers work days.

In contrast, the assembly line employee usually will perform a single repetitive task throughout the workday. From an ergonomic standpoint, the work performed on the shop floor is preferred over the assembly line. There are several reasons this type of work is favored. Mainly, the shop floor employee has the advantage of using different muscles over the eight-hour workday. This benefit allows for certain muscles groups to rest and recuperate while other tasks using a different muscle are performed. Thus, the effects of certain ergonomics risk factors are minimized.

Also, there are organizational factors that can influence or aggravate the known ergonomics risk factors. The employee on the shop will usually exhibit a higher level of job satisfaction than the employee on the assembly line since the latter has little opportunity for work enrichment or empowerment. Therefore, the latter can have a greater risk for ergonomics hazards than the former. A potential downfall to shop floor work is that several risk factors can be present as the employee moves from one work task to another. Another problem that can occur in shop floor facilities is underreporting of injuries. This is a problem since ergonomic incidents can be viewed as isolated and therefore the bigger picture could be missed, as a consequence the extent of the ergonomic problems could be overlooked. These issues have to be considered when setting up a safety and health program on the shop floor.

To deal with these ergonomics risk factors, there are three main control measures. These are, in order of importance: engineering controls, administrative controls, and personal protective equipment. Engineering control should always be the first option since it will eliminate or substantially reduce the ergonomics hazard through system redesign. Administrative controls will follow and they deal mainly with job procedures and proper work rotation. Personal protective equipment should be used as a last alternative in situation when all other control measures are not possible or feasible to implement.

A case study was carried out at a plastic manufacturing facility. Based on the work being done at this shop floor facility and the literature review for ergonomics, recommendation were made on how to implement an ergonomics program on the shop floor. A successful ergonomics program for the shop floor has to take into consideration its distinctive characteristics. The use of participatory ergonomics to evaluate work place hazards and implement workstation redesign is strongly recommended. The benefits of this approach include better management-employee relations and the implementation of engineering controls by the people that understand the work best, the workers themselves.

The philosophy of participatory ergonomics must be an active part of the overall elements of a good safety and health program. The program should consist of the following: management training, employee training and participation, hazard recognition, evaluation and control, medical program, and program monitoring and evaluation.

Since most shop floor facilities will be of smaller size than assembly line facilities, it's important to properly train managers in safety and health. For ergonomics, proper recognition of risk factors is a must. Also, managers and floor supervisors should readily communicate to employees the proper ways to report potential problem jobs.

Management and supervisors should receive support and commitment from upper management in order for the program to succeed. This trickle down effect is necessary for the program to be viewed as serious and credible by all employees. The use of participatory ergonomics will increase enormously the level of credibility and acceptance from the employees.

Employee training and participation is especially important in a shop floor layout. As mentioned before, shop floor employees are skilled and thus will know their jobs better than anyone else. This will also include safety issues. With proper training employees will be able to recognize ergonomics hazards and promptly inform their supervisors. In the case of participatory ergonomics, the expertise of both managers and employees will be used to the fullest since teams conformed of both groups will continuously evaluate the shop floor for ergonomic and other safety concerns.

Once management and employees are correctly trained then hazard recognition, evaluation and control will come with greater ease. Hazard recognition will be done either by management or the employees themselves. If participatory ergonomics is implemented, then hazard identification and control is a mutual effort from management and workers. Hazard evaluation and control, in some instances, might require further expertise thus the need for ergonomics consultants may be necessary. An important way to minimize the expenses associated with hiring a consultant is for industry to work close with the universities and possibly organized labor. These institutions and organizations have the expertise of many professionals and students well acquainted with occupational health and safety. This relationship will considerably benefit the liaison between industry, academia, and other sectors interested in workers safety.

Once an employee is suspected to have the signs and symptoms of a cumulative trauma disorder, then proper medical evaluation will be necessary. Early medical evaluation is important since, as discussed previously in this paper, early medical intervention and diagnosis improves prognosis. A medical program should include a health care professional that is in constant communication with management and is familiar with the type of work tasks performed by the employees. This communication is important since temporary work restrictions for the affected employee has to be clearly and rapidly communicated to management. Thus, a strong and cooperative relation between the health care professional and management is desired.

The overall safety and health program should be monitored and evaluated regularly. This will insure that the control methods are working properly and that all the program elements are also giving satisfactory results. If any changes are necessary it is best if done as promptly as possible. The use of participatory ergonomics would facilitate considerably the ease in which the control methods are monitored and evaluated.

Safety and health hazards are potential issues that can enormously affect workers ability to perform their jobs and thus affecting their livelihood. Among other numerous incentives for achieving a safe workplace are workers compensation costs, public image, federal and state law, and a moral obligation to protect the one thing that makes everything possible for industry, it's workforce. Furthermore, it is also an issue that affects productivity and thus concerns the company bottom line.

There are several important limitations in this paper. First, the recommendations and conclusions are based on one particular case study. Although many shop floors will exhibit similar characteristics and thus similar ergonomic concerns, this study did not take into consideration the characteristics or ergonomic issues that might affect other facilities. Also, the observations made in the case study were done at a time when normal work pace was prevalent. Issues involving fast pace production and worker stress were not observed and therefore not considered in this paper. Furthermore, the case study was a one-day evaluation; proper interaction with the employees was not entirely achieved.

Finally, more research needs to be performed in this area since their will always be the need for the shop floor or workshop type of facilities. This issue is especially important in developing countries where the evolution from shop floor production to assembly line manufacturing has not completely taken place.

APPENDIX A

RULA RESULTS

The following pages are a computer output of the RULA analysis for the postures described earlier in this paper. The software used was ERGO 2000 (2000).

RULA Results for Crimper

RESULTS:

Posture Index

Group A (Arm, Wrist)	4
Group B (Neck, Trunk, Legs)	4

Frequency Score

Group A (Arm, Wrist)	0
Group B (Neck, Trunk, Legs)	0

Force Score

Group A (Arm, Wrist)	0
Group B (Neck, Trunk, Legs)	0

Total Score

Group A (Arm, Wrist)	4
Group B (Neck, Trunk, Legs)	4

Grand Score 4

ACTION:

Level	Score	Comment
1	1 - 2	Posture is acceptable if not maintained or repeated for long periods
2	3 - 4	Further investigation is needed; changes may be required.
3	5 - 6	Investigation and changes are required soon.
4	7	Investigation and changes are required immediately.

RULA Results for Whip Valve

RESULTS:

Posture Index

Group A (Arm, Wrist)	3
Group B (Neck, Trunk, Legs)	6

Frequency Score

Group A (Arm, Wrist)	1
Group B (Neck, Trunk, Legs)	1

Force Score

Group A (Arm, Wrist)	0
Group B (Neck, Trunk, Legs)	0

Total Score

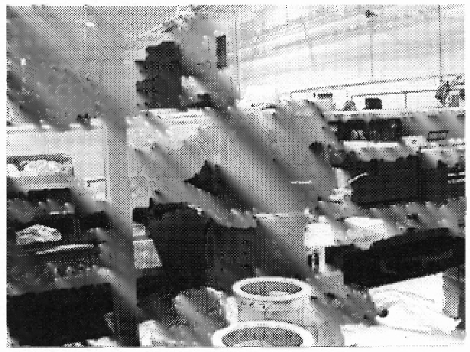
Group A (Arm, Wrist)	4
Group B (Neck, Trunk, Legs)	7

Grand Score 6

ACTION:

Level	Score	Comment
1	1 - 2	Posture is acceptable if not maintained or repeated for long periods
2	3 - 4	Further investigation is needed; changes may be required.
3	5 - 6	Investigation and changes are required soon.
4	7	Investigation and changes are required immediately.

RESULTS:



RULA Results for Plastic Welding

Posture Index	
Group A (Arm, Wrist)	4
Group B (Neck, Trunk, Legs)	5
Frequency Score	
Group A (Arm, Wrist)	0
Group B (Neck, Trunk, Legs)	1
Force Score	
Group A (Arm, Wrist)	0
Group B (Neck, Trunk, Legs)	0
Total Score	
Group A (Arm, Wrist)	4
Group B (Neck, Trunk, Legs)	6
Grand Score	6

ACTION:

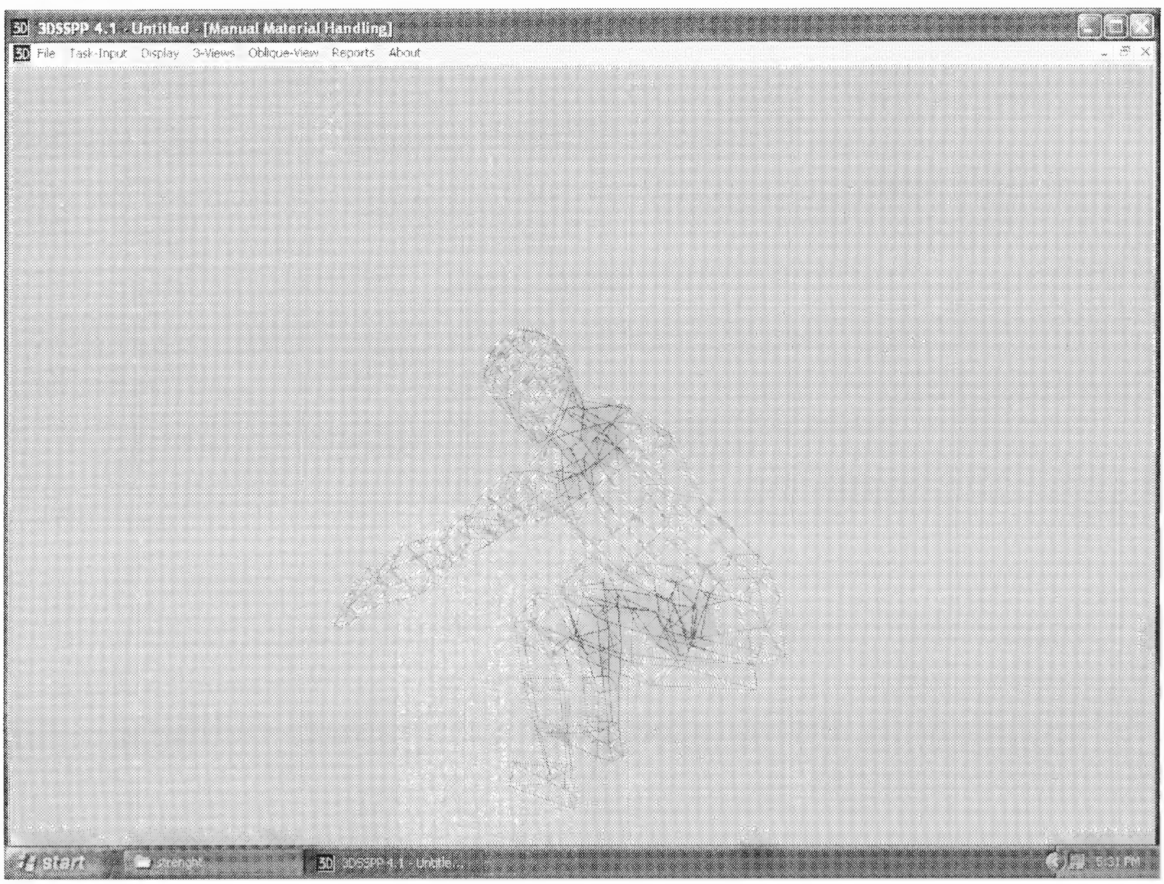
Level	Score	Comment
1	1 - 2	Posture is acceptable if not maintained or repeated for long periods
2	3 - 4	Further investigation is needed; changes may be required.
3	5 - 6	Investigation and changes are required soon.
4	7	Investigation and changes are required immediately.

APPENDIX B

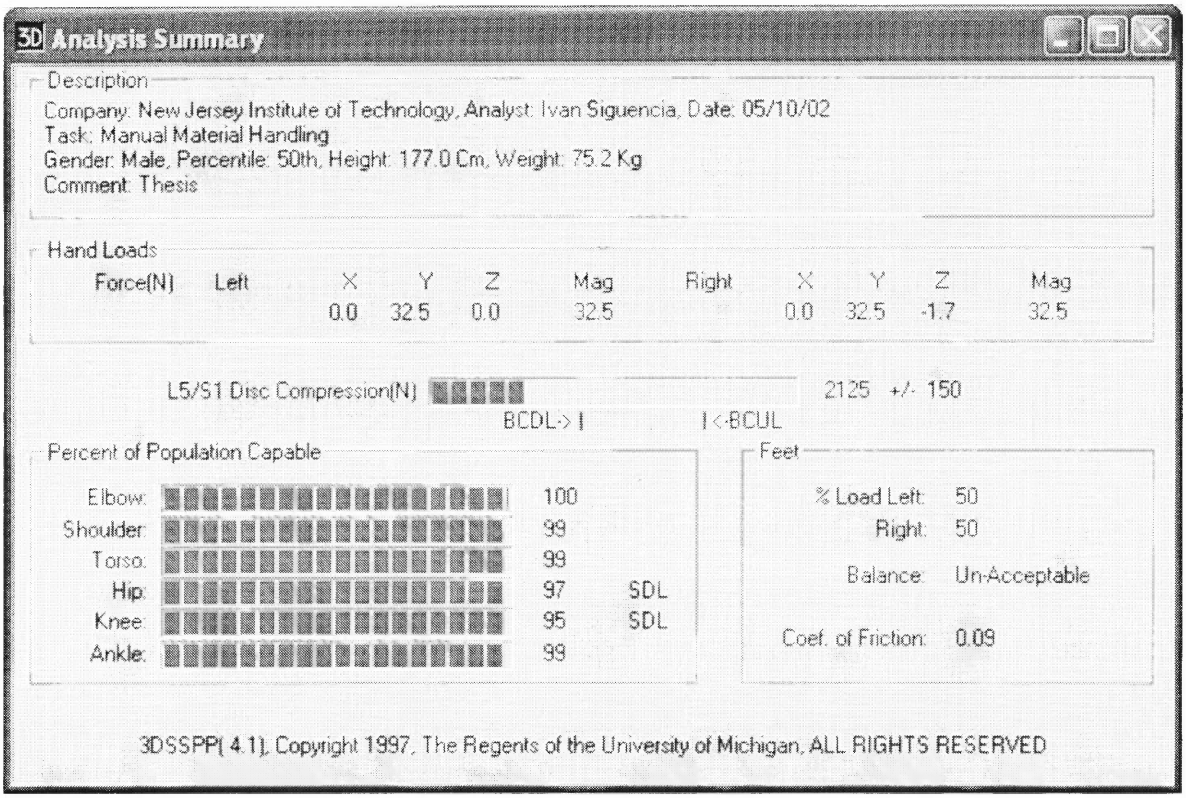
THREE-DIMENSIONAL STATIC STRENGTH PREDICTION PROGRAM

The following pages are the 3D static strength prediction program output for the posture of concern using the University of Michigan 3D SSPP software (1998).

3D Posture Required



Computer Output With Results



REFERENCES

Aaras, A., "The impact of ergonomic intervention on individual health and corporate prosperity in a telecommunications environment." *Ergonomics*, 37 (10), 1679-1696, 1994.

Ankrum, D.R., K.J. Nemeth, "Posture, comfort, and monitor placement." *Ergonomics in Design*, 3 (2), 7-9, 1995.

Armstrong, T., L. Fine, and B. Silverstein, "Occupational Risk Factors: Final Contract Report to NIOSH." No. 22-82-2507, Cincinnati, 1985.

Armstrong, T.J. and D.B. Chaffin, "Carpal tunnel syndrome and selected personal attributes." *J. Occup. Med.*, 21(7), 481-486, 1979.

Bergqvist, U., E. Wolgast, B. Nilsson, M. Voss, "Musculoskeletal disorders among visual display terminal workers: individual, ergonomic and work organizational factors." *Ergonomics*, 38 (4), 763-776, 1995.

Biggs, L., "The Rational Factory: Architecture, Technology, and Work in America's Age of Mass production." Baltimore and London: John Hopkins University Press, 1996.

Bigos, S.J., M.C. Battie, D.M. Spengler, L.D. Fisher, W.E. Fordyce, T.H. Hansson, A.L. Nachemson, M.D. Wortley, "A prospective study of work perceptions and psychosocial factors affecting the report of back injury." *Spine* 16, 1-6, 1991.

Bongers, P.M., C.R. de Winter, M.A.J. Kompier, V.H. Hildebrandt, "Psychosocial factors at work and musculoskeletal disease." *Scandinavian Journal of Work, Environment and Health* 19, 287-312, 1993.

Brogmus, G.E., G.S. Sorock, B.S. Webster, "Recent trends in work-related cumulative trauma disorders of the upper extremities in the United States: An evaluation of possible reasons." *J Occup Environ Med*, 38, 401-11, 1996.

Bullinger, H.J., P.J. Rally, J. Schipfer, "Some aspects of ergonomics in assembly planning." *International Journal of Industrial Ergonomics*, 20, 389-397, 1997.

Bureau of Labour Statistics, "Occupational injuries and illnesses in the United States by industry, 1991." U.S. Department of Labor, Washington, DC, bulletin 2424, 1993.

Bureau of Labour Statistics, "Workplace injuries and illnesses in 1993." U.S. Department of Labor, Washington, DC, USDL 94-600, 1994.

Burgess-Limerick, R., J. Shemmell, R. Scadden, A. Plooy, "Wrist posture during computer pointing device use." *Clinical Biomechanics*, 14, 280-286, 1999.

Carson, R., "Ergonomically designed tools: Selecting the right tool for the job." *Industrial Engineering*, 27-29, July 1993.

Cederqvist, T., and M. Lindberg, "Screwdrivers and their use from a Swedish construction industry perspective." *Applied Ergonomics*, 24, 148-157, 1993.

Chapanis, A., "Ergonomics in product development: A personal view." *Ergonomics*, 38, 1625-1638, 1995.

Chatterjee D.S., "Repetition strain injury – a recent review" *J Soc Occup Med*, 37, 100-05, 1987.

Cook, C., K. Kothiyal, "Influence of mouse position on muscular activity in the neck, shoulder and arm in computer users." *Applied Ergonomics*, 29 (6), 439-443, 1998.

Deursen, D.L., L.L.J.M. van Deursen, C.J. Snijders, R.H.M. Goossens, "Effect of continuous rotary seat pan movements on physiological oedema of the lower extremities during prolonged sitting." *International Journal of Industrial Ergonomics*, 26 (2000), 521-526, 2000.

Eastman Kodak Company, "Ergonomic Design for People at Work Vol. 2." John Wiley & Sons, Inc., 1986.

ERGO 2000, Holcomb Hathaway, Inc., Scottsdale, AZ, 2000.

Fernstrom, E., M.O. Ericson, "Computer mouse or track-point – effects of muscular load and operator experience." *Applied Ergonomics*, 28 (5-6), 347-354, 1997.

Flor, H. and D.C. Turk, "Etiological theories and treatments for chronic back pain. II: Psychological models and interventions." *Pain*, 19, 226-229, 1984.

Fordyce, W.E., et al., "Acute back pain: A control group comparison of behavioral vs. traditional management methods." *Journal of Behavioral Medicine*, 9, 127-140, 1986.

Funk and Wagnalls New World Encyclopedia, "Factory System." Funk and Wagnalls Corporation.

Gerr F., R. Letx, P.J. Landrigan, "Upper-extremity musculoskeletal disorders of occupational origin." *Annu Rev Publ Health,* 12, 543-66, 1991.

Guidotti, T.L., "Occupational repetitive strain injury." *Am Fam Phys*, 45, 585-92, 1992.

Hagan, P.E., J.F. Montgomery, J.T. O'Reilly, "Accident prevention manual, for business & industry: administration & programs 12th Ed." National Safety Council, NSC Press, Itasca, Illinois, 2001.

Hagberg, M., "Occupational musculoskeletal disorders – a new epidemiological challenge?" in C. Hogstedt and C. Reuterwall (eds), *Progress in Occupational Epidemiology* (Amsterdam: Elsevier), 15-26, 1988.

Hagberg, M., B. Silverstein, R. Wells, M.J. Smith, H.W. Hendrick, P. Carayon, M. Pirusse, "Work related musculoskeletal disorders (WMSDs): A reference book for prevention." Taylor & Francis, London, 1995.

Hagberg, M., D. Wegman, "Prevalence rates and odds ratio of shoulder-neck disease in different occupational groups." *British J. Industrial Medicine*, Vol. 44, 602-10, 1987.

Hales, T.R., B.P. Bernard, "Epidemiology of work-related musculoskeletal disorders." *Occupational Disorder Management*, 27 (4), 679-709, 1996.

Hartley, L., B. Boultwood, and M. Dunne, "Noise and verbal or spatial solutions of Rubik's cube." *Ergonomics*, Vol. 30, No. 3, 503-509, 1987.

Helander, M., "A guide to the ergonomics of manufacturing." Taylor & Francis, Buffalo, NY, 1995.

Helander, M.G., G.J. Burri, "Cost effectiveness of ergonomics and quality improvements in electronic manufacturing." *International Journal of Ergonomics*, 15, 137-151, 1995.

Hocking, B., "Epidemiological aspects of repetitive strain injury in telecom Australia." *Medical Journal of Australia*, 220-222, Sept. 1987.

Hunting, W., TH. Lauble and E. Grandjean, "Constrained postures of VDU operators." in E. Grandejean and E. Vigliani (eds), Ergonomic Aspects of Visual Display Terminals (London: Taylor & Francis), 175-184, 1980.

Hunting, W., T. Lauble, E. Grandjean, "Postural and visual loads at VDT workplaces." *Ergonomics*, 24 (12), 917-933, 1981.

Irle, H., J.M. Hesse, H. Strasser, "Physiological cost of energy-equivalent noise exposures with a rating level of 85 dB(A): Hearing threshold shifts associated with energetically negligible continuous and impulse noise." *International Journal of Industrial Ergonomics*, 21, 451-463, 1998.

Kadefors, R., T. Engstrom, J. Petzall, L. Sundstrom, "Ergonomics in parallelized car assembly: a case study, with references also to productivity aspects." *Applied Ergonomics*, 27 (2), 101-110, 1996.

Kamwendo, K., S. Linton, U. Moritz, "Neck and shoulder disorders in medical secretaries. Part 1. Pain prevalence and risk factors." *Scandinavian Journal of Rehabilitation and Medicine*, 23, 127-133, 1991.

Karlqvist, L., M. Hagberg, K. Selin, "Variation in upper limb posture and movement during word processing with and without mouse use." *Ergonomics*, 37 (7), 1261-1267, 1994.

Karwowski, W., "Complexity, fuzziness, and ergonomic incompatibility issues in the control of dynamic work environments." *Ergonomics*, 34, 671-688, 1991.

Khalil, T., "Ergonomic issues in low back pain: Origin and magnitude of the problem." *Proceedings of the Human Factors Society*, 820-24, 1991.

Kilbom, A., "Repetitive work of the upper extremity: Part II – The scientific basis (Knowledge base) for the guide." *International Journal of Industrial Ergonomics*, 14, 59-86, 1994.

Kilbom, A., J. Persson, and B. Jonsson, "Risk factors for work-related disorders of the neck and shoulders – With special emphasis on working postures and movements." In The Ergonomics of Working Postures, Corlett, N., J. Wilson, and I. Manenica, London, Taylor & Francis, 1986.

Kjellberg, A., "Subjective, behavioral and psychophysiological effects of noise." *Scand. J. Work. Environ. Health*, Vol. 16 (suppl. 1), 29-38, 1990.

Knave, B., R. Wibom, M. Voss, L. Hedstrom, U. Bergqvist, "Work with video display terminals among office employees." *Scandinavian Journal of Work, Environment and Health*, 11, 457-466, 1985.

Knill, B., "Ergonomics tools for home improvement." *Material Handling Engineering*, 46-51, March 1997.

Konz, S., and S. Johnson, "Work Design; Industrial Ergonomics" 5th Ed., Holcomb Hathaway Publishers, Scottsdale, Arizona, 2000.

Kryter, K., "The effects of noise on man." 2d ed., New York, Academic Press, 1985.

Laitinen, H., J. Saari, J. Kuusela, "Initiating an innovative change process for improved working conditions and ergonomics with participation and performance feedback: a case study in an engineering workshop." *International Journal of Industrial Ergonomics*, 19, 299-305, 1997.

Li, G., and P. Buckle, "Current Techniques for assessing physical exposure to work-related musculoskeletal risks, with emphasis on posture-based methods." *Ergonomics*, vol. 42, no. 5, 674-695, 1999.

Lindh, M., "Biomechanics of the lumbar spine." In Basic Biomechanics of the Skeletal System, edited by V.H. Frankel and M. Nordin, Philadelphia, PA, Lea and Febiger, 255-290, 1980.

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

Mital A., "Industrial Ergonomics Techniques." Research in Human Engineering by Jon Weimer, Prentice Hall PTR, 1995.

Nagamachi, M., "Requisites and practices of participatory ergonomics." *International Journal of Industrial Ergonomics*, 15, 371-377, 1995.

Nathan, P.A., et al., "Longitudinal Study of Median Nerve Sensory Conduction in Industry." *Journal of Hand Surgery*, 850-857, 1992a.

Nathan, P.A., et al., "Obesity as a risk factor for slowing of sensory conduction of the median nerve in industry." *Journal of Occupational Medicine*, 379-383, 1992b.

National Institute for Occupational Safety and Health, "Cumulative trauma disorders in the workplace: bibliography." Washington DC: U.S. Department of Health and Human Services, 1995.

National Institute for Occupational Safety and Health, "Elements of ergonomics programs: A primer based on workplace evaluations of musculoskeletal disorders." DHHS (NIOSH), Publication No. 97-117, Washington, DC, U.S. Department of Health and Human Services, Center for Disease Control and Prevention, 1997a.

National Institute of Occupational Safety and Health (NIOSH), "Musculoskeletal disorders and workplace factors: A critical review of epidemiological evidence for work-related musculoskeletal disorders of the neck, upper extremity and low back pain." DHHS (NIOSH) Publication No. 97-141, Washington, DC, U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, 1997b.

National Institute of Occupational Safety and Health, "Workplace use of back belts." DHHS, NIOSH No. 94-122, Cincinnati, OH, 1994.

National Safety Council, "Accident prevention manual for business & industry: administration & programs 10th Ed." NSC, 1992.

Neelam, S., "Using torque arms to reduce CTDs." *Ergonomics in Design*, 25-28, Oct. 1994.

Pack, J., H. Buck, "Arbeitsgestaltung in der Serienmontage." Fortschritt-Berichte VDI. VDI-Verlag GmbH, Dusseldorf, 1992.

Parenmark, G., A.K. Malmkvist, R. Ortengren, "Ergonomic moves in an engineering industry: effects on sick leave frequency, labor turnover and productivity." *International Journal of Industrial Ergonomics*, 11 (4), 291-300, 1993.

Pascarelli, E., J. Kella, "Soft-tissue injuries related to use of the computer keyboard." *Journal of Occupational Medicine*, 35, 522-532, 1993.

Pheasant, S., and D. O'Neill, "Performance in griping and turning-a study in hand/handle effectiveness." *Applied Ergonomics*, 6, 205-208, 1975.

Putz-Anderson, V., "Prevention strategies adopted by select countries for work-related musculoskeletal disorders from repetitive trauma." *Trends Ergonomics/Human Factors*, 5, 601-11, 1988.

Radwin, R., E. VanBergeijk, and T. Armstrong, "Muscle response to pneumatic hand tool torque reaction forces." *Ergonomics*, 32, 665-673, 1989.

Rempel, D.M., R.J. Harrison, S. Barnhart, "Work-related cumulative trauma disorders of the upper extremity." *JAMA*, 267, 838-42, 1992.

Rossignol, A.M., E.P. Morse, V.M. Summers, L. Pagnotto, "Video display terminal use and reported health symptoms among Massachusetts clerical workers." *Journal of Occupational Medicine*, 29 (2), 112-118, 1987.

Sanders, M., and E. McCormick, "Human Factors in Engineering and Design, 7th Ed." McGraw-Hill, Inc., 1993.

Silverstein B.A., L.J. Fine, T.J. Armstrong, "Hand wrist cumulative trauma disorders in industry." *Br J Ind Med,* 43, 779-84, 1986.

Singleton, W.T., "Introduction to Ergonomics." Geneva: World Health Organization, 1972.

Smith, M., P. Carayon, "Work organization stress and cumulative trauma disorders." In: Moon, S.D., Sauter, S.L. (Eds.), Beyond Biomechanics. Physiological Aspects of Musculoskeletal Disorders in Office Work, Taylor & Francis, London, 23-42, 1996.

Snook, S., "Low back disorders in industry." *Proceedings of the Human Factors Society*, 830-33, 1991.

Sommerich, C., J. McGlothlin, and W. Marras, "Occupational risk factors associated with soft tissue disorders of the shoulder: A review of recent investigations of the literature." *Ergonomics*, Vol 36, No. 6, 697-717, 1993.

Stock, S., "Workplace ergonomic factors and the development of musculoskeletal disorders of the neck and upper limbs: a meta-analysis." *American Journal of Industrial Medicine*, 19, 87-107, 1991.

Stranden, E., P. Ogreid, E. Seem, "Venous pressure gradients in controls and in patients with chronic venous disease." *Phlebology*, 1, 47-50, 1986.

University of Michigan, "3D static strength prediction program." User's Manual, 1998.

Van Wely, P., "Design and Disease." *Applied Ergonomics*, 1, 262-269, 1970.

Vasseljen, o., R.H. Westgaard, "Can stress-related shoulder and neck pain develop independently of muscle activity?" *Pain* 64, 221-230, 1996.

Westgaard, R. H., A. Aaras, "Postural muscle strain as a casual factor in the development of musculo-skeletal illness." *Applied Ergonomics*, 15, 162-174, 1984.

Westgaard, R.H., J. Winkel, "Ergonomic intervention research for improved musculoskeletal health: A critical review." *International Journal of Industrial Ergonomics*, 20, 463-500, 1997.

Wick, J.L., "Productivity and ergonomic improvement of a packaging line: a case study." In: Asfour, S.S. (Ed.), Trends in Ergonomics/Human Factors IV, Proceedings of the Annual International Industrial Ergonomics and Safety Conference, Miami, FL, 9-12 June 1987, Elsevier, Amsterdam, Part A, 97-102, 1987.

Winkel, J. and S.E. Mathiassen, "Assesment of physical work load in epidemiologic studies: concepts, issues and operational considerations." *Ergonomics*, 37, 979-988, 1994.

Winkel, J. and R. Westgaard, "Occupational and individual risk factors for shoulder-neck complaints: Part II. The scientific basis (literature review) for the guide." *International Journal of Industrial Ergonomics*, 10, 85-104, 1992.

Winkel, J., R.H. Westgaard, "Editorial: A model for solving work related musculoskeletal problems in a profitable way." *Applied Ergonomics*, 27, 71-78, 1996.

Winkel, J., "Swelling of the lower leg in sedentary work. A pilot study." *Journal of Human Ergology*, 10, 139-149, 1981.

Yassi, A., J. Sprout, R. Tate, "Upper limb repetitive strain injuries in Manitoba." *Am J Ind Med*, 1997.

Yassi, A., "Repetitive Strain Injuries." *Lancet*, 349, 943-47, 1997.