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PREEMPLOYMENT STRENGTH TESTING

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE / Public Health Service
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PREEMPLOYMENT STRENGTH TESTING

In Selecting Workers For Materials Handling Jobs

Don B. Chaffin
Gary D. Herrin
W. Monroe Keyserling
James A. Foulke

The University of Michigan
Ann Arbor, Michigan

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U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Center for Disease Control
National Institute for Occupational Safety and Health
Physiology and Ergonomics Branch
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ABSTRACT

This research project was initiated to extend earlier studies which disclosed that weaker workers incurred a larger proportion of musculoskeletal problems when placed on jobs requiring significant physical effort than their stronger counterparts. The project entailed the evaluation of over 900 jobs in six plants to establish the relative strength requirements of each. For workers placed on these jobs, a medical history, physical examination, and physical activity history were documented. Also, isometric strength tests obtained in several different postures were obtained. During the period when workers were on one of the study jobs, all medical problems they incurred were carefully documented. Supervisors of these employees were also queried as to the worker's apparent ability or lack thereof to perform the physical aspects of the job. The data were collected over a one and one-half year period.

Several major findings resulted from this study. These are:

* The activity of lifting heavy loads, especially when done frequently, is associated with increased numbers and severity of musculoskeletal incidents.
* Weaker workers when performing high strength requiring activities, have an increased incidence and severity of musculoskeletal and contact type injuries.
* Strength varies greatly in the working population and is not well predicted based on gender, age, body weight, or stature.
* Strength which relates to personal risk of later injury can be equally assessed by testing a worker in postures which are standardized or which reflect the maximum load related postures required on the job.

New in-depth biomechanical and metabolic job evaluation methodologies are also employed on selected jobs which demonstrate how re-engineering could be accomplished to reduce the potential for different types of musculoskeletal injuries.

A recommendation is proposed that an action level be developed to control the hazards of excessive physical exertions for weaker workers. Such an action level would reflect a concern for the adverse effects of load magnitude, load handling frequency, and load size and/or location on a job. If these conditions exceed the prescribed action level, then a medical examination with strength assessment would be required for all workers going onto such jobs. Also, such an action level when exceeded would require a biomechanical evaluation of the job to determine the type of engineering redesign which would be most effective in reducing the hazard levels.

Other recommendations regarding type of strength testing and their potential contributions to worker health and safety are given.

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CHAPTER I

INTRODUCTION

BACKGROUND

Historically, manual materials handling has been recognized as providing a major hazard to industrial workers by many authorities on occupational health and safety. A particular concern has been shown for women and children performing such acts. In fact, during the period from 1930 to 1950 almost all the states enacted laws specifically limiting the loads that women and children could handle. It should quickly be added that all of these statutes have been recently struck-down as unconstitutional in that they discriminate against employment of all women without recognition of the large variation in capabilities between women.

As late as 1962, the International Labour Office published an Information Sheet which stated limits shown in Table 1. These limits were primarily based on inspection of injury and illness statistics. Compared to sedentary jobs, materials handling jobs showed a three times greater incidence of spinal, knee and shoulder problems, a ten times greater incidence of elbow problems, and about a five times greater incidence of hip problems. (International Labour Office, 1962).

Table 1: ILO suggested limits for occasional weight lifting (lbs.) (ILO, 1962).

Age (years	Men	Women
14-16	32.25	21.50
16-18	40.85	25.80
18-20	49.85	30.10
20-35	53.75	32.25
35-50	45.15	27.95
Over 50	34.40	21.50

More recently, the work of Snook, Irvine and Ciriello (1974) has resulted in suggested limits for occasional lifting as depicted in Table 2. These limits are based on a psychophysical method, wherein various workers have demonstrated their capabilities to lift such loads in a controlled laboratory setting.

A recent epidemiological study by Chaffin and Park (1973) also confirmed that lifting of what would normally be classified as "moderate" loads (about 25 to 45 pounds) did indeed significantly increase the risk of low-back pain in a group of 400 workers studied in five plants. This same study disclosed that the lifting of "heavy" loads on the order of 60 to 100 pounds increased the incidence rate of low-back pain by as much as eight times that reported by workers performing only light load lifting. Interestingly, the study did not find any significant difference between women and men in the incidence rates of

Table 2: Maximum weights (lbs.) acceptable to various percentages of the male and female populations while lifting a 19 x 13-1/2 x 5-1/2 inch tote box. (Snook and Ciriello, 1974)

Type of Lift	Population Group	Percentile Capable				
		90%	75%	50%	25%	10%
Shoulder Height to Arm Reach	Industrial Men	29	39	49	59	68
	Industrial Women	24	26	29	32	35
	Housewives	13	15	18	21	23
Knuckle Height to Shoulder Height	Industrial Men	34	43	53	62	71
	Industrial Women	25	29	34	38	42
	Housewives	16	18	21	23	26
Floor Level to Knuckle Height	Industrial Men	37	45	54	63	70
	Industrial Women	28	33	37	42	47
	Housewives	14	17	21	24	27

low-back pain when both were employed on moderate load lifting jobs. No women in the study were employed on the heavier load lifting jobs. When the strengths of the women employed on the moderate load lifting jobs were tested and compared with the strengths of those on more sedentary jobs, it was found that the former group was stronger. This led the authors to speculate that the women performing the more strenuous work were selected by either "natural" or some other means, and such selection equilibrated their capabilities to those of the men on the same jobs. Whether such protective selection has remained intact in such plants since this earlier 1972 study remains open to question. Identifying the possible nature of such selection and its ability to protect the person is, in fact, the basis for the present study.

From the biomechanical standpoint, there is little doubt that the lifting of moderate to heavy loads can create excessive mechanical stresses on various components of the musculoskeletal system. The biomechanical rationales of importance are presented in recent review articles by Tichauer (1973) and Chaffin (1975a). Such biomechanical stresses on the lumbosacral disc have been found to be high enough when lifting compact loads of about 35 pounds that they would probably exceed the cartilage end-plate or annulus fibrosus stress tolerances in people who have pre-existing weaknesses in these structures (Chaffin, 1975b). In other words, from a biomechanical view point, some people should not be allowed to lift more than about 35 pounds relatively close to the body, or even ten pounds at arms length. These kinds of limits would pertain to even occasional lifting for some people.

In this latter regard, if the load handling frequency is rapid wherein continuous lifting and carrying is performed over a few hours or more, then the aerobic metabolic energy expenditure rate can become the limiting factor (Aquilano, 1968). In fact, repeated lifting of 25 pound loads from the floor to table height without rest has been shown to result in energy expenditures high enough that only a very physically fit individual with an aerobic capacity about 16 Kcal/minute could be expected to sustain such an act for more than about one hour without undue fatigue and cardiovascular stress (Chaffin, 1975b). Recent work by Lind and Petrofsky (1976) has confirmed the excessively high cardiovascular stresses imposed by repeated load lifting of even moderate weight for some people.

What should be evident from the preceding is that manual materials handling has been recognized by many different authorities as being hazardous to a large number of people comprising the general work population. Manual materials handling activities have been cited by both the National Safety Council (1974) and in an Arthur D. Little Company (1972) survey of safety conditions in industry as providing the most hazardous type of worker activity in general. Clearly, the lifting and handling of extremely heavy loads must be more limited than has been the case in the past. Unfortunately, because of the many different sizes and shapes in products, tools, and workpieces that must be moved in industry today, mechanization to reduce the loads to levels that can be safely handled by almost anyone is believed by most authorities to be socially and economically infeasible in the near future. Thus, a major recommendation of three different meetings of national and international authorities on this subject has consistently been to pursue the research necessary to establish valid criteria for the selection of workers who can safely perform at least moderate load handling tasks (Badger, Dukes-Dobos and Chaffin, 1972; Herrin, Chaffin and Mach, 1974; Drury, in press).

Clearly, a number of different types of personnel selection criteria could be utilized to determine who could safely handle loads in industry. An extensive review of over 600 papers pertaining to manual materials handling research was performed by these authors two years ago (Herrin, et al., 1974). About 40% of the papers mentioned at least one worker attribute as being important in assigning the degree of risk to a person who is to perform manual materials handling activities. Table 3 describes some of these attributes and the relative number of references found that included them as important in determining personal risk of injury in manual materials handling jobs.

Table 3: Worker characteristics cited by various researchers as important in determining personal risk of injury in manual materials handling. (Herrin, et al., 1974)

Personal Attribute	% of Citations
Physical (age, gender, anthropometry)	38%
Sensory (visual, tactile, kinesthetic)	2%
Motor (strength, endurance, ROM)	13%
Psychomotor (coordination, reaction time)	3%
Personality (risk acceptance, job satisfaction)	6%
Training/Experience (in manual materials handling)	8%
Health Status (general health and physical condition)	30%
Leisure Activities (sports, second job)	0%

It would appear from this gross categorization of the literature that a large number of authorities believe the state of a worker's health and motor capabilities combined with the person's age, gender and anthropometry account for why some people are more prone to materials handling injuries and illnesses than others. Unfortunately, when a panel of experts reviewed many of these papers, it was the consensus that though many specific attributes probably contributed to a person's risk level, there were often insignificant and even conflicting reports as to the individual and combined effects of each attribute. This led to the following statement by this earlier review group:

> "It is recommended that functional tests be more quickly developed and evaluated in well-controlled laboratory and field studies." (Herrin, et al, 1974)

REVIEW OF PAST STUDIES TO DEVELOP MEDICAL SELECTION CRITERIA

What major attempts have been made to develop valid personnel selection criteria for manual materials handling jobs? It is beyond this document to review all of the literature, but a few of the approaches which have received major general recognition will be presented.

Gender

The literature reveals that the sex of the worker may be related to the risk of a materials handling injury or illness. It must be noted that both the ILO (1966) and more recently the U.S. Department of Labor (1970) recommended that women not be permitted to lift as much as men. It appears to be accepted that on the average a woman's lifting strengths (primarily arms and torso strengths) are about 60% to 70% of a man's according to Asmussen and Heeboll-Nielson (1962), Chaffin (1974), Snook and Ciriello (1974) and Petrofsky and Lind (1974). For specific strengths, however, female strength may be as low as 35% or as high as 86% of a man's according to Laubach (1976). Furthermore, the biomechanical linkage mechanism when lifting differs between males and females with respect to the lever systems employed as reported by both Tichauer (1973) and Chaffin (1969). Hence, if asked to handle a given load, a women is often more highly stressed than a man relative to their individual strengths. However, it must be noted that the intra-gender variability in the strength of males and females is very large. Gender thus appears to become secondary to strength per se.

It has also been reported that women have higher heart rates for given lifting tasks, (Snook and Ciriello, 1974), and similarly the metabolic rates were higher for certain above shoulder lifts, (Tichauer, 1970). It is, therefore, possible that women are at higher risk of injury or illness during highly repetitive and continuous materials handling tasks since, in general, they work closer to their maximum aerobic capacities than men. As in the case of strength, however, individual variability in aerobic capacities within each sex are far greater than between the sexes. Thus, the aerobic capacity becomes more important in assigning personal risk than does one's gender.

In regard to low-back injuries, Brown (1970), in a survey of industrial workers reports that women appear to have larger relative numbers of complaints than men when required to perform heavy, physical jobs. Magora (1970) reports a similar result. As commented upon earlier, Chaffin and Park (1974) studied both men and women performing equally demanding, light-to-moderate load handling jobs, and reported equal incidence rates of low-back pain. However, the women in this latter study who were performing moderate load handling jobs were stronger than the average women in the study (i.e., an unknown selection process was operating). This last study demonstrates the complexity of the issue. Clearly, gender is confounded with many other worker and job characteristics, and hence only carefully designed multifactor studies must be considered as valid approaches to understanding the hazard related to gender alone.

Age

Age, like gender, has often been considered as a valid criterion for placing people on jobs requiring the manual handling of materials. In practice, advanced age is often used in restricting a person from load handling jobs. This policy appears to be based on the speculation that older workers have diminished capacity to withstand physical stresses (Åberg, 1961). Yet the literature indicates the greatest incidence of low-back pain occurs in the 30 to 50 year old group (Herndon, 1927; Hult, 1954; Kosiek, et al., 1968; Magora and Taustine, 1969; Rowe, 1969 and Brown, 1973). Whether this is because older workers are not as likely to be exposed to the injury producing stresses of manual materials handling, or whether only those older workers who have survived a rigorous history of earlier stresses remain in the work force is not clear. It appears, however, that heavy physical work, even when performed in the twenties, can cause accelerated rates of injury and musculoskeletal illness, (Blow and Jackson, 1971). Clearly, age and aging have a complex effect on many attributes necessary for workers to handle heavy loads safely. It seems likely that the younger person may not have developed the requisite abilities to recognize and control the hazards of manual materials handling as has the older worker. He may be overly stressing his body but not be sensitive to the chronic effects yet. On the other hand, the older individual, while having perfected his skills in handling heavy or cumbersome loads, is likely to have diminished physical capabilities. Age must therefore be viewed as a potential risk factor. Nonetheless, it is probably secondary to many other attributes discussed in the following subsections.

Body Weight

Body weight has a potentially complex affect on an individual's risk of injury during manual materials handling. First, it is generally accepted that body weight has a direct affect on the metabolic rate of a person while lifting and carrying loads (Kamon and Belding, 1971 and Garg, 1976). Thus, a heavier person would have a greater metabolic rate and concomitant circulatory load, which could lead to earlier fatigue or cardiovascular problems if the person were so predisposed. On the other hand, a heavier person is usually stronger than his lighter counterpart, and usually has the mass necessary to counterbalance the handling of large objects (Snook and Irvine, 1967; Troup and Chapman, 1969a and Konz, et al., 1973), though isometric muscular fatigue has been shown to develop more readily in overweight people (Petrofsky and Lind, 1976). It is concluded, therefore, that body weight probably influences the assignment of personal risk, but its role is complex and probably secondary compared to strength and endurance attributes of an individual.

Stature, Posture and Mobility

Besides body weight, there are several other anthropometric variables which appear to have a potential influence on individual risk. Tauber (1970), for instance, indicates taller people have larger numbers of low-back incidents than shorter people. Certainly from the biomechanics viewpoint it is easy to rationalize that a tall person would overstress the low-back in particular because of leaning and reaching further to pick-up or set-down a load. In contrast, however, a smaller person may be forced into more awkward postures when handling an object located horizontally away from or above the person's normal reach. Once again, it is unclear as to how such a simplistic attribute as stature would effect the risk level when a person is assigned to various types of materials handling jobs.

Torso posture during load handling has been found to be a personal risk factor by Tichauer, Miller and Nathan (1973). They have demonstrated in the laboratory that changes in the lordotic curvature of the low-back while holding a load in front of the body is a good indication of an existing weakness in this structure. Unfortunately, field data was not available to validate this measure of risk.

In still another laboratory study trunk-hip mobility was investigated to determine the correlation with torso strengths by Troup and Chapman (1969a). No significant correlation was found, leading these authors to the opinion that this attribute was not important in assigning personal risk.

Clinical Examination and X-rays

At the time of an employment examination a variety of clinical tests have been used to predict individual risk of later injury or illness. The literature summarized below examines some of the complexities of this issue.

There are strong opinions, as summarized by such experienced physicians as Clark and Russek (1958), Hanman (1958) and Peres (1960), that a clinical impression based on a good physical examination is effective in reducing the number of workers who will later experience low-back pain if placed on manual materials handling jobs. Studies by Magnuson and Coulter (1921), Becker (1955), Moretone, Winston and Bilby (1958), McGill (1968), Kosiek, Aurelius and Hartfield (1968) and Rowe (1969) appear to justify this approach. More skeptical opinions are expressed by White (1966) and, earlier by Osgood (1919). Rowe (1969) states about 10% of later low-back pain sufferers could be detected by a complete physical examination, including a lumbo-sacral radiographic evaluation upon employment.

The literature also indicates that medical and occupational histories are important in determining an individual's risk according to Rowe (1969). Magora and Taustine (1969), Meyers (1967) and Koyl and Hanson (1969) all strongly urge consideration of various psychosocial factors as well as physical factors when determining the capability of a person to perform manual materials handling. Unfortunately, exact criteria for using such information to assign personal risk are rarely disclosed, and if such are described their validity is not proven.

In contrast, the use of radiographic findings for assessing the risk of later low-back pain potential has been thoroughly debated. Though papers by Stewart (1947), Becker (1955), Kosiek, et al., (1968) and McGill (1968) strongly advocate the use of X-rays for pre-placement of people, more recent papers by LaRocca and MacNab (1970) and Redfield (1971) seriously question the predictive validity of such X-rays. It is the recent opinion of Leggo and Mathiasen (1973) that only the grossest of skeletal anomalies would be allowed to exclude a person from a materials handling job. Along these lines Runge (1958) had earlier suggested spondylioisthesis and obvious disc degeneration be considered as grounds for rejecting a person's placement on heavy manual materials handling jobs. Stewart (1947) and Kosiek, et al. (1968) indicated disc degeneration be considered as a basis for rejection of a person on jobs requiring heavy labor. A more recent review article by Montgomery (1976) concluded otherwise, as follows:

> "The use of pre-employment back X-rays has been based primarily upon the hypothesis that developmental abnormalities predispose to an increased incidence of low back injury. The preponderance of evidence would indicate this hypothesis has not been substantiated." (Montgomery, 1976)

Finally, a recent panel of experts gathered together by the American College of Radiology in conjunction with NIOSH concluded:

> "The incorporation of an X-ray examination of the lumbar spine in a pre-employment assessment of an individual is valuable in assessing the current status of the individual's spine but less positively valuable in predicting the possible trauma or disability which might result from that individual engaging in a physically stressful occupation." (American College of Radiology, 1973)

Because of the current controversy over the effectiveness of back X-rays and the concern over excessive radiation exposure, an increased demand has been created to develop and test other measures of physical capability, as noted earlier in this report. What follows is a brief description of previous work to develop and evaluate strength testing as an effective functional test for pre-employment purposes.

Strength Testing

The ability to measure reliably isometric strength has been well established, provided certain conditions are maintained during the testing. Kroemer (1970), Caldwell, et al., (1974) and Chaffin (1975) have delineated these conditions in several position papers, in collaboration with other experts. In general, a test-retest coefficient of variation should be on the order of 10% if these conditions are met. It has also been the concensus of these experts that standardized isometric strength testing is safe.

Over the last couple of decades a large number of strength data have been gathered on various populations. The primary intent of these data has been to develop guides for engineering design. Recently, there has developed an awareness that such strength testing could be useful as part of a medical examination to determine the personal risk of injury to a person assigned to materials handling activities. Kraus (1967) believed that strength tests should be an essential part of pre-employment examiantions. Rowe (1971) also stated that abdominal weakness correlated with increased incidence of low-back pain. From the biomechanical point of view, abdominal strength has been shown to be a major factor in reducing the compressive forces acting on the lumbar spine while lifting by Davis (1969), Bartelink (1957), Alston, et al., (1966) and Morris, et al., (1961). Further, Troup and Chapman (1969b) and Poulsen and Jorgenson (1971) believe the strength of the back extensors are of primary importance in protecting the back during manual materials handling jobs. Also, Koyl and Hanson (1969) require a specific evaluation of muscle strength as input into their worker functional profile evaluation plan.

Because of the recognized potential for individual strength data being useful in assigning personal risk, a study by Chaffin (1974) was initiated in 1971 to test the potential protective capacity of such tests for the low back. Over 400 employees in five plants were strength tested, and their incidence of low back pain tabulated over a one-year period. The results of this study indicated about a three-fold increase in the incidence rate of low back pain in those people who could not demonstrate the isometric strength necessary to properly lift the loads required on their jobs as compared with their stronger cohorts.

Based on many of the preceding results, Badger, et al., (1972) summarized the opinions of a number of experts who recommended that strength testing techniques be developed and evaluated as possible means to reduce the occupational low-back pain problem. Hence, this present study was formulated and justified.

OBJECTIVE OF PRESENT STUDY

There are two major objectives in the present study. The first is very specific:

> "To evaluate whether knowledge of a person's isometric strength can predict the risk of later injury and illness when the person is placed on jobs having various degrees of manual materials handling."

The second objective developed as an off-shoot of attempts to satisfy the first objective. To meet the first objective, various statistics were necessary from cooperating plants. These statistics described 1) the degree of manual materials handling required in each job to be included in the study, 2) the general health, age, gender, body weight, stature and specific strengths of workers to be employed on jobs included in the study, 3) the diagnosis and severity of various injuries and illnesses that developed in workers participating in the study, and 4) the performance rating of the workers on the jobs as determined by their supervisors. All of these statistics needed to be gathered, reported, and stored in a systematic fashion. Also, the means to easily retrieve the statistics and use them for various analyses had to be derived. Hence, the second objective became:

> "To develop a comprehensive occupational health monitoring and evaluation system for manual materials handling jobs."

At first, this second objective may appear to be of limited general value. It is now believed, however, that the development of such a system is in fact essential to the eventual control of not only manual materials handling health and safety problems, but to the control of many other types of diverse occupational hazards. Early detection and identification of potential problems due to job or personnel changes is only possible with such systems. In this regard, it is hoped that the system developed in this project can serve as a reference for the further development of such systems in the more general occupational health and safety arena.

ORDER OF REPORTING

Following this introduction is a section which describes the design of the occupational health monitoring and evaluation system (OHMES) used in this study. After this four results sections are presented. Each of these addresses an issue related to the first objective of this project. The issues are:

* How can the physical demands of a job be evaluated in a systematic and practical way?
* How can an employee's strength be evaluated in a systematic and practical way?
* What are the medical consequences of mismatching a person's physical capabilities with a job's physical demands?
* What are the effects on performance when a person's physical capabilities are mismatched with the demands of a job?

Chapter VII summarizes the findings of several in-depth case studies which were performed on selected study jobs. Chapter VIII summarizes the major results of the study, and presents recommendations as to the methods by which worker strength testing in conjunction with an OHMES could be used to better control the hazards of manual materials handling on various jobs.

CHAPTER II

METHODOLOGY

APPROACH

As stated in Chapter I, the primary objective of this study is to evaluate whether the knowledge of a person's isometric strength can predict the risk of later illness and injury to that person when placed on a job requiring manual materials handling. To meet this objective, data describing jobs and employees have been gathered in six plants representing two industries. These plants are located in different geographical regions of the United States. The details of plant participation, in terms of the numbers of workers and jobs studied, are discussed later in this chapter.

A longitudinal design is implemented for the purposes of collecting the experimental data. This means that employees are strength tested prior to their first exposure to a new job. (The job has already undergone analysis to determine biomechanical stresses.) Should a worker ever experience a job related medical incident during the course of his employment, the information describing this occurrence is entered into the experimental data base.

There are several advantages associated with the longitudinal design. Three of these advantages are briefly discussed in the paragraphs below.

First, since employees are strength tested prior to going on the job, the test is a measure of the individual's innate ability rather than a learned skill. This prior ability (or lack of it) can be analyzed with respect to future medical incidents and job performance. Furthermore, the results of the strength tests are unaffected by exposure to the job. For example, the worker may be the unfortunate victim of a disabling medical incident which would reduce the strength capabilities. If strength were to be measured retrospectively, the relationship between the unimpaired capability and the person's medical performance would be lost.

Second, the longitudinal design requires that medical incidents be reported soon after their occurrence. This practice enhances the completeness and accuracy of medical reporting and reduces the likelihood of missing data.

Finally, the longitudinal approach allows a more random matching of employees and jobs to be observed. No data is lost as a result of the self selection process where a worker voluntarily terminates employment in a given job due to unhappiness (perhaps due to a mismatch) with the job situation. In a retrospective study the strength capabilities of these individuals could not be determined because they would have left the study environment.

In summary, the longitudinal approach includes the following phases:

1. Jobs are analyzed for biomechanical stresses.
2. New employees are tested for strength capability.
3. The medical and job performance of the employee is monitored during exposure to the job.

In order to fulfill the study's objective, it became necessary to develop OHMES, the Occupational Health Monitoring and Evaluation System. The purpose of OHMES is to monitor, report, and integrate data relating to the physical requirements of a job, the capabilities of an employee, and the various consequences of a job/employee match. A block diagram showing the principal inputs of OHMES is presented in Figure 1.

At the micro level, OHMES integrates various job descriptors (loads lifted, distances moved, frequency of task occurrences, etc.) and employee characteristics (anthropometric data, biographical data, and isometric strength) into a job/employee match system. The resulting system is then monitored in two areas: health effects and employee performance. The health consequences resulting from a job/employee match are reflected in the work related medical history of the individual while on the job. The effectiveness of the employee in performing assigned jobs can be evaluated using supervisor ratings. The combination of medical history and supervisor ratings can be used to measure the "goodness" of the match. OHMES performs the above functions of assigning specific employees to specific jobs and monitoring the results of the match with the assistance of a computerized data base management system. A detailed description of this system is given later in this chapter.

At the macro level, OHMES generates composite statistics describing classes of jobs, employees, medical incidents, and supervisor ratings. These statistics have many and varied applications. At the simplest level composite statistics can be used to describe and compare the physical stresses associated with a collection of jobs or the characteristics associated with a collection of employees. Using this information, it is possible to answer such questions as "Do jobs in industry A require more load handling than jobs in industry B?" or "Are the workers in plant A inherently younger than the workers in plant B?" Queries of this nature are basic to understanding and modeling the employee/job environment.

At a more sophisticated level, composite data from job descriptions, employee characteristics, medical incidents, and supervisor evaluations can be integrated to form composite match data which can then be analyzed to answer specific questions of interest. For example, it is possible to calculate the average strength of all employees on a given job. This mean strength value can be related to the lifting requirements of the job in order to generate a measure of physical stress facing a typical employee on that job. Similar stress ratings can be calculated for other jobs. Medical and performance data can then be compared to stress ratings in order to evaluate whether or not any important relationships exist. Investigations of this type are outlined in the results chapters of this report.

Finally, composite medical incident statistics such as frequency and severity rates can be generated for each job. This information can be used to identify those jobs which are unusually detrimental to the overall health of the work force. Once identified, these jobs can undergo further analyses in order to

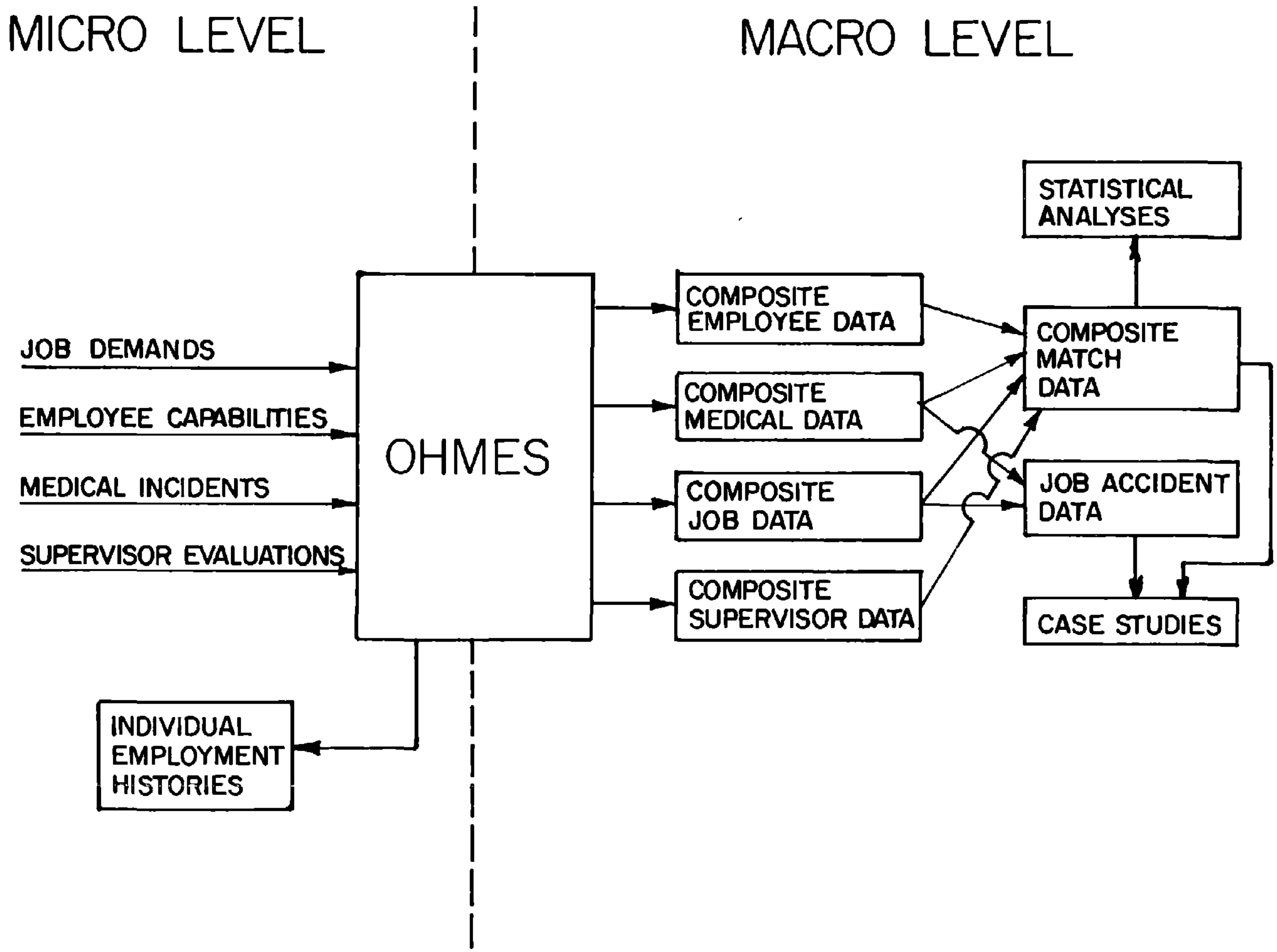


Figure 1: Occupational Health Monitoring and Evaluation System

determine the specific physical stresses which could contribute to the occurrence of medical incidents. During the course of this study, OHMES identified several jobs with higher than normal medical frequency and severity rates. Four of these jobs were selected to undergo in-depth case studies to demonstrate the potential capability of OHMES. To assist in performing the case studies it was necessary to incorporate two human performance models developed at the University of Michigan Human Performance and Safety Engineering Research Laboratory.

The first of these models is a three-dimensional biomechanical simulation of human strength. This model is a computerized mechanical linkage analogy of the musculoskeletal system which predicts static stresses resulting from manual material handling jobs. Once predicted, these stresses were compared to the types of illnesses and injuries occurring on the four selected jobs used in the case analyses.

The second model predicts the metabolic cost of performing a job based on an elemental task description. This information can be used to determine if fatigue could occur over the course of the working day as a result of performing the job; fatigue which might result in injuries.

Both models are described in greater detail in Chapter III. The results of the four case studies are presented in Chapter VII.

VARIABLES UNDER STUDY

This section describes the variables selected for investigation in the main study. For the purpose of organization, these variables have been placed into four categories: job data, employee data, medical data, and supervisor data.

Job Data

In order to determine potential jobs to be included in the study's data base, the industrial engineering and job classification records in each plant were searched for jobs which had some amount of manual materials handling, (in general, greater than 35 pounds handled occasionally). These "candidate" jobs were then inspected by a job analyst who completed a "Biomechanics Job Evaluation" form. An example of this form, hereafter referred to as a Form 1, appears in Figure 2. The top part of the form serves only to document information pertaining to the job title, job identification number, the date of the analysis, and the names of the job supervisor and job analyst. None of this information was used explicitly in any analysis. Following this header, the form is subdivided into the three sections described below.

Primary LSR (Item 1)--

To determine the maximum lift strength ratio (LSR, formerly defined as "lifting strength rating" in other publications), each material handling element of the job was assessed to determine the amount of weight lifted and how far from the worker's balance point (forward foot) the load was located at the beginning and end of a lifting or carrying act. The analyst then compared these data to the graph shown in Figure 3, which predicts the lifting capabilities of the strongest 2.5% of men in the working population. The LSR of each element was then calculated by dividing the weight handled by the predicted strength

CDC 99-74-62
November 1, 1974

Form 1

BIOMECHANICS JOB EVALUATION

Date______________________

Job Title______________________ MS# or Position #______________________

Section Title______________________ Section #______________________

Supervisor______________________ Phone #______________________

Job Analyst______________________ Phone #______________________

1. Primary L.S.R.

(a) The object__________is lifted from________to__________.

(b) Weight lifted______________#.

(c) Horizontal distance from ankle bone nearest the object in the most typical lifting position = ______________".

(d) Vertical distance of the grasping point of the object from the floor = ______________".

(e) The size of the object = ________" x ________" x ________".

(f) The object is lifted__________times/day or week.

(g) Unusual workplace conditions (eg., oily objects, slick floor, no handles on object, etc.):______________________

____

____

____

(h) L.S.R. = __________(est.)

2. Secondary L.S.R.

	Object	Weight	Distance Horiz.	Distance Vert.	Freq./da.,wk.
(a)					
(b)					
(c)					

3. One-Handed or Non-Symmetrical Lifting

Activity Description	Weight/Force	Distance Horiz.	Distance Vert.	Freq.

CC: Internal Coordinator
Medical Department (optional)

Figure 2: Biomechanics job evaluation (Form 1)

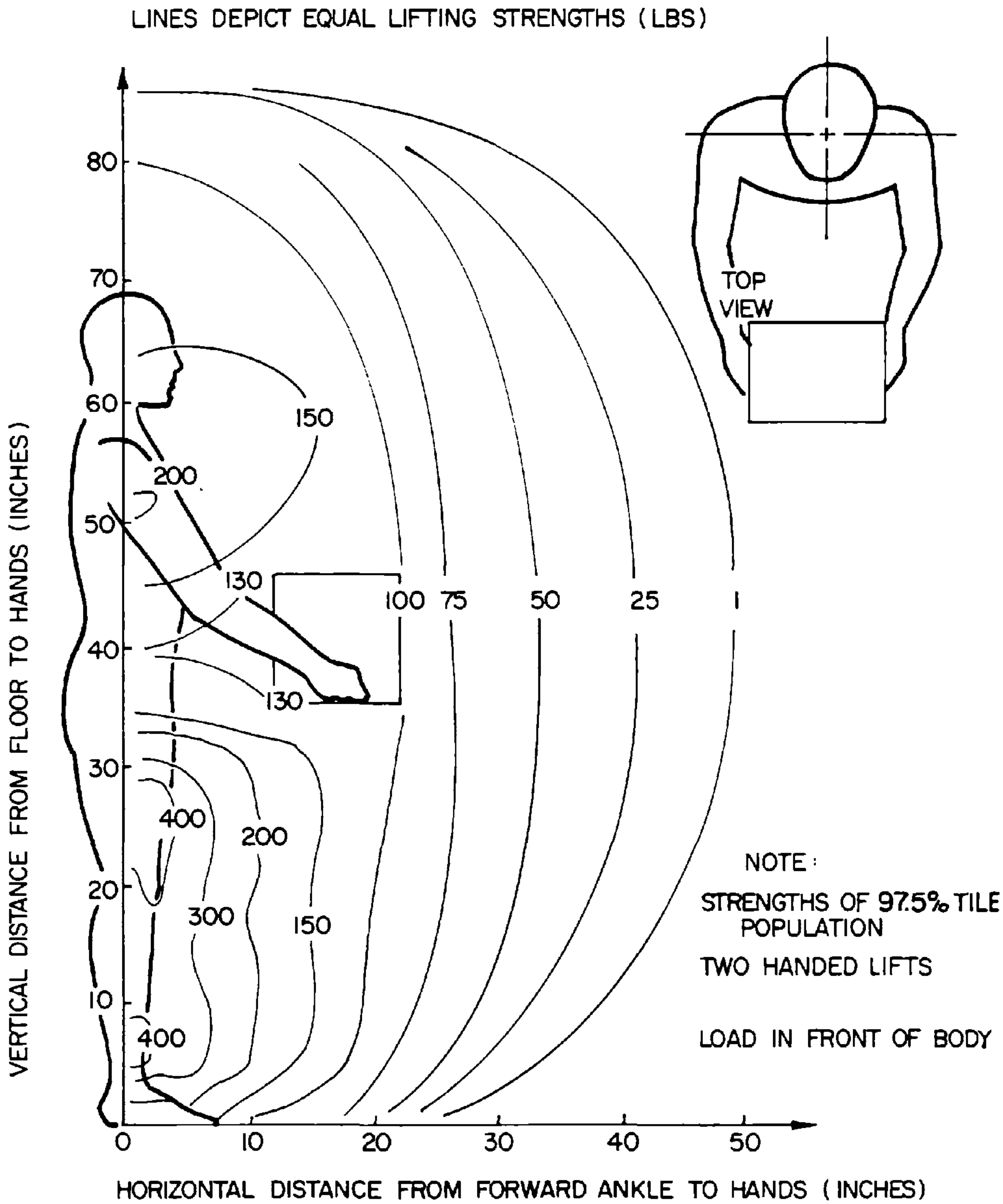


Figure 3: Predicted lifting strength of large/strong male (Chaffin,1974)

value found on Figure 3. A more complete description of this method is given in Chapter III. The lifting task determined by the analyst to be the most stressful element typical to the job was classified as the primary LSR. The following information was documented on the Form 1 for the primary LSR element.

- Item a. - A general description of the object including the origin and destination of the move.
- Item b. - The weight lifted (in pounds).
- Item c. - The horizontal distance (in inches) from the front foot.
- Item d. - The vertical distance (in inches) from the floor.
- Item e. - The width, height, and length of the object (in inches).
- Item f. - The number of times per day or week that the lift occurs.
- Item g. - A brief description of any unusual workplace conditions which might affect a worker's performance.
- Item h. - LSR

$$LSR = \frac{\text{Load (lbs.) Lifted on Job}}{\text{Predicted Strength (from Figure 3) in same position}}$$

NOTE: Items c and d are used to locate coordinates on the Figure for reading the denominator of the calculation.

Secondary LSR (Item 2)--
Clearly, a job usually consists of more than one stressful task. Following the description of the primary LSR task, other job elements found to have large LSR values are documented here. Specifically, the object's name, weight, horizontal distance, vertical distance, and lifting frequency is recorded. This information corresponds to items a, b, c, d, and f described above. Up to three secondary LSR tasks are allowed.

One-handed or non-symmetrical lifting (Item 3)--
Task elements which require forces to be exerted using only one hand or using awkward postures are documented in this section of Form 1. The variables are of the same type and format used to describe the secondary LSR.

Employee Data

Each time a new employee is assigned to a study job, the individual is routed through the plant medical department where he/she is given a pre-employment health status interview. If the person agrees to becoming a participant in the study, he/she signs a consent form (see Figure 4) and is strength tested. The results of the strength test along with other information describing the employee's health and physical condition are documented on a "Medical Evaluation Form," hereafter referred to as a Form 3. An example of this form is presented in Figure 5. The information recorded on the Form 3 is described below.

Top Line - The employee's name is entered on the top line. This piece of data is removed at the plant to protect anonymity of the subject.

Item 1 - The employee number and date of the interview are given here. The employee number is used as an identification key by the data base management system. The date may be used for estimating exposure hours.

Form 2

EMPLOYEE INFORMATION AND CONSENT FORM
CDC-99-74-62
November 1, 1974

I understand that I am being asked to participate in a study conducted by the University of Michigan to determine whether strength testing as part of a medical examination provides an effective method of reducing the risk of incurring future injuries. My inquiries about any matters concerning my participation will be answered by the undersigned witness.

I acknowledge that certain jobs require manual lifting of loads sufficient to warrant consideration of a physical examination and testing of my strength. The results of the strength tests are to be recorded in my medical file and will be treated in a confidential manner as described at the bottom of this page. I have read this statement and understand it.

The results of my strength tests, the physical demands of my job, and my past and future medical and job performance records will be statistically evaluated in order to determine whether people under similar future conditions will have a higher risk of injury.

Risk of my injuring myself during the strength test has been minimized by first having a physician assess my ability to perform the test. Furthermore, the test itself requires me to slowly pull up on two fixed handles until I have reached what I believe to be a maximum exertion. This effort should be what I believe I am capable of exerting if given a heavy object to lift in my job. If I feel any abnormal discomfort while increasing the forces against the handles, I am allowed to stop my exertion at that level. Several such tests will be performed.

Participation in the strength test procedure is strictly voluntary. Whether I participate or not will not jeopardize my job assignment in any way. I fully understand the above and wish to participate by taking the strength test.

I hereby consent to the release of information as a result of my participation. I understand that it will not be released in personally identifiable form.

____
Signature of Employee

____
Date

The identity and relationship to any information in our possession (1) disclosed by a participant in this project and (2) reported by him or derived from him during his participation in this project will not be disclosed without his written consent except as required by law. Such information will be used for statistical and research purposes in such a manner that no individual can be identified.

____
Witness (Medical Dept. Representative)

CC: Medical File only

Figure 4: Employee information and consent form (Form 2)

Form 3 MEDICAL EVALUATION FOR: ______________________________ CDC 99-74-62
Name November 1, 1974

---

1. Employee No. ______________________ Date ______________

2. Job Title ______________ MS# or Position # ______________

3. Height ______ Weight ________ Age ________ Sex ________
Soc. Sec. # ______________

4. Medical history which would limit physical activity:

Date | Diagnosis | Residual Impairment

5. Prognosis for success in future physical activities:
______ excellent ______ good ______ fair.

6. Previous occupations or sports which required lifting:

Date involved | Type of Activity

7. Past experience in physical activities:
______ excellent ______ good ______ fair ______ poor.

---

8. Job Evaluation Data:

Max. Weight Lifted ________ Horiz. Dist. ______ Vert. Dist. ________

9. Job Position Test

1. ______ lbs.

2. ______ lbs.

3. ______ lbs.

4. ______ lbs.

Total: ______ ÷ 4 = ______ lbs. avg.

10. Standard Position Tests

Torso Strength ______ lbs.

Arm Strength ______ lbs.

Leg Strength ______ lbs.

CC: Medical File
Internal Coordinator

Figure 5: Medical Evaluation Form (Form 3)

Item 2 - The job title and job identification number are recorded here. The job title is used only for documentation purposes and the identification number is used by the data base management system to cross-reference the Form 1 for this job.

Item 3 - The height, weight, age and sex of the employee are documented here. This anthropometric data can be used in the strength prediction models. (See Chapter IV.)

Item 4 - Any previous medical incidents which in the opinion of the plant physician could limit the individual's physical activity are recorded here. The date of the incident, a description of the diagnosis, and residual impairment (if any) are specified.

Item 5 - For this question, the plant physician assigns an excellent, good, or fair prognosis for the new employee's success in future physical activities.

Item 6 - If the new employee has had previous experience in manual materials handling jobs or has participated in recreational activities requiring lifting, this information is recorded here. A brief description of the activity along with the beginning and ending year of participation is reported.

Item 7 - The employee is asked to rate his/her previous experience in physical activities. Possible responses are excellent, good, fair, and poor.

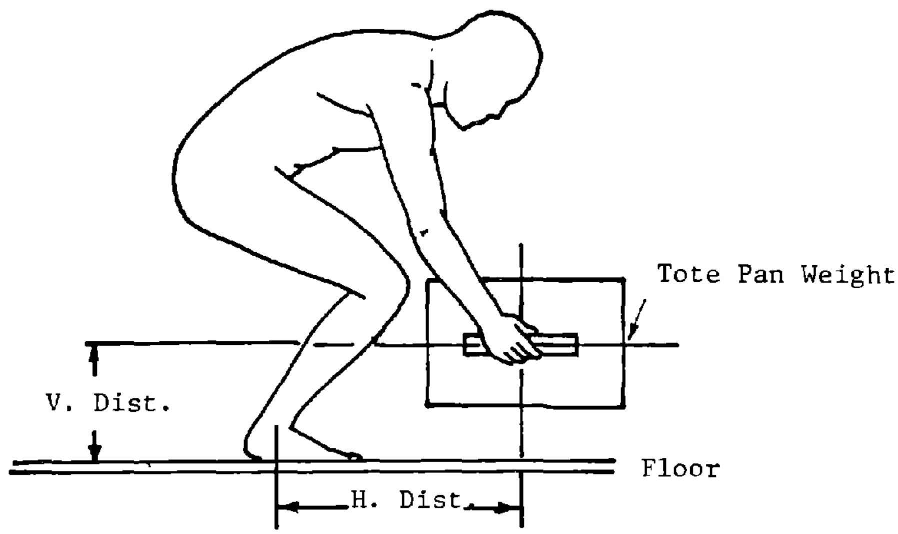
NOTE: Items 4 through 9 were included as part of the Form 3 to evaluate whether or not this type of information has any relationship to future medical incidents. This issue will be addressed in Chapter V.

Item 8 - The information recorded here is taken directly from items b, c, and d of the Form 1 describing the employee's new job. This information is used by the medical department to measure the person's isometric strength in a position simulating the primary LSR task.

Item 9 - For this part, the person is asked to demonstrate lifting capability in a position which approximates the lifting requirements of the job. See Figure 6. Specifically, the person is asked to exert a maximal voluntary isometric exertion in the vertical direction, and to hold it for five seconds. The magnitude of this exertion is recorded on a special strength testing instrument which integrates the demonstrated strength into a time weighted average. This procedure is repeated four times, and the results of each test is recorded.

Item 10- This item requires single trials of three different strengths. The general procedure is the same as reported for item 5, with the exception of changes in the foot/handle locations which are described below.

a. Torso strength - This test requires the handle to be located 15 inches above the floor and 15 inches in front of the ankle of the leading foot. See Figure 7. It is important in this test for the person to bend from the hips to reach the handles, as opposed to bending the knees.



Position of Maximum Lifting Strength Required on Job

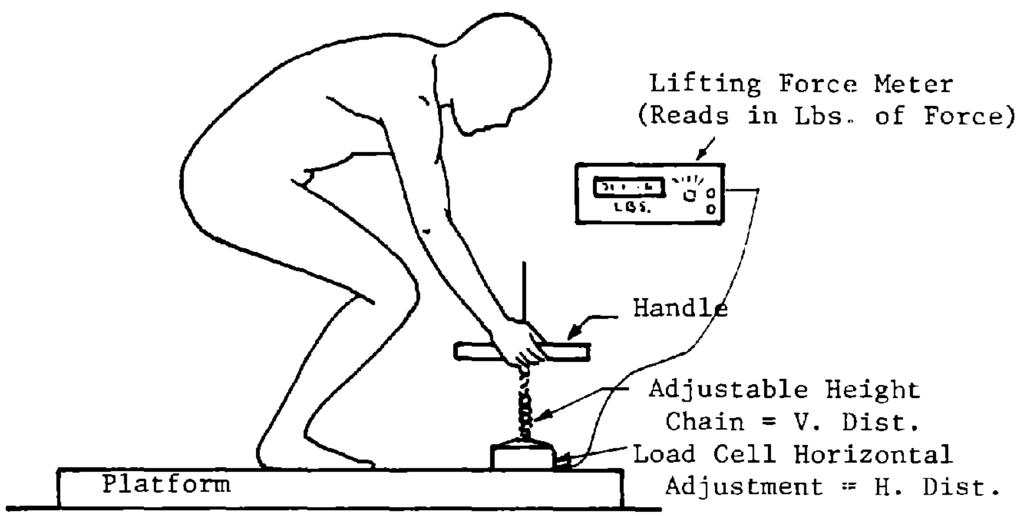


Figure 6: Job position strength test setup

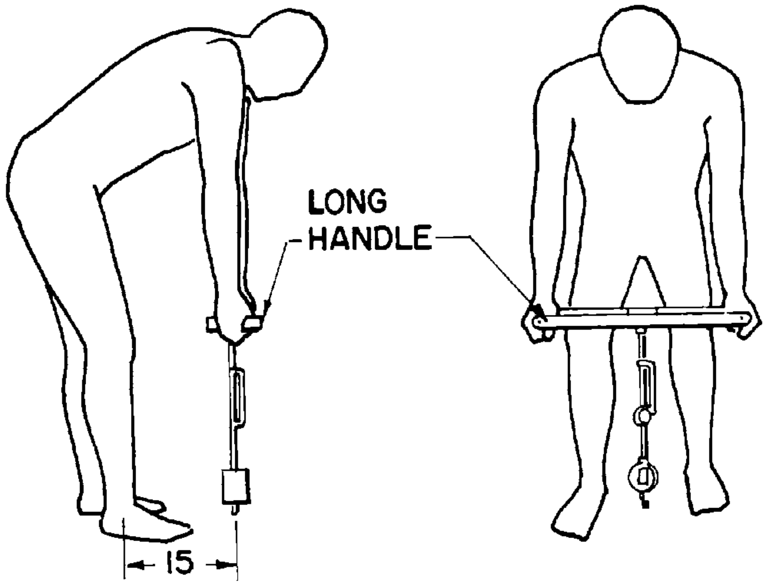


Figure 7: Torso lifting strength test position

b. Arm strength - This test requires that the person's forearms are horizontal and that the upper arms are beside the body (i.e., a 90° elbow angle). The person should stand erect while performing the test. See Figure 8.
c. Leg test - This strength test requires the use of short handles located 15 inches above the floor. This allows the person to squat down and straddle the handles. The person then lifts by extending the legs from the squat position. The arms are extended, and the torso is kept as near to the vertical as possible. See Figure 9.

Medical Incident Data

Each time a study employee reports to the plant medical department with a complaint, a description of the incident is recorded on a Form 4, the medical status report. The function of this report is to give a synopsis of the medical consequences of the incident as well as a brief description of activities preceding the incident. See Figure 10 for the format of this form. After receiving the Form 4, OHMES adds this information to the data base and it becomes part of the worker's employment history. A brief description of the medical status report is given below.

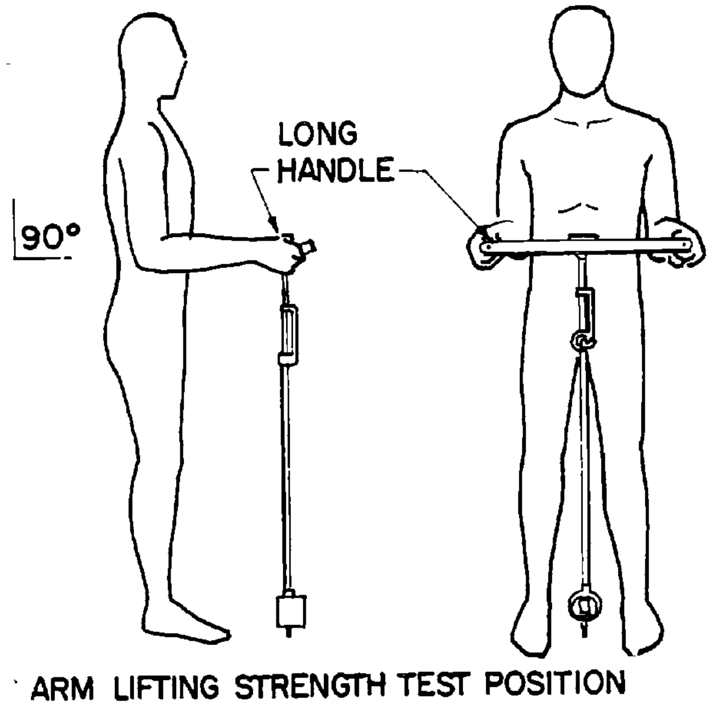


Figure 8: Arm lifting strength test position

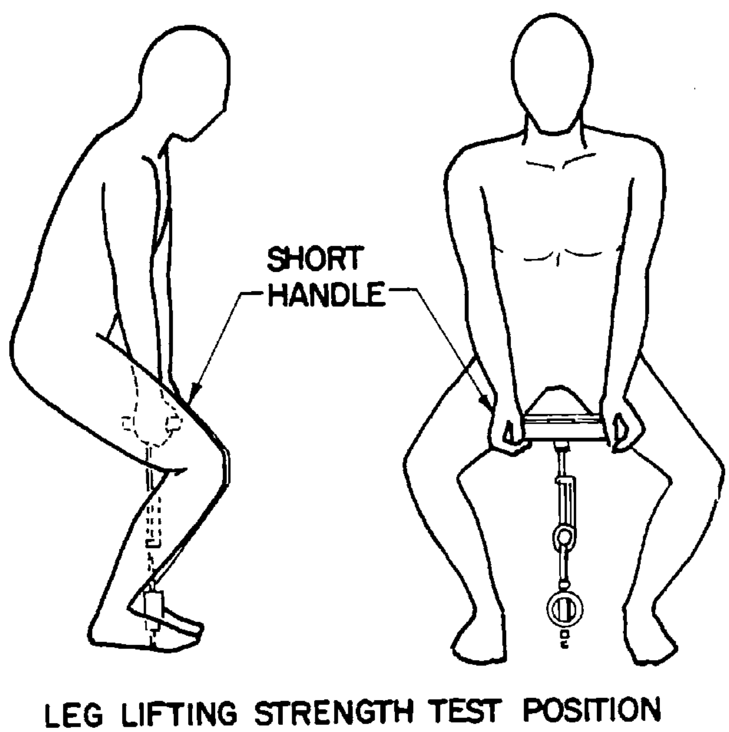


Figure 9: Leg lifting strength test position

CDC 99-74-62
November 1, 1974

Form 4 MEDICAL STATUS REPORT FOR ______________________________
Name

Employee No: ______________________________ Date of Report ____________

1. Portion of Body Involved: (check)

__Head __Upper Back
__Neck __Lower Back
__Shoulder __Abdomen
__Elbow __Chest
__Arm __Thigh
__Wrist __Knee
__Hand __Lower Leg
__Foot __Ankle
__Other ______________________

2. Type of Complaint: (check)

__Sprain or strain
__Abrasion, scratch, laceration, bruise or other cutaneous disorders
__Muscle weakness
__Persistent deep localized pain
__Pain only with motion or with exertion
__Radiating pain
__Muscle spasms
__Intermittent pain
__Other (Specify) ______________

3. Diagnosis: (specify) ______________________________

4. Treatment: (specify) ______________________________

5. Days Lost ____________ Days on restriction ____________

6. If off the job, what conditions does patient state precipitated complaint?

7. If on the job, please determine the following information:

Was exertion involved? _____Yes _____No
If yes, describe:
Hand force involved __________lbs. Size of object: ___W____H____L
Direction: Lifting____Pushing_____ Pulling_____
One hand_____or two hands______

8. General Activity:

Walking___
Ascending Stairs___
Seated___
Stooped over___
Torso turned to one side___
Descending stairs___
Carrying object___
Standing erect___
Squatted down___
Hours after shift start___(hrs.)

9. Working Conditions:

Slippery footing___
Temperature: cold___comfortable___hot___
Other: ______________________________

CC: Medical File
Internal Coordinator

Figure 10: Medical status report (Form 4)

Line 1 - The name of the employee is recorded here to assist the plant in internal record keeping. This piece of information is cut off prior to receipt by the investigators.

Line 2 - The employee's identification number and the date of the incident are recorded here. The I.D. number is used by the data base management system as a sort key.

Item 1 - The area(s) of the body affected by this complaint are reported here. A maximum of six body parts may be reported for each incident.

Item 2 - The nature of the complaint is classified into one of eight categories or "other". Please refer to Figure 10 for a listing of the categories.

Item 3 - The attending physician records his diagnosis of the patient's condition here. If applicable the physician will assign this diagnosis a numerical code. A list of diagnosis codes and descriptions adapted for use in the study appears in Figure 11.

Item 4 - The attending physician records his recommended treatment of the patient's condition here. A numerical code may be used here in addition to the verbal description. For an explanation of this coding system, refer to Figure 12.

Item 5 - Any days lost or restricted are reported here.

Item 6 - If the patient's appearance in medical is due to an off the job incident, a description of the conditions leading up to the incident is recorded here. Note: items 7, 8, and 9 apply only to on the job incidents.

Item 7 - If physical exertion was a factor in the onset of the incident, this item is completed. Information documented here includes, the number of hands used in the exertion, the direction of hand motion, the magnitude of the hand force and the object size.

Item 8 - The employee's general activity at the onset of the incident is reported here. For a list of possible activity categories, refer to Figure 10. In addition the time of the incident (measured in hours after the shift start) is reported here.

Item 9 - Any unusual or hazardous working conditions contributing to the incident are reported here.

Supervisor Data

Line supervisors have the responsibility of evaluating the performance of a study employee on two occasions. The first evaluation is submitted approximately three weeks after the new employee assumes his job. The second evaluation is submitted when the employee leaves the job or at the termination of the study, whichever comes first. The evaluation procedure consists of filling out a Form 5, which can be examined in Figure 13.

As with the other forms, the top line of the supervisors evaluation, which contains the employee's name is removed at the plant. The remaining information at the top of the form is used for the purposes of documenting job and employee identification codes and interfacing with the data base management system.

In questions 1-6, the supervisor is requested to rate the employee's performance on the job based on six different evaluation criteria. The rating is done on a

Code	Diagnosis
00	Infective and Parasitic Disease (Excluding acute Respiratory Infections, Influenza and localized Infections)
14	Neoplasms
24	Endocrine, Nutritional and Metabolic Diseases
28	Diseases of Blood and Blood Forming Organs
29	Mental Disorders
32	Diseases of Nervous System and Sense Organs
39	Diseases of Circulatory System
46	Diseases of Respiratory System (Including Acute Respiratory Infections and Influenza
52	Diseases of Digestive System
58	Diseases of Genitourinary System
63	Complications of Pregnancy
68	Diseases of Skin and Subcutaneous Tissue
71	Diseases of Musculo-Skeletal System and Connecting Tissue
78	Symptoms and ill Defined Conditions
80	Fractures, Skull, and Pelvis
81	Fractures of Upper Limb
82	Fractures of Lower Limb
83	Dislocation without fracture excluding Spine
84	Sprain and Strain without open wound excluding back
85	Intracranial injury without fracture
86	Internal injury to torso without fracture
87	Laceration and open wound including avulsion, cut, amputation (Excluding burn, superficial injury, and when incidental to dislocation, fracture, internal injury, intracranial injury and nerve injury).
88	Fractures, Spine
89	Dislocation, Spine with fracture
90	Sprain and strain, Back without open wound
91	Superficial injury, abrasion, blister, scratch
92	Contusion without break in skin, bruise, hematoma, hemarthrosis
93	Effects of Foreign Body entering through body orifice
94	Burn (excluding burns from swallowing corrosive substances, and effects of electricity, lightning and sun)
95	Injury to nerves or spinal cord without fracture
96	Adverse effects of chemicals and substances including internal chemical burn and excluding external chemical burns
99	Other adverse effects from external causes including heat, cold, radiation, dampness, electricity and other unspecified external causes.

Figure 11: Diagnosis Codes for Item 4 on Form 3 and for Item 4 on Form 4 (Adapted from 8th Revision International Classification of Diseases)

scale ranging from 0 to 5 where a higher score implies a better rating. Question 7, concerning absenteeism, makes use of an inverted scale (i.e., a high score means low performance). The inverted scale used here serves as a control device -- if a Form 5 is filed showing consistently high (or low) scores for all seven questions, there is a fair possibility that the form was not completed in the proper way. (A few such forms were detected and returned to the supervisors for alterations.)

Code	Treatment
0	No specific treatment required
1	Mild medication for symptomatic relief with possible medical work restriction for up to 3 days
2	Medication with repeated visits to medical department and possible medical work restriction up to 7 days
3	Medication and other therapy with up to 3 days off job and up to 14 days on medical work restriction
4	Medication and other therapy, up to 14 days off job and/or up to one month on medical work restriction
5	Medication, other therapy, and/or hospitalization, over 14 days off job and/or over one month on medical work restriction

Figure 12: Treatment codes for Item 4 on Form 4

The bottom line of the form is completed by the plant's payroll office. The total hours accumulated by the employee on the study job is recorded here. This datum is a most critical part of the worker's employment history since it is the only information available showing his exposure to the job. Such information is vital in the computation of medical incident rates of all types.

Descriptive Statistics

Descriptive statistics, by plant, are summarized for major study variables in Appendix A. These statistics are computed on the employee level. A time series graph, showing the cumulative number of forms received is also included in this Appendix.

PLANT PARTICIPATION

All study data was collected in the field with the cooperation and active participation of six industrial plants. Five of the plants were operated by a large electronic components manufacturer. The sixth plant was operated by a major steel producer. Both of these industries make use of complex and diversified manufacturing techniques, many of which have manual materials handling as an integral part. The selection of these six plants permitted a wide variety of jobs to be studied.

Furthermore, by using six plants it was possible to overcome any plant specific biases. For example, the degree of mechanization of a plant may be a function of its age. Newer plants are likely to have more modern equipment which could alter the nature of materials handling jobs. By including both modern and older plants in the study design, this type of bias was prevented. Other biases might have resulted from the geographical location of the plant, and the work force it would attract. To minimize such a possibility the plants selected were scattered throughout the United States. Participants in the study were drawn from the work force in the states of Georgia, Illinois, Indiana, Louisiana and Missouri.

CDC 99-74-62
November 1, 1974

Form 5 SUPERVISOR'S EVALUATION OF: ______________________________
Name

---

3 wk./Transfer/Final Evaluation (circle one) Employee No.: ____________________

Date: ____________________

Recently, this employee was assigned to your section to perform the duties of
________________________________, Occ. Code # ____________.
This job has been designated as requiring significant manual lifting. The above individual was given a strength test prior to beginning work on this job.

All persons so tested are being monitored to determine the success or failure of this program. As a further evaluation, you are requested to reply on this form to the following questions:

1. The person was/is physically capable of performing the duties of the job.
Strongly Disagree 0 1 2 3 4 5 Strongly Agree

2. This person performs/ed all the physical lifting duties required.
Strongly Disagree 0 1 2 3 4 5 Strongly Agree

3. The person accepts/ed the manual lifting as a reasonable part of the job.
Strongly Disagree 0 1 2 3 4 5 Strongly Agree

4. The person has/had no accidents or injuries as a direct result of manual lifting on the job.
Strongly Disagree 0 1 2 3 4 5 Strongly Agree

5. The person was/is able to maintain the pace demanded by the job.
Strongly Disagree 0 1 2 3 4 5 Strongly Agree

6. The person and the job were/are well matched.
Strongly Disagree 0 1 2 3 4 5 Strongly Agree

7. If the person has left the job, or is often absent, it was because of the manual lifting required.
Strongly Disagree 0 1 2 3 4 5 Strongly Agree

Signature ______________________________

Personnel or Payroll Records:

I. The above employee did/did not (circle one) stay on the job.

II. Accumulated hours on above job as of ________ (date) is/was __________ (hrs.).

CC: Internal Coordinator

Figure 13: Supervisor's Evaluation of Newly Assigned Employee (Form 5)

Personnel Involved

Plant personnel assisting in the study included representatives of the Medical and Industrial Engineering Departments. The plant physician supervised all strength testing procedures and prepared all medical evaluations. He was assisted in his efforts in several instances by an industrial nurse. All job analyses were conducted by an engineer with special training in biomechanics. In a few plants, the Industrial Hygiene Department coordinated the efforts of the above two groups.

Job Analyses

A total of 901 jobs throughout the six plants were analyzed biomechanically and added to the OHMES data base. (Refer to Table 4 for a breakdown by plant of the number of jobs analyzed.) Of these jobs, only 128 were eventually filled by an employee serving as a study subject. The low percentage of filled jobs (14.2%) was attributed to the general decline of the national economy during the data collection period (late 1974 through mid 1976). Specifically, the hiring rate was considerably lower than originally anticipated; therefore, fewer jobs were available to be filled by employees who were not experienced, which was required by the study protocol. In many instances when a job opened up, it was filled by a worker who had previously been laid off from that job. In an effort to maintain the longitudinal integrity of the study design, these workers could not be included in the experiment because of previous exposure to the job.

Several other statistics in Table 4 are worth noting. Over half (61%) of the jobs that were eventually filled had more than one study employee while the average number of employees per filled job was 4.3. The placement of more than one employee per job was an important issue in the experimental design due to the need for separating an individual worker's attributes from the effects of job-employee interactions during the analysis phase.

Employee Strength Testing and Follow Up Surveillance

Summary statistics showing the level of employee participation in the study are given in Table 5. A total of 594 individuals underwent pre-employment interviews including the strength testing procedure. Of these people, 551 successfully completed the study. Successful completion implies that the worker reported to his new job, stayed there at least three weeks, and was the recipient of a final supervisor's evaluation showing the total number of hours exposed to the job. Of the 43 workers who failed to complete the study, the four most common explanations were:

1. The worker never reported to his assigned job.
2. The worker reported to his job, but stayed for less than three weeks.
3. The assigned job was previously held by the worker, thus destroying the longitudinal nature of his exposure.
4. A major material handling element of the assigned job was eliminated by job redesign, thus invalidating the original LSR analysis.

Additional analysis of Table 5 reveals that the average period of exposure was approximately 1200 hours. Assuming 2000 hours as a standard work year approximately 330 man years of data were obtained.

Table 4: Plant participation - jobs studied and filled

Item	PLANT 1	2	3	4	5	6	Total
Number of Jobs Analyzed	200	167	78	35	166	255	901
Number of Jobs Actually Filled	34	31	12	20	7	24	128
Percentage of Jobs Actually Filled	17.0	18.6	15.4	57.1	4.2	9.4	14.2
Number of Jobs with More than One Employee	22	16	7	12	3	18	78
Percentage of Filled Jobs with More Than One Employee	64.7	51.6	58.3	60.0	42.9	75.0	61.0
Average Number of Employees per Filled Job	3.17	2.35	5.50	2.40	4.57	9.33	4.3

Table 5: Plant participation - employee testing and participation

Item	PLANT 1	2	3	4	5	6	Total
Number of Employees Strength Tested	114	80	71	49	38	242	594
Number of Employees Completing Study	108	73	66	48	32	224	551
Percentage of Employees Completing Study	94.7	91.3	93.0	98.0	84.2	92.6	92.8
Number of Medical Incidents Reported	107	66	137	28	32	139	509
Average Exposure Hours/Employee	1297	998	1106	757	1085	1361	1201
Number of 3 Week Evaluations	100	73	64	48	25	184	494
Percentage of Employees Receiving 3 Week & Final	92.6	100	97.0	100	78.1	82.1	98.7

MANAGEMENT INFORMATION SYSTEM REQUIREMENTS OF OHMES

All data relevant to the experiment is sent from the plants to the University on one of the four types of reporting forms described in the previous section of this chapter. Form 2 is an Employee Consent Form which is retained by the plant in the employee's medical file and is not forwarded to the University. Thus, the University is not aware of the name of any employee participating in the study.

Once received, the data is coded, keypunched, and entered into the Experimental Data Base. The general structure of this data base is shown in Figure 14. This diagram demonstrates the hierarchical nature of the system -- each plant is independent of all other plants and is populated by a set of job descriptions (Form 1's) and a set of employee descriptions (Form 3's). In turn, each employee possesses a set of medical complaints (Form 4's) and a set of supervisor's evaluations (Form 5's). The internal structure of each of these record types showing the position of each data filed is given in Figures 15 through 18.

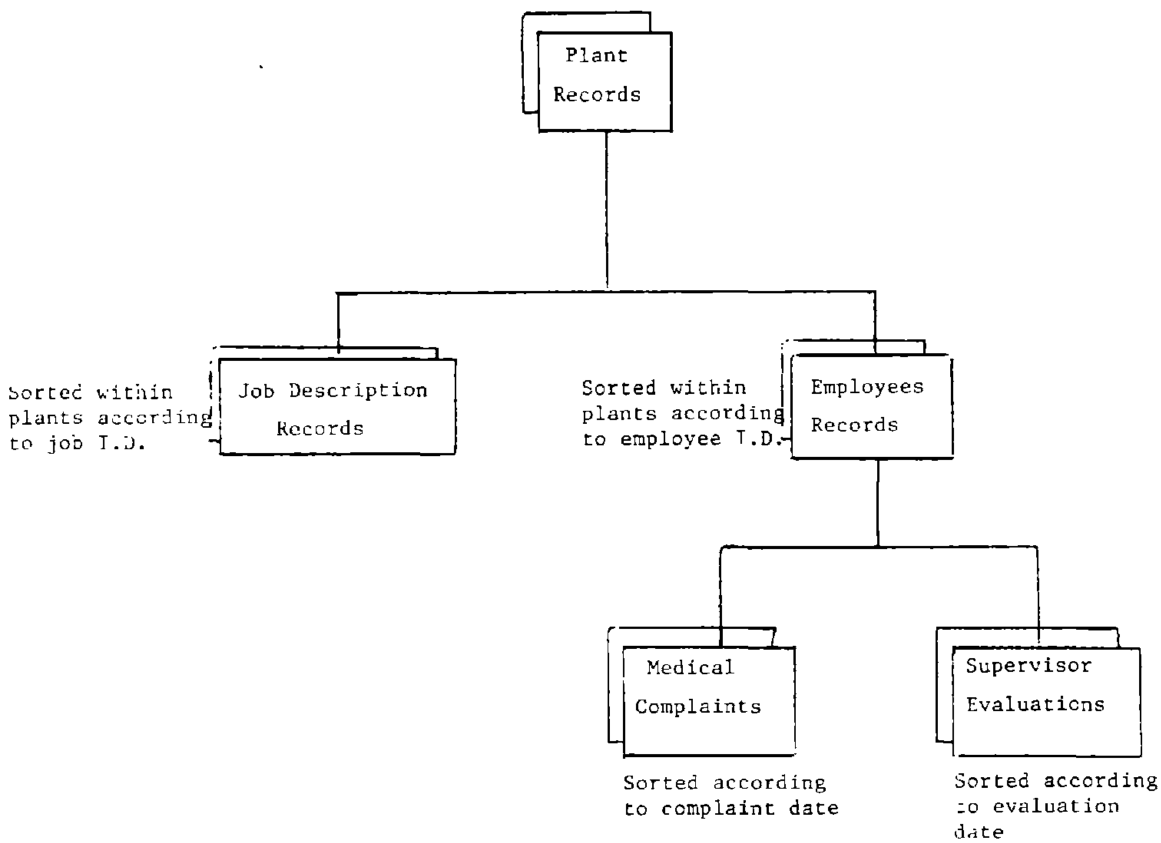


Figure 14: The general structure of the data base

Word		
1	Job I.D. (16 Char.)	
2		
3		
4		
5	Form 1 date	
6	Primary lifting object	Weight
7	Horizontal distance	Vertical distance
8	Object length	Object width
9	Object height	Lifting freq. per day
10	Lifting freq. per week	Hot/cold conditions
11	Slippery conditions	Prime LSR
12	Secondary object (1)	Secondary weight
13	" horizontal dist.	" vertical dist.
14	" freq. per day	" freq. per week
15	(as 12-14 for secondary	
16	lifting No. 2)	
17		
18	(As 12-14 for secondary	
19	lifting No. 3)	
20		
21	(As 12-14 for non-symmetric	
22	lifting No. 1)	
23		
24	(As 12-14 for non-symmetric	
25	lifting No. 2)	
26		
27	(As 12-14 for non-symmetric	
28	lifting No. 3)	
29		
30	(Reserve)	

Figure 15: Job descriptions (Form 1) record structure

Word			
1	Employee I.D. (16 Char.)		
2	"		
3	"		
4	"		
5	Form 3 date		
6	Job I.D. (16 Char.)		
7	"		
8	"		
9	"		
10	Height	Weight	
11	Age	Sex	
12	Accident history date (case 1)		
13	" " " (case 2)		
14	" " " (case 3)		
15	Diagnosis 1 (Case 1)	Diagnosis 2 (Case 2)	Accidents
16	Impairment (Case 1)	Diagnosis 1 (Case 2)	History
17	Diagnosis 2 (Case 2)	Impairment (Case 2)	
18	Diagnosis 1 (Case 3)	Diagnosis 2 (Case 3)	
19	Impairment (Case 3)	Prognosis	
20	Experience Date (1)		
21	Experience type (1)	Form 2 signed	Experience
22	Experience Date (2)		
23	Experience type (2)	Experience evaluation	
24	Test 1	Test 2	Job
25	Test 3	Test 4	Tests
26	Tests Average Result		
27	Torso	Arm	Strength
28	Leg	(Reserve)	Tests

Figure 16: Employee's record structure

Word		
1	Complaint (Form 4) date	
2	Body member (1)	Body member (2)
3	" " (3)	" " (4)
4	" " (5)	" " (6)
5	Complaint type (1)	Complaint type (2)
6	" " (3)	" " (4)
7	" " (5)	Diagnosis (1)
8	Diagnosis (2)	Treatment (1)
9	Treatment (2)	Days lost
10	Days restriction	Case off job
11	Exertion involved	Hand force
12	Direction	One/two hands
13	Object width	Object height
14	Object length	Activity (1)
15	Activity (2)	Hours after shift start
16	Slippery conditions	Temperature conditions
17	Other conditions	(Reserve)

Figure 17: Injury complaint (Form 4) record structure

Word		
1	Evaluation date	
2	Job I.D. (16 Char.)	
3		
4		
5		
6	Evaluation type	Capability
7	Performance	Acceptance
8	Injury information	Working pace
9	Job match	Absenteeism
10	Total hours on job	
11	As of date (# hrs. on job)	
12	(Reserve)	

Figure 18: Supervisor evaluation (Form 5) record structure

The need for this computerized, highly structured data base results from the large amount of information to be processed and analyzed throughout the course of the experiment. At the conclusion of the study approximately 105,000 individual data items had been received by the University. Successful and complete analysis of this information requires extensive cross referencing among jobs, employees, medical incidents, and supervisor's evaluations. To control and manipulate such a large quantity of information is a formidable task without the use of a comprehensive data management system. Such a system was developed specifically for the experiment. This system implemented several features of a General Data Base Management System developed by the Department of Industrial and Operations Engineering at the University of Michigan.

SOFTWARE DESCRIPTION OF OHMES

The data management system is composed of over 2500 statements organized into 36 subroutines which input, edit, maintain, and report information related to the progress of the experiment. In addition, the data base can be used in conjunction with MIDAS (Michigan Interactive Data Analysis System), a sophisticated and extensive statistical software package. Developed by the University of Michigan Statistical Research Laboratory, MIDAS has many data reduction and analysis capabilities and is capable of handling large data sets.

A brief description of the principal components of computer software developed for the study is given below:

1. A main program to receive input data from all forms.
2. Sub-programs to process data from the individual form types and store this information in the data base.
3. Sub-programs to report all new information added to the data base during the monthly update runs. This allows the verification of all data in order to insure correctness.
4. A program to produce a monthly summary report which gives the status and level of participation of the various plants involved in the experiment.
5. Programs to produce histograms and summary statistics of the data collected on the four types of reporting forms. These statistics are calculated for the individual plants as well as a grand total for all plants.
6. A program to extract information from the data base and organize it into a format compatible with MIDAS and other existing statistical analysis software. This permits further reduction and analysis of experimental data.
7. An on-line information retrieval system which allows University personnel to obtain a complete description of any job being studied in the experiment or a complete description (including all medical evaluations, strength test results, medical incidents, and supervisors' evaluations) of any employee. This system accesses the data base via teletype and retrieves the desired information in a matter of seconds.

8. A program to produce summary reports of medical incidents by plant. This program prints out a brief description of every medical incident as well as a cross matrix showing medical diagnosis vs. body part affected.

PROCEDURES

To insure completeness and accuracy of the experimental data base, a formal set of data handling procedures was adopted by the University. A brief summary of these procedures is given in Figure 19, and explained below.

1. The plants collect data on a regular basis, complete the various reporting forms, and forward these documents to the University.
2. The University keeps a log of all forms received. This log records the type and quantity of incoming forms, the sending plant, and the date of receipt. Any forms returned to the plants for corrections or additional information are also recorded here.
3. As soon as possible, all forms are given a preliminary check. An examination is made to disclose any errors or deletions that might exist. Forms found to contain errors are immediately returned to the plants for corrections. Including a preliminary check early in the data handling process helps to minimize the recycle time for correcting problems.
4. The data contained on each form must be converted into a format readable by the computer. This procedure is known as coding and consists of taking information from the original forms and converting it into a series of digits and/or letters separated by commas. Occasionally the coding process will uncover errors and deletions that were not detected during the preliminary check. When this occurs, the incorrect forms are returned to the plants.
5. Once coded, a form is ready to be entered into the computer. This step is done by a keypuncher using an on-line teletype system. The data is first entered into a transaction file which is essentially a temporary storage location. This procedure allows all data to be checked after it is entered into the computer, but before it is added to the data base. Called the "First Level Check," its purpose is to detect and correct any keypunching mistakes prior to the monthly update run. This procedure reduces the quantity of erroneous information entering the data base. When the "First Level Check" is completed, the original forms are sorted and filed for future reference.
6. At the end of every month, a monthly update run is executed. This procedure transfers information from the transaction file (which then becomes obsolete) to the permanent data base. Not all data in the transaction file is accepted by the data base. An example of rejected data is a supervisor's evaluation of an employee who has not received a medical evaluation and who has not been strength tested. In addition, the program checks to assure that jobs, employee, medical incidents, and supervisors' evaluations are 1) complete, 2) fully cross-referenced, and 3) unique (no multiple entries for a single job or employee). Whenever problems are detected, the computer gives a warning message on the printed output and

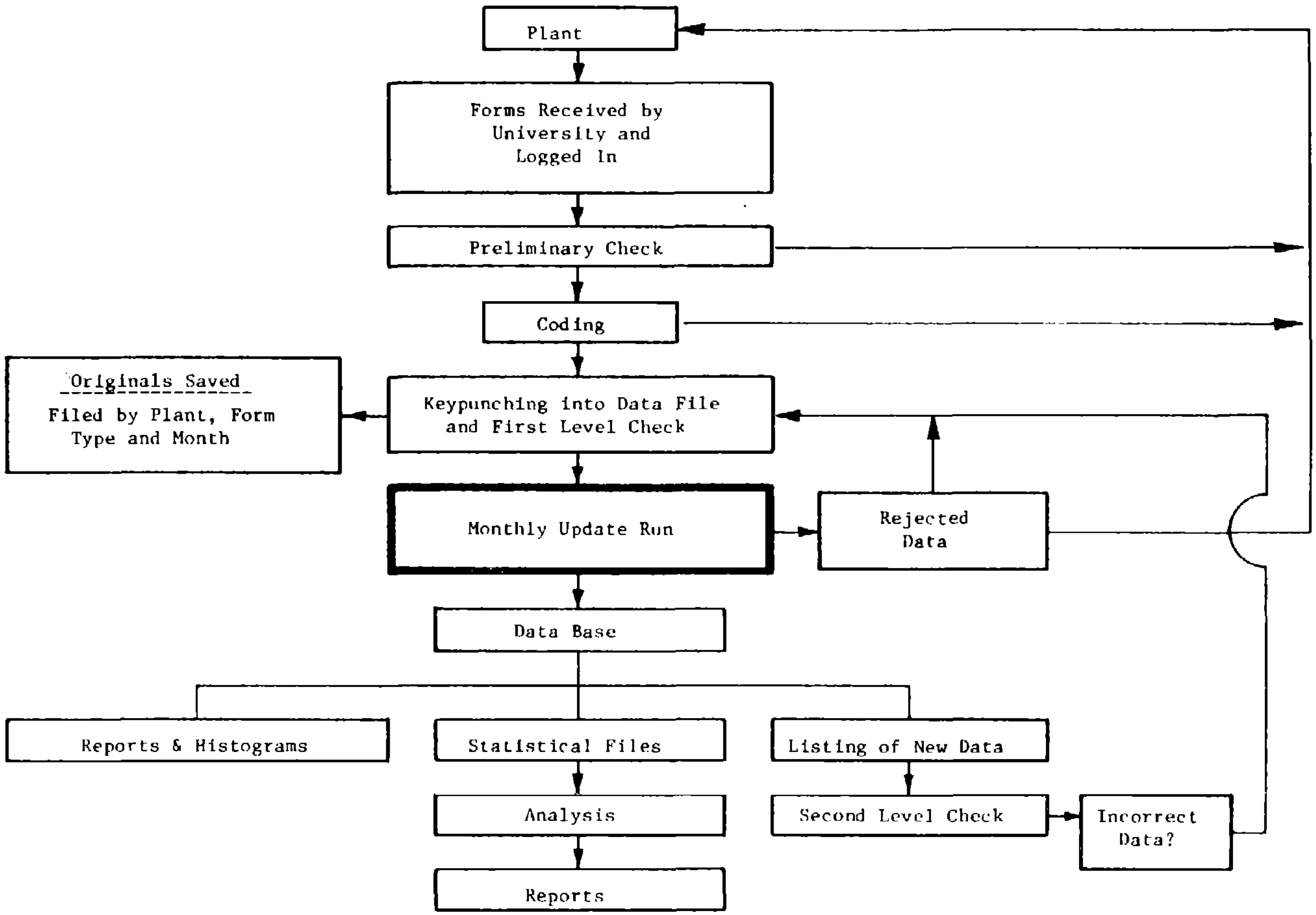


Figure 19: Data handling procedures

the plant is later contacted to alleviate the problem. Information not rejected by the computer enters the data base where it can be accessed at a later time.

7. Following each monthly update, extensive information is extracted from the data base. This information can be grouped into the three categories described below:

   A. Reports and Histograms - Once a month, a summary report is produced which shows the status and level of participation of the various plants involved in the experiment. By comparing the information contained in a series of these reports, the rate of progress in data collection can be determined.

   B. Statistical Files - Because the available statistical software packages cannot access the data base directly, data desired for analysis must be extracted and stored in a special file with a format compatible with these systems. Following the monthly update, these statistical files are also updated in order to provide the most accurate and complete set of data for analysis.

   C. Listing of New Data - Following the monthly update, all new data entered during the month is printed out by the computer. Because this printout is accessed directly from the freshly updated data base, it allows University personnel to see information exactly as the computer sees it. At this time the "Second Level Check" is done, in which this printout is very carefully compared to the original forms sent by the plants. All discrepancies are noted and any incorrect data is re-entered into the computer via the subsequent transaction file. The correction then becomes effective during the next monthly update. Although this procedure results in a one-month lag in the correction process, it is the most economical and efficient technique for insuring an accurate data base due to a relatively high fixed cost associated with any update run.

CHAPTER III

ASSESSMENT OF JOB PHYSICAL STRESSES

As mentioned in the previous Chapter, the Occupational Health Monitoring and Evaluation System (OHMES) utilized in this study required a rigorous evaluation of the physical stresses imposed on a worker while performing manual materials handling activities. This evaluation resulted in the data entered into Form 1, described earlier in Figure 2. It is the purpose of this chapter to enlarge upon the methodology used to gather these data. In addition, descriptions of the more elaborate physical stress evaluation methods used to perform the case studies are described. It is the hope of these authors that this chapter will demonstrate how jobs can be more rigorously evaluated to quantitatively determine the degree and type of physical stress imposed on workers performing a job containing significant manual activity.

What follows is a description of the three job evaluation methodologies that have been used in this project. All of these have been developed and described in other publications, but their application in this project is unique and deserves special attention. The methods are, in order of reporting:

* Lift Strength Ratio (LSR)
* Biomechanical Strength Modeling
* Metabolic Energy Expenditure Rate Modeling

The first method was used to evaluate the 901 jobs included in this study. The second and third methods were only used in the four job case analyses described later in Chapter VII.

LIFT STRENGTH RATIO (LSR) OF JOB

The most simple rating of the strength requirement of a manual materials handling job is determining the maximum weight to be lifted at least once in performing the job. This is highly intuitive, since people grow up with a good understanding of the magnitude of a weight that is "light" or "heavy" when lifting.

Unfortunately, such a simple rating does not reflect a major factor, the load distance effect. In essence, if the load is held at a distance from the body (e.g., horizontally at arms length) then the effect, or stress, of the load is much greater, particularly to the back and shoulders than if the load is held in close to the torso. This effect of the load distance has also been referred to by Tichauer (1965) as the bulk moment effect.

In addition to a horizontal effect of the load location on the musculoskeletal system, the height of the load is critical. If a load must be handled above the head or shoulders, body balance is much more difficult to maintain, leading to the possibility of sudden dynamic motions which can greatly stress the entire musculoskeletal system. It is also true that if a load is compact and can be lifted between the knees while in a squat lifting posture, the strong leg and back muscles can develop higher strengths than when the load is at waist height, which relies on the often weaker shoulder and elbow flexor and abductor muscle actions.

Because the location of the load in the hands is critical in determining how much and where the musculoskeletal system is particularly stressed, the Lift Strength Ratio (LSR) System was devised. It relies on the use of a graph of the predicted lifting strength capability of a large/strong male, as predicted from an earlier study by Martin and Chaffin (1972). The predicted strength graph, depicted earlier in Figure 3, is for symmetric lifting (both hands) of relatively compact objects in the sagittal plane. These assumptions, though highly restrictive, do provide a practical means to incorporate the effect of the load location when assessing a jobs' strength requirements. The use of a biomechanical strength model described later in this section greatly increases the generality of such analyses.

The LSR is simply computed by first observing the job and determining the weights handled and their extreme locations from the ankle of the forward foot and the floor. If the person can easily step closer to the load, the smaller distance is used. Each load is then compared with the predicted strength in the LSR Graph for a large/strong man when lifting the load with his hands located in the position demonstrated by the worker performing the job. Thus, the primary LSR becomes the maximum value of these comparisons, or:

$$LSR_{Primary} = \frac{\text{Load (lbs.) Lifted on Job}}{\text{Predicted Strength (lbs.) in same position}}$$

The secondary LSR's are simply lesser values of these ratios, and are also tabulated in Form 1. It should be noted then that the LSR values can simply be interpreted as the proportion of a large/strong males' strength required to perform a job.

As an example, if a worker was observed lifting a 50 pound object to a shelf which required the hands and CG of the mass to be located 25 inches in front of the ankle of the leading foot and 50 inches above the floor, the LSR would be:

$$LSR = \frac{50}{75} \approx .67$$

where 75 is predicted strength from Figure 3. Thus, the LSR in this example indicates such an act would require about two-thirds of a large/strong man's strength to perform the lift.

From experience, this simplified analysis is probably applicable for rank ordering about 70 percent of manual materials handling jobs. The other 30 percent require much more rigorous strength analyses because of the non-symmetric, one-handed, and/or dynamic nature of the activities that stress the musculoskeletal system to its maximum capability.

BIOMECHANICAL STRENGTH MODELS

The preceding LSR concept relies on a graphical solution, which by nature limits the generality and meaningfulness of the results. Often it is desirable not only to rank order the gross strength requirements of various jobs, but one would like to know which specific muscle actions are limiting the workers' performance, and how many people in a general worker population could perform such an activity. Also, many manual materials handling activities are not just lifting of loads, but often involve pushing and pulling actions with perhaps one hand located or loaded quite differently than the other.

To solve these more complex questions, a computerized biomechanical strength model must be employed. The development of such models has been a primary goal of the Human Performance and Safety Engineering Research Laboratory for the past 12 years. This effort has resulted in a three-dimensional biomechanical strength model. It is this model which was used in the case studies described in Chapter VII. What follows is a brief description of this technology.

The three-dimensional strength model utilized in the case evaluations is depicted spatially in Figure 20. The specific details of the model have been published elsewhere by Garg and Chaffin (1975). Essentially, the model develops resultant torque estimates at each joint center for specified external

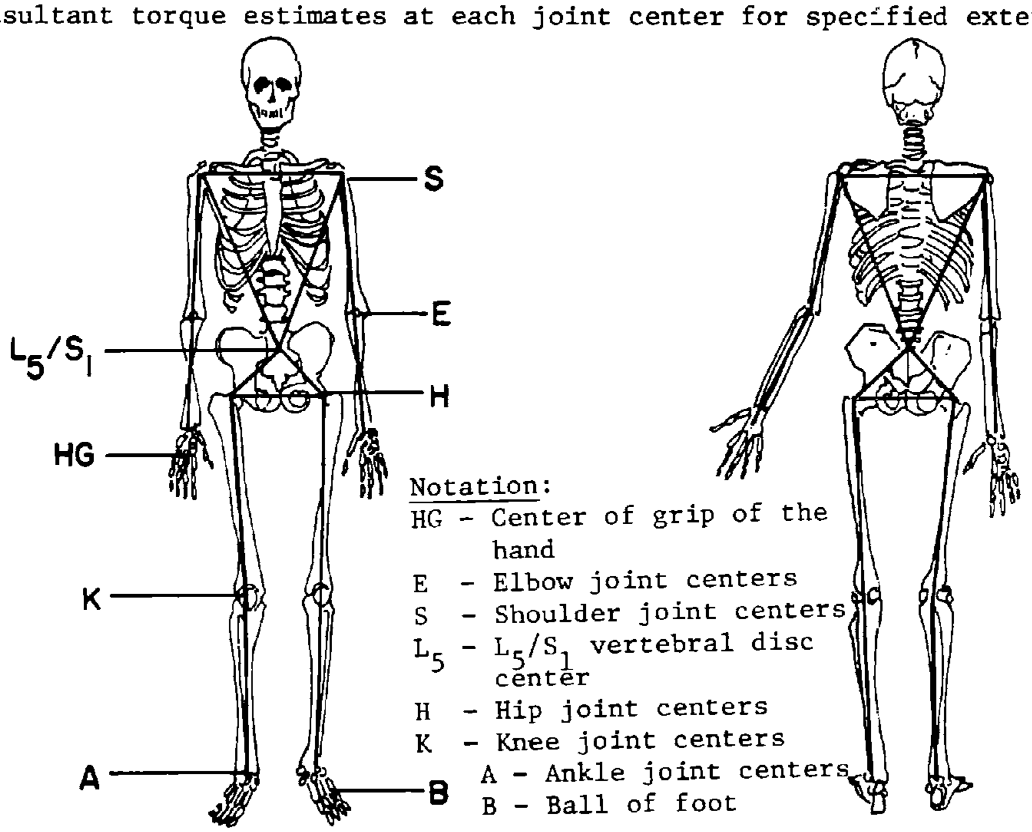


Figure 20: Linkage representation used in the biomechanical model (Garg and Chaffin, 1975)

forces acting on the body. These are then compared to the inputted reactive volitional torques that can be achieved at each joint (i.e., to the muscle group strengths). Figure 21 depicts the body angles used to describe the posture of a person for modeling. For each angle there are at least two opposing muscle strengths that must be inputted to the model to act as the limiting reactive voluntary torques at each joint. These inputted muscle strengths need to either be measured, or population distribution strengths can be assumed by the user. The model then allows the user to manipulate the external forces and postures of interest to determine the maximum hand forces that can be produced by a designated population without having a joint resultant torque exceed a given joint reactive torque strength. Thus, at this point, the model can be thought of as depicting the static muscular capability of a person in any posture and load combination described.

Two other human limitations are recognized by the model for strength predicting. One is the body balance capability. As an example it is possible when standing that the external forces on the body may cause the line of gravity of the total person/load system center-of-gravity to be outside the area bounded by the feet, and hence the person will fall over if a rapid postural correction is not made. This loss of static equilibrium is assessed for any posture and force combination inputted to the model, and hence the user can easily determine when balance is critical to task performance.

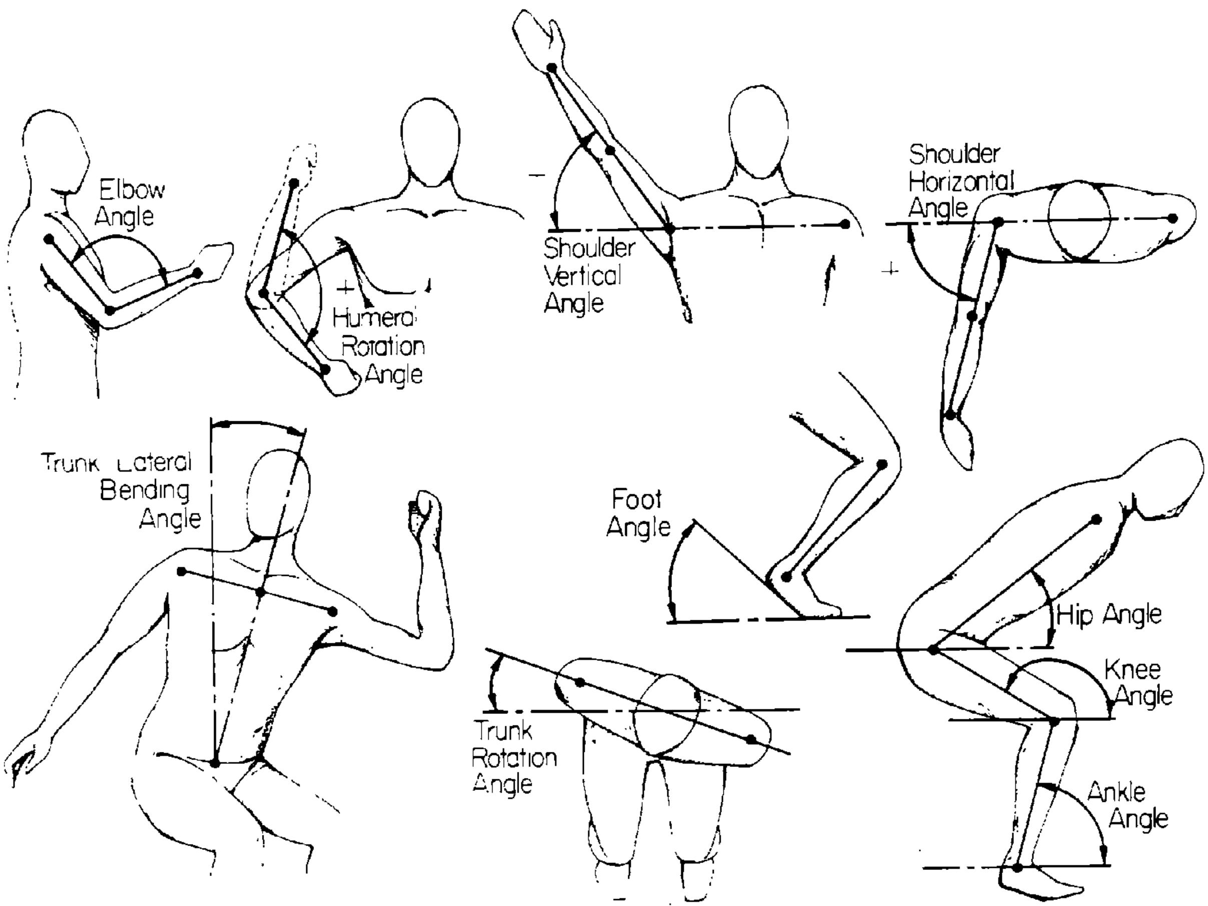


Figure 21: Body angles used in the biomechanical model (Garg and Chaffin, 1975)

The final constraint in the model is based on evidence that lumbar compression forces may limit a person's volitional capability (Chaffin and Baker, 1970) and also, if large, these forces may lead to disc degeneration and low-back pain (Chaffin and Park, 1973). Thus, an assessment similar to the Morris, Lucas and Bressler Model of low-back compression has been included in the strength model, with acceptable compression limits being selected by the user.

The macro-logic of the model is depicted in Figure 22.

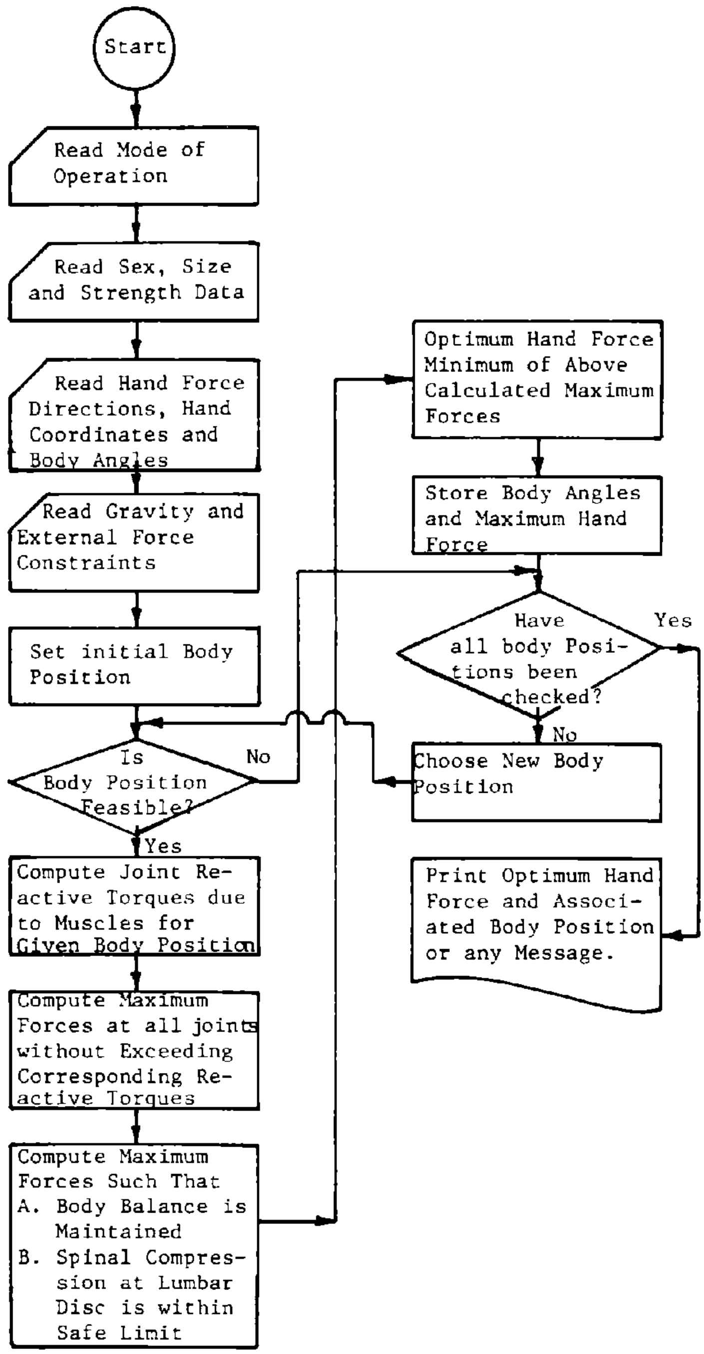


Figure 22: Macro logic flow diagram (Garg and Chaffin, 1975)

USING BIOMECHANICAL MODELS FOR JOB STRESS EVALUATIONS

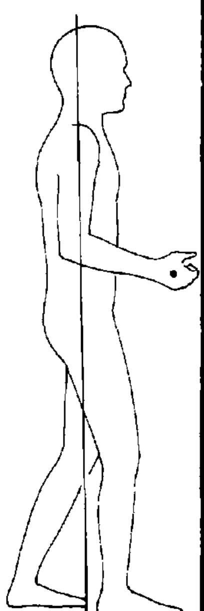
To input data to this model a simplified job physical stress evalution form has been developed and is depicted in Figure 23. The top line of the "Physical Stress Job Analysis Data Sheet" is used to record background and identification information for each job. The current format of the header is subject to change at the discretion of the plant using it in order to meet the specific requirements of the plant. Data items may be omitted, added, or changed in size as needed. (The numbers in parentheses are the current character fields.)

Following the header, each task element comprising the job is described on a separate line. Recommended procedures for completing this portion are as follows:

TASK NUMBER - A three digit integer in the range (1-999) is used to identify each physical element of the job. It is suggested that the first task be given the number 1, and that subsequent tasks be numbered sequentially. The function of these numbers is to assist in identifying the output lines.

TASK - Each job element will be classified into one of the 16 categories which appear below. Classifications 1 through 10 are used to describe biomechanical stresses and are concerned with direction of exertions and external loads and are depicted in Table 6. Classifications 11-16 are used to describe general physical activities and are important in evaluating metabolic loads. These are described in Table 7. Each task is assigned a two digit code according to the scheme described in Tables 6 and 7.

Table 6: Task load types for strength analyses



Code	Task	Direction of Load	Direction of Motion
01	LIFT	↓	↑
02	LOWER	↓	↓
03	PUSH	←	→
04	PULL IN	→	←
05	PULL RIGHT	→ Left	← Right
06	PULL LEFT	→ Right	← Left
07	PULL DOWN	↑	↓
08	HOLD	↓	0
09	TORQUE (R)	CCW	CW
10	TORQUE (L)	CW	CCW

Col (1-8) Date	(9-18) Plant	(19-25) Department	(26-32) Analyst	(33) Rep.	(34) Non. Rep.	(35-42) Job Classification	(43-61) Job Location	(62-81) Job Title	Subdescription and Comments (82-101)
**									

Task Number (1-3)	(4-5) Task Code	(6) Body Posture Code	(7-16) Object	Force (lbs.)		Hand Location (inches)												(59-62) Body Movement in Feet (Walk, Carry, Climb, etc.)	Task Duration (minutes) (63-65)	Frequency		(71-94) Remarks	(95-101) Classification
				(17-19) Avg.	(20-22) Max.	Origin						Destination								65 67	68 70		
						Right Hand			Left Hand Displacement			Right Hand			Left Hand Displacement					Repetitions per Cycle	Cycles per Day		
						23 25 V	26 28 L	29 31 H	32 34 V	35 37 L	38 40 H	41 43 V	44 46 L	47 49 H	50 52 V	53 55 L	56 58 H						

Figure 23: Physical stress job analysis data sheet

Table 7: Tasks used for metabolic energy expenditure predictions

Code	Task Description
11	CARRY - Walking with a load
12	WALK
13	LIGHT WORK - Non-strenuous hand work from a standing or seated position
14	WAIT
15	CLIMB - May be done with or without external load
16	OTHER - specify in remarks

BODY POSTURE - Each job element is classified as being performed using one of the seven postures which appear in Table 8. Each posture is assigned a one digit code according to the given scheme in Table 8.

Table 8: General posture data descriptors

Code	Posture	Description*
1	STAND	Body is in upright position with no significant deviation from the vertical. Included angles at knee, hip and trunk are near 180°.
2	SIT	Body is seated.
3	SQUAT	Body is in a crouched position with significant bending of the knees (included angle < 150°). Slight to moderate trunk flexion (bending forward) will occur.
4	DEEP SQUAT	Similar to squat, however included angle at knee is less than 100°.
5	STOOP	Trunk is flexed forward with slight bending of the knees.
6	LEAN	Joint angles at knee, hip and trunk remain at or near 180°. Lower leg angle with respect to the floor is allowed to deviate forward or backward from 90°.
7	SPLIT	One foot is significantly forward of the other foot. Included angle at knee of the forward leg deviates from 180°, rear leg remains straight.

* Pictoral discriptions are also given to the job analysts.

OBJECT - This item contains a ten character alphanumeric string describing tht object that is being lifted, lowered, pushed, pulled, etc.

FORCE (AVG) - This value is the average force (lbs.) that is required to oppose the load on the hands.

FORCE (MAX) - This value is the maximum force (lbs.) that is required to oppose the load on the hands for a given task. For situations where loads are constant (lifting 50 lbs. bags, for example) the average force and the maximum force will be equal. Procedures for measuring each force in different operating situations have been developed to assist the job analyst.

HAND LOCATION - The location of the hands is determined and recorded at the beginning (origin) and completion (destination) of each task element. The recommended procedure for obtaining these data is to determine first the vertical, lateral and horizontal displacements of the right hand from the midpoint of the line joining the ankle of each foot. These three measurements are made along three orthogonal axes with a common origin between the ankles. See Figure 24 for a definition of axes. Once the position of the right had has been determined, the next step is to measure the displacement of the left hand from the right hand along the same axes. NOTE: FOR ONE HANDED TASKS, ALL DISPLACEMENTS ARE ENTERED AS ZERO.

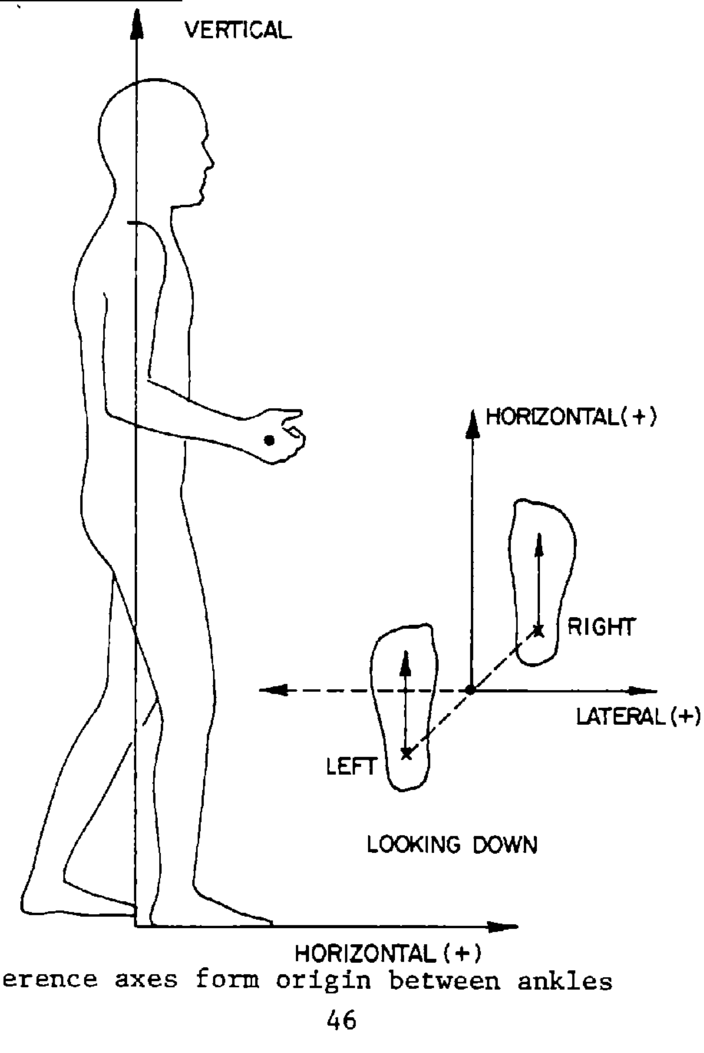


Figure 24: Reference axes form origin between ankles

Once the hand locations for the origin have been documented, the above procedure is repeated for the destination.

BODY MOVEMENT - This item contains the number of feet traversed during the walk, carry and climb tasks. For all other tasks classifications, it is left blank.

TASK DURATION - This item is the normal time required to perform the task element. The time is expressed in minutes and fractions thereof.

FREQUENCY - The two items in this section are used to describe the number of times per day that the task element is performed. REPETITIONS PER CYCLE is the number of times the particular element is performed in a single cycle of the task. CYCLES PER DAY is the number of task cycles performed during an average day.

REMARKS - This 22 character alphanumeric string is used to document any comments pertaining to the task. If not used, it may be left blank.

CLASSIFICATION - This 8 character alphanumeric string contains the same job classification code that appears in the header so as to identify each task line with the job specified.

To acquire the data necessary to fill-in the Physical Stress Job Analysis Form the job analyst must observe the worker and determine by direct measurement what forces, hand positions, motion times and general body postures are involved in the manual activities of the job. For a strength analysis this often requires an average of seven or eight tasks to be described for each job. Of course, the motion time data is not critical in the strength analysis, as these data pertain to the metabolic energy requirements and resulting fatigue issues to be described later in this chapter.

It might be added that not only has this technology been applied to the four case studies described later in Chapter VII, but over 500 different jobs have been evaluated by this methodology in other projects. Thus, the approach is not only feasible but has been utilized by industry in the last year.

The output from such analyses are presented in the later Case Studies. Essentially, the output is a set of predictions for each task described. The predictions are:

* The proportion of men and women that could perform each task based on the strengths of their muscle functions as measured in this and earlier studies.

* The particular muscle function that is most limiting during the performance of each task.

* The metabolic expenditure rate for the job based on the model described later in this section.

VALIDITY OF BIOMECHANICAL STRENGTH MODELS

Earlier two-dimensional sagittal plane strength models were shown by Chaffin and Baker (1970) to predict human lifting strengths with an error coefficient of variation of approximately 15%. Schanne (1972) showed that if complete anthropometry and specific muscle group strengths are used as inputs to a three-dimensional seated model, the error coefficient of variation is about the same value of 15% for non-awkward arm and body postures. Garg and Chaffin (1975) showed this same degree of error for the model described in this paper using a seated task with an assumed set of inputted strength and anthropometric data. This latter validation also disclosed that the model was particularly weak in predicting strengths with the arm extended, abducted, or when working with the arm behind the torso plane. These more awkward postures will require further development.

METABOLIC ENERGY PREDICTIONS BASED ON ELEMENTAL JOB ANALYSES

As was discussed in the Introduction, the metabolic expenditure rate is high for many common manual materials handling tasks. It is, therefore, necessary to consider both strength and physical endurance as human attributes which would effect a person's risk of subsequent illness of injury. It is beyond the scope of this project to perform an analysis of the effects of high metabolic requirements on worker health, but the development of a metabolic prediction methodology as part of another project did allow the estimation of metabolic rates on the four jobs utilized in the Case Analysis section of Chapter VII. What follows is a brief description of this methodology. The complete description is given by Garg (1976).

The metabolic energy expenditure rate prediction methodology is based on the assumption that a job can be described as a sequence of discrete manual activities for which the metabolic expenditure E_{task} can be predicted. Thus, the average job energy expenditure rate $\bar{E}_{job}$ is:

$$\bar{E}_{job} = \frac{\sum_{i=1}^{N} E_{task_i}}{\text{Work Time}}$$

To predict each task energy expenditure the job analyst must observe the workers and record the data described earlier in the Physical Stress Job Analysis Data Sheet, Figure 23. These data are sufficient to allow the analyst to predict the energy expenditure rates for the 28 different types of common manual materials handling tasks described in Table 9. The actual predictions are accomplished with reference to either empirical prediction equations or graphs of the values developed by Garg (1976).

The validation of this methodology indicates that it results in an unbiased estimate of the average metabolic energy expenditure rate on a job with an error coefficient of variation of about 10%. It appears that if the job contains a great deal of manual materials handling activities, as opposed to more

Table 9: Breakdown of a job into tasks

1. Vertical Lift	2. Vertical Lower	3. Walking and Carrying	4. Push/Pull	5. Lateral Arm Work	6. Horizontal Arm Work	7. Holding
A. Squat	A. Squat	A. Walking	A. Push at bench height	A. Standing with movement of the foot (i) 1 hand (ii) 2 hands	A. Standing (i) 1 hand (ii) 2 hands	A. 1 hand on the side
B. Stoop	B. Stoop	B. Carry 1-hand at the side	B. Push at chin height	B. Standing with feet stationary (i) 1 hand (ii) 2 hands	B. Sitting (i) 1 hand (ii) 2 hands	B. 2 hands on the side
C. 1 hand	C. Arm	C. Carry both hands at the side		C. Sitting (i) 1 hand (ii) 2 hands		C. Against thigh
D. Arm		D. Carry against thighs				D. In front against waist
		E. Carry in front against waist				

limited arm/hand motions utilized in bench type assembly and inspection work, the methodology is highly accurate and useful.

As mentioned before, four jobs have been analyzed using both the strength and metabolic expenditure methodologies. These are described in Chapter VII.

CHAPTER IV

ASSESSMENT OF EMPLOYEE STRENGTH

Each of the 551 workers completing this study were asked to participate in a strength testing program prior to placement on the job (or within the first week of employment). The procedure used is detailed in Chapter II. Basically, two types of strength were observed:

1. standardized tests of arms, legs, and torso isometric capabilities, and
2. most demanding, primary LSR job position isometric strength tests.

Four repeated measurements were taken for the LSR job position strengths. These measures required the horizontal and vertical distances of the job's most stressful task to be simulated in the medical department. Each of the three standard tests (torso, arms, legs) were recorded for single isometric exertions.

STANDARDIZED STRENGTH

A number of variables can be expected to influence the standardized strengths of workers. The worker characteristics specifically related in this study included:

1. gender
2. age
3. height (stature), and
4. body weight

Figure 25 illustrates the observed distribution of worker strengths as a function of gender. This figure shows the anticipated reductions in average strengths and variability of strengths (between individuals) for the female population. Similar histograms could be drawn for different stratifications of age (negative correlation), height (positive correlation), or body weight (positive correlation). The fact that each of the worker characteristics are themselves correlated, however, may produce misleading results.

Rather it is easier to relate the relative importance of each of these worker attributes through a multiple regression model composed of main effects and all first order interaction terms of the form:

$$y_i = a_0 + a_1S_i + a_2A_i + a_3H_i + a_4W_i + a_5S_iA_i + a_6S_iH_i + a_7S_iW_i$$
$$+ a_8A_iH_i + a_9A_iW_i + a_{10}H_iW_i + a_{11}S_iA_iH_i + a_{12}S_iA_iW_i$$
$$+ a_{13}S_iH_iW_i + a_{14}A_iH_iW_i + a_{15}S_iA_iH_iW_i + \text{error}$$

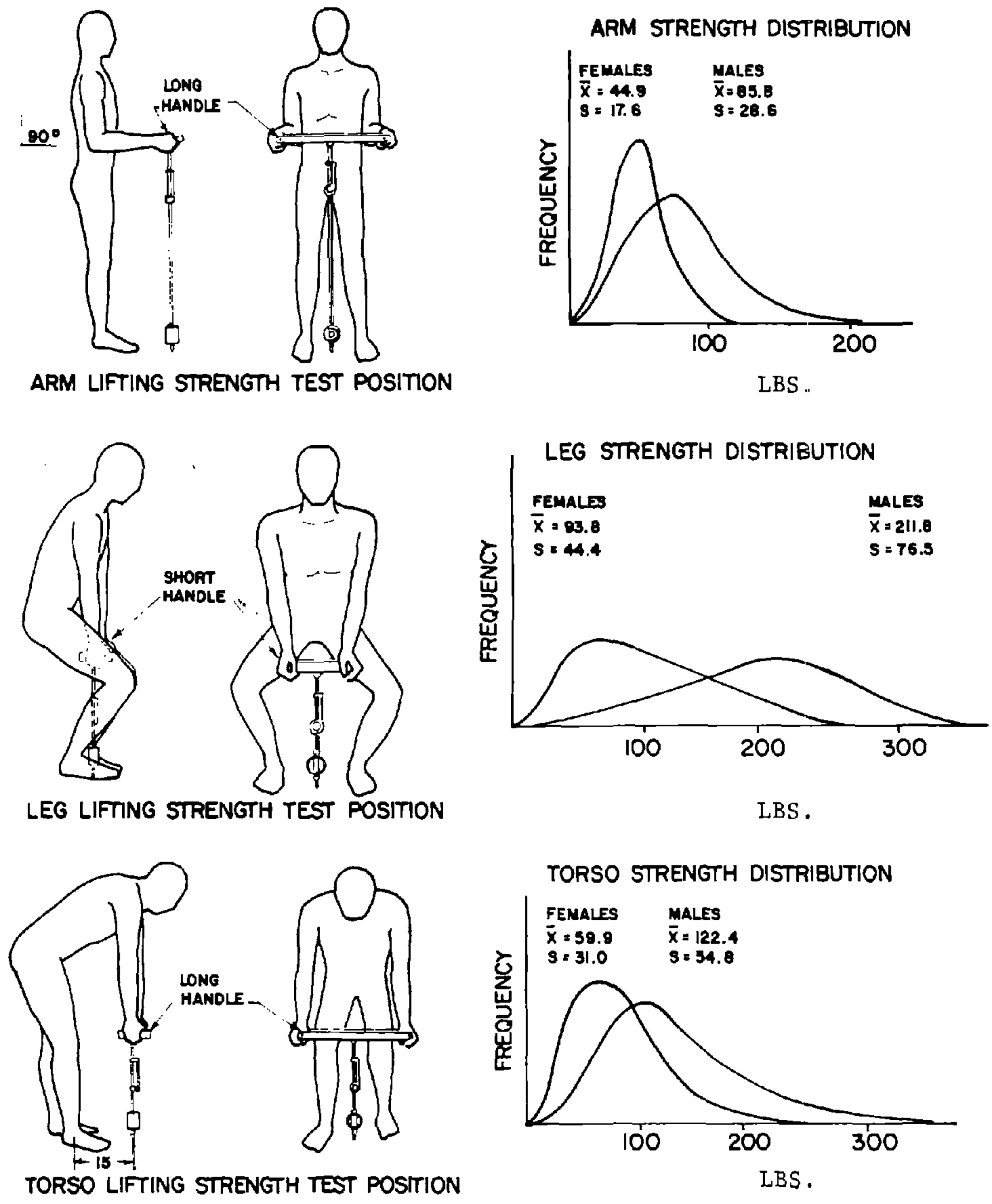


Figure 25: Standardized pre-employment strength positions and results for 443 males, 108 females

where:

y_i = observed strength of worker i = 1, ..., 551
S_i = gender of worker i (1 = female, 0 = male)
A_i = age of worker i in years
H_i = height (stature) of worker i in inches
W_i = body weight of worker i in pounds
a_j = regression coefficients (j = 0, 1, ..., 15)

Applying this model to the data of the study the following predictive equations were observed by forward stepwise regression (α = .05 for inclusion of coefficients).

Torso Strength (lbs.) = $21.736 + .01102\, H_iW_i - .006296\, A_iW_i - .24974\, S_iW_i$

with a standard prediction error (σ = 46.8 lbs.) and multiple correlation coefficient (R = .56).

Arm Strength (lbs.) = $56.848 - 32.36\, S_i + .0035\, H_iW_i - .002647\, A_iW_i$

with a standard prediction error (σ = 25.7) and multiple correlation coefficient (R = .56).

Leg Strength (lbs.) = $128.07 - 95.125\, S_i + .0111\, H_iW_i - .000143\, A_iH_iW_i$

with a standard prediction error (σ = 67.5) and multiple correlation coefficient (R = .59).

Each of the above regression equations illustrates mathematically the effects of combinations of factors on standard strengths. Torso strength, for example, is greater for tall, heavy, young, male workers. Further, body weight works most to the advantage of tall workers (H_iW_i interaction) but the weight advantage is partially cancelled for older workers (A_iW_i interaction). Further, females do not use their body weight to the full advantage as do their male counterparts (S_iW_i interaction). It is interesting to note that body weight (W_i) is the controlling variable for predicting torso strengths, while height (H_i), age (A_i) and gender (S_i) act to modify the relative importance of body weight. This finding concurs with that of other researchers as discussed in the Introduction.

Arm strength behaves similarly with body weight again as the controlling variable and height increasing the effect of body weight and age depreciating it slightly. The gender differences here (32.36 pounds) do not appear to be influenced by body weight, age, or stature. Leg strength shows a similar pattern with gender accounting for about 95 pounds absolute advantage for males and height and body weight acting to the worker's advantage (especially for the young worker).

This verbal interpretation of the preceding regression equations is, perhaps, not as graphic as the predicted strengths shown in Table 10. This table shows the predictions which would result from the preceding regression equation by substituting ages of 20 or 50 years, body weights of 100 or 200 pounds, statures of 5 or 6 feet (expressed as 60 or 72 inches) for males (0) and females (1). Obviously the greatest average strengths in each case (torso, arm,

Table 10: Average standard strength predictions (lbs.)

		Torso Strength				Arm Strength				Leg Strength			
		Male		Female				Female		Male		Female	
		Body Weight		Body Weight		Body Weight		Body Weight		Body Weight		Body Weight	
	Stature	100#	200#	100#	200#	100#	200#	100#	200#	100#	200#	100#	200#
Age 20 yrs.	5'0"	75.3	128.8	50.3	78.8	72.5	88.3	41.2	55.9	117.5	226.9	82.4	131.8
	6'0"	88.5	(max.) 155.2	63.5	105.3	76.8	(max.) 96.7	44.4	64.3	187.4	(max.) 246.7	92.2	151.5
Age 50 yrs.	5'0"	56.4	91.0	(min.) 31.4	41.1	64.6	72.4	(min.) 32.3	40.0	151.7	175.4	(min.) 56.6	80.2
	6'0"	69.6	117.5	44.6	67.5	68.8	80.8	36.5	48.4	156.5	184.8	61.3	89.7

leg) are associated with the 20 year old, 200 pound, 6 foot tall male and the least strengths for the 50 year old, 100 pound, 5 foot tall female. What is more interesting (and meaningful) is the relative tradeoffs between effects as one moves from cell to cell varying one factor at a time.

PREDICTION OF JOB STRENGTH

An issue of primary importance in this study is the determination of the predictability of job position strength given information about any particular employee's anthropology, the results of the standard position strength tests, and descriptors of the job. To explore this possibility a number of simple multiple regression models have been examined using forward stepwise selection procedures.

The first step in characterizing the relationship between anthropology, standardized tests, and job descriptors is to correlate each of the variables with the job position strength. Table 11 illustrates the correlations between the primary worker characteristics and task characteristics used in this study and job position strengths. It is important to note from this table that in general the worker variables are positively correlated (contribute to increasing job position strength) while the task variables are negatively correlated (are associated with reduced strengths). The relative importance of any particular variables, however, is not identical across the 6 plants in the study. The characteristic differences in worker and job profiles were recognized in planning this study and were the reason for studying multiple plants. The following analyses will not attempt to thoroughly itemize each of the plant differences in terms of ages of workers and/or difficulty of tasks. What is more interesting is to determine the appropriate model to apply for the average plant (which may not necessarily fit any particular plant exactly).

A simple illustration of the importance of each class of prediction variables is in order. It is observed (see Appendix A) that the total variability of job position strength is approximately 51.5 pounds ($\sigma = 51.5$) across all workers, all plants, all jobs. This uncertainy in any particular worker's job position strength is reduced to $\sigma = 39$ pounds (43% variance reduction) by modeling job strength as a function of standard strength tests, i.e.,

JOB POSITION STRENGTH = 8.6 + .294 (Torso Strength) + .661 (Arm Strength)

It should be noted that all strength measurements are highly positively correlated and that leg strengths and all interactions (for example, the product of torso and arm strength) contribute little to better predictions of job position strength.

By including height, weight, age, and gender as candidate variable for predicting job position strength the average plant prediction model can be only modestly improved to

JOB POSITION STRENGTH = 44.177 + .102 (Arm Strength) + .0023 (Torso Strength x Arm Strength) + 2.2245 (Worker Height) + .6533 (Worker Age)

Table 11: Job Strength Correlates (r)

			PLANT:	Industry A: 1	2	3	4	5	TOTAL	Industry B: 6	Combined Industries Total
WORKER CHARACTERISTICS	ANTHROPOLOGIC VARIABLES	MAIN EFFECTS	Height, Ht (inches)	.29	.62	.37	.50	*	.43	.23	.32
			Weight, Wt (pounds)	.26	.52	.37	.43	*	.39	.28	.33
			Age (years)	*	*	*	*	*	*	*	*
			Sex (1=male)	.45	.70	.40	*	**	.47	*	.33
		INTERACTIVE EFFECTS	Ht x Wt	.29	.58	.41	.49	*	.43	.30	.36
			Ht x Age	*	*	*	*	*	*	*	.12
			Ht x Sex	.45	.69	.40	*	**	.47	*	.32
			Wt x Age	*	*	*	*	*	.23	*	.22
			Wt x Sex	.44	.69	.40	*	**	.47	*	.31
			Age x Sex	.42	.66	.39	*	**	.43	*	.30
	STRENGTH VARIABLES	MAIN EFFECTS	Torso Strength, T (lbs.)	.63	.73	.64	.68	.48	.65	.32	.42
			Arm Strength, A (lbs.)	.53	.77	.61	.52	.65	.62	.31	.50
			Leg Strength, L (lbs.)	.50	.74	.62	.63	.47	.61	.26	.44
		INTERACTIVE EFFECTS	T x A	.59	.74	.63	.67	.63	.66	.35	.48
			T x L	.56	.73	.66	.70	.46	.65	.32	.43
			A x L	.52	.77	.63	.63	.64	.63	.33	.50
			T x A x L	.53	.68	.63	.67	.57	.62	.35	.46
TASK CHARACTERISTICS		MAIN EFFECTS	Horizontal, Ho (inches)	-.41	*	*	*	*	-.21	-.52	-.36
			Vertical, Ve (inches)	*	-.37	*	-.61	*	*	-.39	-.21
			LSR (percent)	*	*	*	*	*	-.14	*	*
		INTERACTIVE EFFECTS	Ho^2	-.40	*	*	*	*	-.23	-.42	-.33
			Ve^2	*	-.32	*	-.63	*	*	-.30	-.16
			Ho x Ve	*	-.37	*	-.45	*	*	-.45	-.28
			Ho x Ve^2	*	-.31	*	-.52	*	*	-.34	-.19
			Ho^2 x Ve	-.26	-.35	*	*	*	*	-.40	-.26
			Ho^2 x Ve^2	*	-.30	*	*	*	*	-.32	-.19
			LSR^2	*	*	*	*	*	-.16	.18	*
			Sample Size (n)	114	80	71	49	38	352	242	594

* = not significantly different from 0.0 for $\alpha \leq .01$

** - no female workers at plant 5

with a standard error of σ = 38.5 lbs. (a net variance reduction of 2% due to anthropologic variables). This result is interesting in that it shows the masking or high degree of multicollinearity between the standard strength scores and the anthropologic variables. Given a known set of variables one has diminished need for the other. Also note that all contributions are positive (coefficients positive) and torso strength is only important in conjunction with workers of large arm strength.

Obviously, the job position or posture used should affect job position strength. Candidate job descriptors including vertical distance, horizontal distance, and the squared value of each (these dimensions may affect strength quadratically) show job strength may be predicted as

$$\begin{aligned}\text{JOB POSITION STRENGTH} = & -45 + .224\ (\text{Torso Strength}) + .549\ (\text{Arm Strength}) \\ & + .068\ (\text{Leg Strength}) + 2.588\ (\text{Worker Height}) \\ & + .645\ (\text{Worker Age}) - 4.369\ (\text{Horizontal Distance}) \\ & - 1.93\ (\text{Vertical Distance}) + .020\ (\text{Vertical Distance})^2.\end{aligned}$$

With this model, the prediction error variance is further reduced by 20% to σ = 30.8 (R^2 = .65).

A simple graph may illustrate the relative importance of each of these modeling variables. Figure 26 shows the relative components of error in terms of standard error variance (σ^2) and variance explained (components of R^2). This figure illustrates the general proportions characteristic of this type of research. Of course, the predictions are far from the ideal (σ^2 = 0).

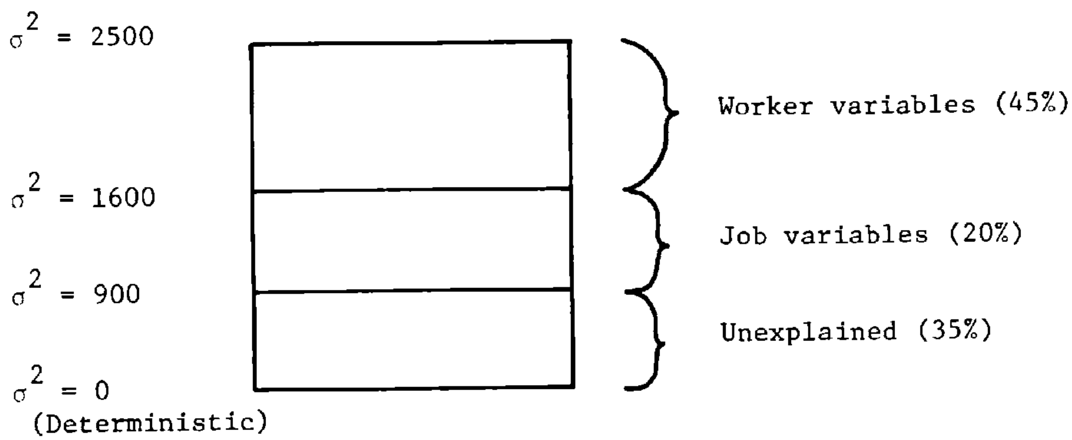


Figure 26: Illustration of job strength variance components

Rather than itemizing the prediction equations for each plant individually, Table 12 itemizes the worker and task characteristics which showed significant effects in by plant stepwise multiple regressions. Again, it should be emphasized that due to the high degree of multicollinearity between job characteristics and worker profiles within and between plants, the predictive equations are inherently different for each individual plant.

The predictive equations errors (σ) range from 22 to 29 pounds if the standardized strengths are included in the models (Model 1). These errors are increased from 31 to 38 pounds if the standardized strengths are unknown for predictive purposes (Model 2). Thus, the standardized strengths are important predictors of job strength.

By pooling the plants together, the residual error in predicting with Model 1 inflates to 34 pounds and for Model 2 to 39 pounds. This suggests that making special adjustments to the predictions of job strength due to the particular plant of interest is of little practical value.

The relative errors in the model predictions appear to be quite large without perspective for comparison. Since each worker performed the job position test four times, we were able to estimate separately the pure intra-individual variability (test-retest) of strength. The average intra-subject variance (across workers) was $\sigma^2 = 193.6$ or a standard error of $\sigma = 13.9$. This is an absolute minimum error which could be expected with a "perfect" model. In this context, the errors itemized in Table 11 are quite reasonable.

DISTRIBUTION ANALYSES

An important factor in predicting standardized strength is the underlying statistical distribution for strength. As evidenced in Figure 25 of the preceding discussion, the usual "normal approximation" may be inadequate for predicting the tails (5% or 95%) of the distribution.

Since strength is bounded by zero (i.e., a negative strength score cannot exist) and the variance tends to increase with the mean, we may speculate that a lognormal distribution would more adequately represent the underlying process.

To examine the viability of the normal and lognormal approximations, a series of distribution analyses were performed using the methodology of Phillips (1972).

Table 13 illustrates the relative goodness of fit to the data of this study produced by a normal distribution assumption versus a lognormal distribution assumption. For this analysis it was observed that both Kolmogorov/Smirnov and Chi-Square tests indicated that neither the normal nor the lognormal distributions gave best fits to the observed data. This is due primarily to the very large data base (n=551) in the study and the nature of these statistical "poorness of fit" tests. Though the distributions were statistically inappropriate (significantly different from normal and lognormal) they were not, in most cases, of practical importance. This practical importance is evidenced by the predictions shown in Table 13. For most cases, the error in predicting a particular percentile strength was less than 4% using the lognormal distri-

Table 12: Prediction of job strength by plant

				Industry A												Industry B		Combined Industries	
			Plant:	1		2		3		4		5		Total		6		Total	
			Model:	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Worker Characteristics	Anthropologic Variables	Main Effects	Height, Ht (inches)					●						●				●	
			Weight, Wt (pounds)												●	●	●		
			Age (years)																
			Sex (1 = female)	●		●	●								●	●	●		
		Interactive Effects	Ht x Wt				●		●	●	●				●	●	●		●
			Ht x Age																
			Ht x Sex		●														
			Wt x Age											●				●	
			Wt x Sex						●										●
			Age x Sex																
	Strength Variables	Main Effects	Torso Str., T (lbs.)	●	X	●	X		X		X		X		X		X		X
			Arm Str., A (lbs.)		X	●	X	●	X		X	●	X		X		X	●	X
			Leg Str., L (lbs.)		X		X		X		X		X	●	X		X	●	X
		Interactive Effects	T x A		X		X		X		X		X	●	X	●	X		X
			T x L		X		X	●	X	●	X		X		X		X		X
			A x L		X	●	X		X		X		X		X		X		X
			T x A x L		X		X		X		X		X	●	X		X		X
Task Characteristics		Main Effects	Horiz., Ho (inches)	●	●	●								●	●	●	●	●	●
			Vertical, Ve (inches)	●		●								●	●	●	●	●	●
			LSR (percent)											●				●	●
		Interactive Effects	Ho^2	●										●	●	●	●		
			Ve^2							●	●			●		●		●	
			Ho x Ve												●				
			Ho x Ve^2														●		●
			Ho^2 x Ve				●				●			●				●	
			Ho^2 x Ve^2													●	●		
			LSR^2	●										●	●				
			Sample Size (n)	114		80		71		49		38		352		242		594	
			Standard Error σ	22	31	26	37	31	38	24	33	27	---	29	37	29	32	34	39
			Variance Explained (R^2)	.72	.44	.81	.61	.54	.26	.79	.58	.43	---	.68	.47	.72	.66	.58	.42

● = variable appears significant in stepwise multiple regression model for α ≤ .05

Model 1 = all task and worker variables included as candidates for stepwise M.R. model

Model 2 = strength variables deleted from candidate list

Table 13: Distribution analysis for standard strengths (lbs.) (without adjustment for anthropometric norms of US population)

Population			Observed	Predicted	
				Assuming Normality (X)	Log Transform Y Data
Torso Strength	Male	5%	46.5	33.0	52.0
		50%	110.0	122.0	110.4
		95%	230.0	211.0	235.0
	Female	5%	21.0	6.0	21.0
		50%	52.0	59.0	51.0
		95%	128.0	112.0	121.5
Arm Strength	Male	5%	43.0	39.0	45.0
		50%	83.0	86.0	81.0
		95%	133.0	132.0	142.0
	Female	5%	15.0	15.5	19.5
		50%	45.0	45.0	41.0
		95%	79.0	74.5	86.5
Leg Strength	Male	5%	86.5	88.0	99.5
		50%	210.0	211.0	196.0
		95%	330.0	333.0	389.0
	Female	5%	33.0	23.0	36.0
		50%	85.0	94.0	83.0
		95%	171.0	165.0	193.0

bution assumption (i.e., a 50% prediction may be only a 46%) and the errors were most evident in the central portion of the distributions rather than in the upper tails (high strength individuals) or low strength 5% and 10% (susceptible) groups.

Based on the results of the above analysis, it was determined that the assumption of normality was not satisfactory for describing the distribution of standard strengths. Though imperfect in fit, it is believed that these distributions may be better approximated by the lognormal function.

In implementing the preceding distribution analysis it is important to point out two additional considerations. First, how should the lognormal function be "fit" to the data? Second, are these study workers really representative of the U.S. population workforce?

Neither in the past nor in the future can we expect to have raw data such as the strength data of this study at our immediate disposal. Summary statistics such as means, variances and coefficients of variation are stored and used in communicating results. There are slight differences in whether we have the data, take a log transform, then compute parameters of the lognormal distribution or compute sample means and variances of the raw data and then perform necessary transformations (i.e., the mean of the log transformed data (preferred) is not the log transform of the mean of the data).

If we assume that we have computed means and variances without regard to the appropriate lognormal transform we must estimate the parameters of the lognormal distribution by

$$\sigma^2_{\text{Lognormal}} = \ln [1 + \exp [\ln \sigma^2 - 2 * \ln \mu]]$$

and

$$\mu_{\text{Lognormal}} = \ln \mu - \sigma^2_{\text{lognormal}}/2$$

where we estimate μ and σ^2 with $\overline{X}$ and S^2 respectively from the raw sample data.

The preferred transformation involves taking the natural logarithm (Y) of the adjusted raw strength data (X) and computing the descriptive statistics shown in Table 14.

Table 14: Log transform statistics Y = LN(X)

Test	Male		Female	
	$\overline{Y}$	S_y	$\overline{Y}$	S_y
Torso	4.5676	.46156	3.8465	.40929
Arm	4.2726	.36112	3.5968	.43039
Leg	5.1606	.38112	4.2636	.149719

The second transformation assumes that the raw strength data are no longer available, but only the descriptive statistics from Figure 25. In this case predicted log transform statistics (Z) are calculated from $\overline{X}$ and S_x as shown in Table 15.

Table 15: Predicted log transform statistics ($Z = f(\overline{X}, S_x)$)

Test	Male		Female	
	$\overline{Z}$	S_z	$\overline{Z}$	S_z
Torso	4.5862	.44903	3.8596	.50169
Arm	4.2750	.35723	3.5840	.47711
Leg	5.1522	.41630	4.2712	.50514

The errors induced in predicting 5% (low) strengths using either transformation are nominal (less than 4 pounds). The errors in predicting large strengths (95%), however, are not negligible (i.e. up to 17 pound differences due to transform technique for leg strengths).

The employees in this study were not perfectly representative of the U.S. population norms in terms of age, height and weight as evidenced in Table 16. In general the study population was slightly taller, heavier, and younger than the average U.S. worker. The strength measures of this study were linearly adjusted for age, weight, and height to reflect expected population strengths. These adjusted strengths were examined for relative fit to the lognormal and normal distributions as illustrated in Table 17. Of course, the lognormal distribution is again preferred using either transform technique (Y or Z), with slightly different strength predictions compared to Table 13.

Table 16: Comparison of U.S. population and study population anthropometrics

		Population Norms*		PEST	
		μ	σ	μ	σ
Males	Height (inches)	68.23	2.65	69.57	2.92
	Weight (pounds)	167.8	26.93	171.03	29.18
	Age (years)	37.89	14.37	28.60	8.53
Females	Height (inches)	63.06	2.43	64.26	2.64
	Weight (pounds)	142.2	28.35	139.30	22.82
	Age (years)	37.00	14.49	30.05	9.34

*Population means and standard deviations based upon National Health Survey (1960-1962) and Bureau of Labor Statistics (1974)

All of the above analyses have presumed that our objective is to predict a certain average percentile of the population (5%, 50%, or 95%).

Another important aspect of predicting these average strengths is the distribution of the prediction residuals. Additional analyses of residuals for the prediction equations showed negligible departure from normality. That is, if a particular individual's strength (rather than a population percentile's mean value) is adjusted for the age, weight, and height of the individual then the resultant error or deviation from his demonstrated and predicted strength is reasonably normally distributed.

In general this result would not be expected unless the distributions of the underlying causal anthropometric variables were also skewed. A careful

Table 17: Standard strength predictions

	Population		Predicted			
			Adjusted Data	Assuming Normality (X)	Log Transform Y Data	Log Transform Z Data
Torso Strength	Male	5%	50	27	47	45
		50%	107	107	98	96
		95%	220	187	205	206
	Female	5%	22	8	21	20
		50%	50	53	47	47
		95%	116	9[illegible]	108	108
Arm Strength	Male	5%	40	30	40	40
		50%	81	77	72	72
		95%	125	124	129	130
	Female	5%	14	10	16	18
		50%	40	40	36	36
		95%	78	70	79	74
Leg Strength	Male	5%	86	65	87	93
		50%	200	187	173	74
		95%	327	309	343	326
	Female	5%	31	10	31	31
		50%	79	80	72	72
		95%	171	150	164	161

examination of the distributions of age, weight, and height showed that they, too, were skewed similar to a lognormal distribution.

Interpretation

The results of the preceding sections show that:

1. Average standardized strengths can be predicted reasonably well from anthropologic variables such as age, weight, height, and gender. The residual error, however, is relatively large due to large inter-individual differences (such as training, motivation, etc.) which cannot be specifically included in the analysis.
2. Job position strengths can be predicted quite well by knowing at least two standardized strengths (i.e., torso and arm strengths) and the horizontal and vertical hand locations as specified by the LSR assessment of the job.
3. In predicting population extremes such as lower percentile strengths (1-15%), the lognormal distribution appears to give more accurate predictions compared to the normal distribution.
4. If individual strengths are first adjusted for the anthropometry of the individual, the prediction error (difference between observed strength and predicted strength) will be approximately normal.
5. Comparable predictions of population percentiles can be drawn from either logarithms of the average data or average of log transformed data.

Each of these five conclusions are important considerations in evaluating the worker side of the worker/job match.

USING STANDARDIZED STRENGTHS TO PREDICT JOB POSITION STRENGTHS

The question of whether job position strengths are necessary given standardized strength measurements deserves special mention. The costs associated with simulating the most stressful job task as part of the strength test procedure are quite high relative to standardized measurements which are not job specific. Obviously, we expect the fidelity of the standardized strengths to be less relative to actual job position measures, but what are the trade-offs involved?

One approach is to characterize the workplace as four zones as shown in Figure 27. Zone 1 represents lifting tasks within 30" of the floor and within 15" of the forward ankle reference point, (i.e., the "low, close-in lift."). Similarly, Zone 2 represents the "high, close-in lift," Zone 3 the "low, extended lift" and Zone 4 the "high, extended lift." Obviously, different muscle groups are stressed in each of these zones.

The correlation between job position strengths demonstrated and the three standardized tests (torso, arm, and leg strength) are shown in Table 18 for each of the four workplace zones. It is interesting to note that the close-in small or large object lift is most closely related to the standardized torso strength ($r = .83$ and $.75$, respectively). Arm strength appears to be the best description of zone 2 requirements ($r = .73$ and $.57$) yet the wide object required strength is not much different between each of the standardized tests $.54 < r < .59$. For Zone 3, the extended low lift is best represented by torso strength if the object is narrow. The best test for wide object handling again is not obvious ($.64 \leq r \leq .81$) though the correlations are quite high. The best predictor of Zone 4, (the high extended lift) is again, the arm strength which is only nominally better than the torso measure ($r = .47$ versus $r = .35$) and neither are particularly good in comparison with the "no zone" correlations.

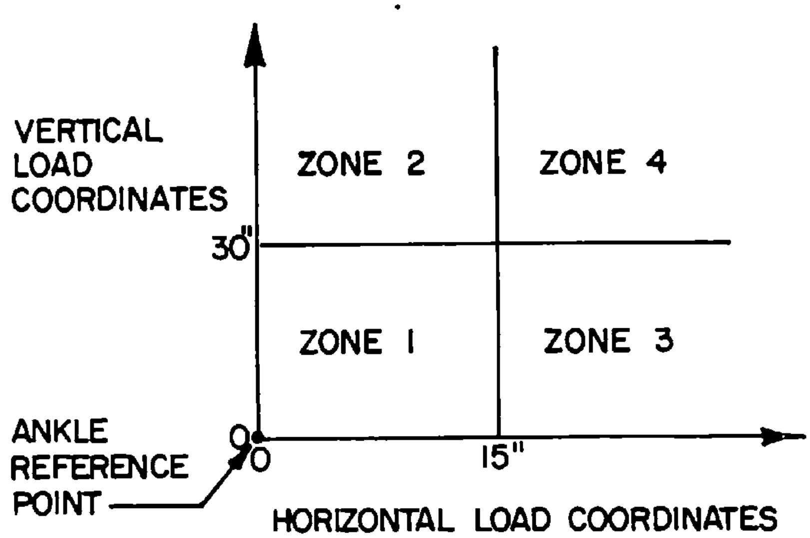


Figure 27: Zone approach to strength testing and job evaluation

Table 18: Correlation coefficients for job and standard strengths by zone

ZONE	OBJECT WIDTH (inches)*	STANDARD STRENGTH USED		
		Torso	Arm	Leg
1	6"	.83	.66	.59
	18"	.75	.69	.72
2	6"	.56	.73	.61
	18"	.54	.57	.59
3	6"	.65	.31	.41
	18"	.76	.81	.64
4	6"	.35	.47	.14
	18"	.47	.55	.34
No Zone or Width Distinction		.42	.49	.44

*Represents the distance between hands.

Without the distinction of job zones (vertical distance, horizontal distance, and object width) the simple correlations between job related and standardized strengths are quite low ($.42 \leq r \leq .49$). The prediction of low job strengths is enhanced by examining torso strengths (zones 1 and 3), while the prediction of high job strengths is facilitated most by considering arm strength, as might be expected.

There is no clear preference between standardized tests (torso or arm) for simple horizontal location. This is perhaps due to a "personal style" for vertical exertions away from the body by workers of differing anthropometries. Since both the wide and narrow object conditions were not part of each standard test, little inference can be drawn from the comparisons by object width. The primary consideration, however, of stratifying the job with zones before predicting job strengths warrants future research consideration.

CHAPTER V

MEDICAL CONSEQUENCES OF MATCHING

EMPLOYEE STRENGTHS WITH JOB PHYSICAL DEMANDS

CHARACTERIZING MEDICAL EXPERIENCES

The prediction of who, when, where, and why any particular employee will experience specific medical incidents is beyond the scope of the current study and of observational methods in general. During the course of this investigation, however, a number of medical data were accumulated with 509 medical department visitations reported by the 551 employees. Given the documented characteristics of the jobs and employees who participated in this study, this chapter outlines the medical consequences which may be expected by matching worker physical attributes with job strength requirements.

Two measures of medical incidents commonly computed are, the incidence rate (number of incidents divided by exposure hours) and the severity rate (number of days lost divided by exposure hours). Since all medical incidents cannot be expected to have the same etiology, it is more reasonable to consider an additional severity measure, days restricted rate (number of days restricted divided by exposure). Some medical incidents remove the worker from the workforce (lost days) while other maladies remove the worker from the particular job normally performed (days restricted). This latter case is not without cost in terms of productivity losses and inherent management costs (such as rescheduling requirements). For purposes of the following analyses, four measures will be summarized:

1. incidents per million man hours.
2. days lost per million man hours.
3. days restricted per million man hours.
4. days lost + days restricted per million man hours.

As mentioned previously, all medical incidents (reports of the employees to the medical departments) were documented in detail. Diagnoses were specified by the attending physicians according to the 8th Revision of International Classification of Diseases. For purposes of the following analyses these diagnoses were pooled into four categories:

Nonspecific
- infective and parasitic diseases
- diseases of blood and blood forming organs
- diseases of nervous system and sense organs
- diseases of the circulatory system
- diseases of the respiratory system
- diseases of the digestive system
- diseases of the genitourinary system
- diseases of the skin and subcutaneous tissue

Nonspecific (cont.)

- adverse effects of chemicals and substances
- adverse effects of the environment (heat, cold, radiation, dampness, etc.)
- effects of foreign body entering through body orifice
- symptoms and ill-defined conditions

Contact

- lacerations with open wound
- superficial injuries (abrasion, blister, scratch)
- contusion without break in skin
- external burns

Musculoskeletal

- diseases of musculoskeletal system and connecting tissue
- fractures
- sprains and strains (without open wound)

Back

- spinal fractures
- sprains and strains of the back

The number of complaints or incidents in each of these diagnosis categories were 178, 231, 63, and 37, respectively. These limited sample sizes make further subdivisions difficult for feasible statistical interpretation. A complete list of the types of incidents encountered in this study is given in Appendix B, along with the summary statistics of each incident.

EMPLOYEE CHARACTERISTICS

Before considering the issues involved in matching particular worker attributes with particular job requirements, it is informative to summarize the separate attributes of workers and jobs as they relate to medical experience. As a first step in the investigation of relative susceptibilities of worker populations, the worker descriptors of this study are summarized by class of medical incidents in Table 19. For purposes of this illustration, individuals who experienced incidents in more than one category are included in the summary statistics of more than one population.

The number of incidents accumulating in each medical diagnosis group did not allow a more thorough modeling of the relative importance of each worker attribute with each diagnosis category. Pooled data (across diagnosis categories) were modeled as a function of worker characteristics with only nominal success. Predictive equations of total medical incidents as a function of worker stature, body weight, age, gender, physician's prognosis and physical activity experience, along with all paired interactions revealed only minor trends. In general, increased age, weight, and stature were associated with nominal increased lost days and days restricted rates. None of the predictive equations, however, accounted for more than 5% of the variability, and are thus suspect in terms of statistical validity and reproducibility.

Table 19: Employee descriptors by class of medical incident

	No Incidents (n = 311)		One or More Incidents (n = 240)		Non-Specific (n = 115)		Contact (n = 160)		Musculoskeletal (n = 53)		Back (n = 30)	
	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S
Height (ins.)	68.7	3.31	68.4	3.75	69.0	3.66	68.5	3.56	67.8	4.07	68.6	3.49
Weight (lbs.)	163.2	29.87	166.2	31.60	167.2	26.56	167.6	34.79	162.4	33.69	167.7	29.14
Age (years)	29.0	8.94	28.9	8.41	29.8	8.83	27.4	7.09	26.7	7.03	30.2	8.36
Gender (0=Male, 1=Female)	.186	.390	.195	.397	.147	.356	.168	.375	.283	.454	.166	.379
Prognosis (0=Fair, 1=Excellent)	.424	.495	.533	.499	.504	.502	.556	.498	.622	.489	.733	.449
Experience (0=Fair, 1=Excellent)	.504	.500	.558	.497	.600	.492	.575	.495	.622	.489	.700	.466
Exposure Hours	1035	739	1416	834	1499	936	1505	842	1398	793	1388	735

It can be concluded from this that the more traditional and simplistic approaches to predicting a person's future risk of injury or illness in a manual materials handling job are not adequate in general. Information about the person's current health and functional capability at the time of employment must be augmented with data regarding the job demands, i.e., the degree of "match" of employee attributes and job demands is of primary importance. This conclusion has been also reached by many researchers, as stated in the Introduction to this report.

JOB CHARACTERISTICS

Before evaluating the concept of employee/job matching effects, we can examine the characteristics of jobs alone which might make them more hazardous to the average worker. Table 20 illustrates the summary descriptors of the job's requirements of the employees in the study related to medical incidents.

Here, too, a set of predictive equations relating total medical experiences to job demands alone was attempted. Relating total medical incidence rate to the job demands showed increased medical incidence rates associated with the product of load handled times the horizontal distance times the vertical distance times the frequency of handling (L x H x V x F). Thus, increased medical incidents rates were associated with heavy loads handled frequently far away from the body (large H and V components). Though statistically significant, only about 6% of the variance in medical incidents rates can be expected by describing job characteristics alone.

Some of the problem in the analysis of the effects of the job characteristics appeared to be due to the fact that a number of jobs were populated by only one employee in the study (50 jobs of the 128 jobs populated). These jobs tended to be more unstructured, and thus the assignment of job requirements had more variability. For this reason, a separate analysis of jobs having two or more employees was performed.

If we consider simply the load handled by employees on multiple employee jobs, we find the most pronounced trends of this study. Table 21 shows the medical experiences on the 78 multiple employee jobs as a function of weight handled. Both back injury and musculoskeletal injury severities significantly increase with heavier loads. This increase is consistent for both days lost and days restricted. The significant increase (9 to 2554) is possibly indicative of a sensitivity of the physician to weight handled on the job though more serious diagnosed incidents did occur on the heavier jobs in general. For back injuries and musculoskeletal injuries the real question appears to be "is this person required to handle heavy loads?" in prescribing a treatment rather than "is this person normally well matched to the job?" It is our opinion that the latter question needs to be addressed in the interest of prevention, as will be discussed later in this chapter.

Including the frequency component of a job evaluation, another index:

WORK = Maximum Object Weight x Frequency of Lifting (per week)

is related to medical experiences in Table 22. As expected from a biomechanics etiology, the trend with back injuries is removed (back injuries may depend

Table 20: Job descriptors by class of medical incident (employee level)

	No Incidents (n = 311)		One or More Incidents (n = 240)		Non-Specific (n = 115)		Contact (n - 160)		Musculoskeletal (n = 53)		Back (n = 30)	
	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S
Load (lbs.)	73.4	25.22	69.5	23.47	71.2	24.95	70.2	22.57	64.1	24.74	60.3	24.15
Horizontal Distance (ins.)	14.0	4.64	13.8	4.15	13.4	4.61	14.26	3.811	13.2	3.42	13.4	4.32
Vertical Distance (ins.)	31.9	18.15	27.8	17.53	32.2	17.17	27.0	18.22	31.13	16.66	29.6	19.48
Frequency/Week	146.7	270.6	181.1	248.99	154.9	224.4	199.2	255.2	261.7	290.96	196.4	248.85
Load x Freq. (lbs. - week)	20912	31769	23744	29063	19901	26653	26515	30839	29029	29325	21705	23573

Table 21: Medical experience by multiple employee jobs (load (lbs.)/multiple employee jobs)

Maximum Object Weight(lbs)	Total Medical	Nonspecific Complaints	Contact Injuries	Musculoskel. Injuries	Back Injuries	No. Jobs	Response
< 50	603	213	235	119	35	16	
50-80	818	265	408	76	106	40	INCIDENTS (per million man-hours)
> 80	671	217	285	97	69	22	
< 50	371	371	---	---	---	16	
50-80	1111	826	---	23	262	40	DAYS LOST (per million man-hours)
> 80	2940	1334	---	188	1418	22	
< 50	158	---	22	126	9	16	
50-80	1928	567	363	649	347	40	DAYS RESTRICTED (per million man-hours)
> 80	2787	123	233	1075	1357	22	
< 50	530	371	22	126	9	16	
50-80	3040	1393	363	672	609	40	DAYS LOST + DAYS RESTRICTED (per million man-hours)
> 80	5935	1457	233	1260	2554	22	

Table 22: Medical experience by multiple employee jobs (work = WT x FREQ)

Work (lbs./wk)	Total Medical	Nonspecific Complaints	Contact Injuries	Musculoskel. Injuries	Back Injuries	No. Jobs	Response
< 500	713	309	304	19	127	22	
500-2000	763	255	361	88	72	22	INCIDENTS (per million man-hours)
> 2000	725	187	345	139	57	34	
< 500	2107	690	---	42	1374	22	
500-2000	2534	1846	---	188	499	22	DAYS LOST (per million man-hours)
> 2000	382	368	---	---	13	34	
< 500	1463	33	77	---	1352	22	
500-2000	2049	1075	256	615	102	22	DAYS RESTRICTED (per million man-hours)
> 2000	1874	30	373	1120	350	34	
< 500	3570	723	77	42	2505	22	
500-2000	4583	2921	256	803	602	22	DAYS LOST + DAYS RESTRICTED (per million man-hours)
> 2000	2391	399	373	1120	363	34	

more on the level of the stress, not the frequency of it) while the trends in incidence rates and severity rates for contact and musculoskeletal injuries are enhanced (because of more frequent exposure and muscular fatigue). The nonspecific complaints are unpredictable. A summary of medical experience versus lift frequency (taken separately) is provided in Appendix Table C-17. There are no strong trends demonstrated here.

A third index may define bulk work as:

$$\text{BULK WORK} = \text{Horizontal Distance} \times \text{Frequency of Lift} \times \text{Object Weight}$$

with the most stressful job requiring large, frequent exertions away from the body. The trends in incidence rates and severity rates continue for contact and musculoskeletal injuries as shown in Table 23. These results do not differ substantially from those in Table 22 so the inclusion of a horizontal distance component may be misleading in terms of its relative importance.

Another index which was described in Chapters II and III is the Lifting Strength Rating of the job (LSR):

$$\text{LSR} = \frac{\text{Object Weight on Job}}{\text{Strength of 97.5\%tile male in the job position}}$$

which also incorporates the effects of horizontal location as well as the vertical location of the hands and load center of gravity. The denominator is in general larger for objects held close to the body and at thigh height. Relating the LSR index to the study medical experience, Table 24 shows an increasing trend in musculoskeletal injury days lost and days restricted rates with LSR. Interestingly, there was also an increase in the number and severity of nonspecific medical complaints on the higher stress jobs by this index. It is concluded, therefore, that load location is important, but its exact effect is not yet well understood from the injury/illness statistics.

JOB/EMPLOYEE MATCH

As expected, the isolation of simple worker attributes does little in explaining why combinations of workers and jobs experience medical problems. Also, the distinction between individual worker's records (n=551 employees) or average worker records (n=128 jobs) does little to explain medical consequences.

The major problem in interpreting the results of this study lies in the lack of mutually exclusive categories of worker abilities and job demands. Weak individuals, for example, did not (in general) occupy high strength requirement jobs. The natural self-selection processes which assigned employees to jobs may have been relatively effective in masking the possible consequences of mismatches, i.e., a weak individual on a demanding job. Since formalized pre-employment screening and placement policies were not in effect in any part of this study, the occurrence of mismatches must be viewed as "fortuitous" in the sense of a well-designed experiment. Weak individuals, for example, were not purposefully placed on high stress jobs to identify the controlled consequences of mismatch.

Table 23: Medical experience by multiple employee jobs (bulk work)

Bulk Work (lbs x in/wk)	Total Medical	Nonspecific Complaints	Contact Injuries	Musculoskel. Injuries	Back Injuries	No. Jobs	Response
< 10K	659	268	278	33	117	26	
10K-50K	749	249	355	88	68	26	INCIDENTS (per million man-hours)
> 50K	789	205	380	151	58	26	
< 10K	1782	572	---	35	1174	26	
10K-50K	2285	1715	---	159	411	26	DAYS LOST (per million man-hours)
> 50K	358	341	---	---	17	26	
< 10K	2119	723	65	98	1231	26	
10K-50K	1422	214	216	991	---	26	DAYS RESTRICTED (per million man-hours)
> 50K	1881	39	489	894	458	26	
< 10K	3901	1296	65	134	2218	26	
10K-50K	3708	1929	216	1151	411	26	DAYS LOST + DAYS RESTRICTED (per million man-hours)
> 50K	2415	380	489	894	475	26	

Table 24: Medical experience by multiple employee jobs (LSR)

LSR	Total Medical	Nonspecific Complaints	Contact Injuries	Musculoskel. Injuries	Back Injuries	No. Jobs	Response
< .4	624	130	324	107	63	20	INCIDENTS (per million man-hours)
.4-.7	820	295	371	82	96	46	
> .7	577	218	233	98	52	12	
< .4	271	271	---	---	---	20	DAYS LOST (per million man-hours)
.4-.7	1917	1012	---	20	885	46	
> .7	1788	1362	---	345	79	12	
< .4	1163	---	347	808	7	20	DAYS RESTRICTED (per million man-hours)
.4-.7	2027	515	171	387	951	46	
> .7	2039	140	433	1465	---	12	
< .4	1435	271	347	808	7	20	DAYS LOST + DAYS RESTRICTED (per million man-hours)
.4-.7	3945	1528	171	408	1731	46	
> .7	4208	1503	433	1811	79	12	

A number of alternative ways of defining "match" were considered in the analysis of the data in this study. The emphasis on analysis is to suggest that these indices of match were not controlled in the design of the study but were considered post hoc. As such, the results must be carefully interpreted to apply to "those who are mismatched under normal self-selection processes" and thus may reflect special characteristics of risk takers, or those with special motives (such as financial or job security needs). This point should not be exaggerated in terms of its relative importance, but should be kept in mind.

Figure 28 illustrates, conceptually, the idea of job/employee match. It is possible to characterize match as a collection of zones. The first zone represents the relatively understressed worker or workforce, the central zone represents those who are submaximally stressed, and the third zone as those who are overmatched or overstressed.

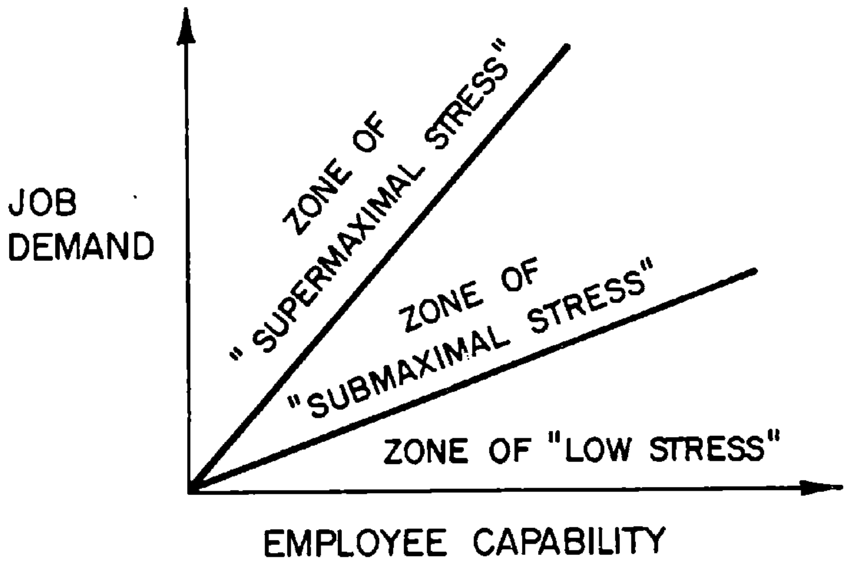


Figure 28: Hypothetical job/employee match zones

For purposes of the analyses which follow, the demarcations between the three zones were selected to provide reasonable balance in sample sizes in each zone. Three zones were selected since two zones would not identify nonlinearities in possible consequences and four levels would partition the data base beyond practical sample sizes.

The medical consequences of this hypothetical match (or mismatch) are summarized on the following pages and in Appendix C according to three categorizations:

1. By employee level - each analysis presumes one datum entry per worker (n=551 employees).
2. By job level - each analysis presumes one datum entry per job (n=128 jobs) for average employee on the job.
3. By multiple employee job level - each analysis presumes one datum entry per job with two or more employees (n=78 jobs).

This partitioning of the analyses is necessary to fully describe the medical experiences in this study. The employee level analyses allow isolation of consequences associated with a particular worker on a particular job, irrespective of his cohort workers. The job level analyses allow the medical experiences of the average worker on a particular job to be identified thus removing the biases in the analyses due to large versus sparsely populated jobs. The job level needs to be further subdivided to identify multiple employee jobs so that inter-worker variabilities can be reduced. There is also some evidence that these multiple employee jobs are more repetitive or cyclic in nature than the single employee jobs and warrant special consideration.

ANALYSIS OF MATCHING WITH REFERENCE TO INDIVIDUAL EMPLOYEE MEDICAL BEHAVIOR

The simplest indicator of match for a particular employee on a particular job may be characterized as the ratio of the weight lifted on the job divided by the job strength demonstrated in the medical department. This index, denoted as ESR (employee strength ratio);

$$ESR = \frac{\text{Object Weight Lifted on Job}}{\text{Employee Strength Demonstrated in Job Position Test}}$$

as an indicator of match demonstrated the medical consequences shown in Table 25. Only minor positive trends appear with both contact and back injury days lost and restricted rates increasing.

Another index of match denoted as FREQ x ESR was designed to test the effect of repeated overloading of an individual on the job:

$$FREQ \times ESR = \frac{\text{Object Weight x Freq of handling (per wk)}}{\text{Employee Strength Demonstrated in Job Position Test}}$$

In other words, this would be a better indicator of possible fatigue type mismatch (i.e., large value if an employee is required to repeatedly exert maximal force). Table 26 shows that when this index increases, there is a corresponding increase (incidents per million man hours and days lost or restricted per million man hours) in contact and musculoskeletal injuries. These results are intuitive since sprains, strains, cuts, and abrasions have been identified as related to exposure in terms of frequency of activicy and muscle fatigue. The lack of a trend with back injuries is expected if a biomechanical etiology is used wherein an isolated stress is as important as a repeated stress loading. The increasing incident rate and decreasing severity rate (lost + restricted) with nonspecific complaints such as colds, headaches, and intestinal disorders are surprising in that while they are more common on the high stress jobs they are not as severe.

One further improvement in the predictive index of match might be to include the horizontal reach aspects of the load lifting task. A third index:

$$HOR \times FREQ \times ESR = \frac{\text{Horizontal Distance x Frequency of Lift x Weight Lifted}}{\text{Employee Strength Demonstated in Job Position Test}}$$

Table 25: Medical experience by employee strength rating (ESR)

ESR	Total Medical	Nonspecific Complaints	Contact Injuries	Musculoskel. Injuries	Back Injuries	No. Empl.	Response
< .5	1444	854	852	145	71	94	INCIDENTS (per million man-hours)
.5-1	1445	481	653	206	108	217	
≥ 1	1308	732	418	108	45	240	
< .5	3123	2948	---	---	174	94	DAYS LOST (per million man-hours)
.5-1	1928	712	---	255	961	217	
≥ 1	1084	659	---	153	272	240	
< .5	1531	310	97	482	641	94	DAYS RESTRICTED (per million man-hours)
.5-1	2309	20	472	1085	730	217	
≥ 1	2226	346	624	342	914	240	
< .5	4654	3259	97	482	815	94	DAYS LOST + DAYS RESTRICTED (per million man-hours)
.5-1	4238	733	473	1341	1589	217	
≥ 1	3645	1006	624	495	1186	240	

Table 26: Medical experience by employee strength rating (FREQ x ESR)

ESR/week	Total Medical	Nonspecific Complaints	Contact Injuries	Musculoskel. Injuries	Back Injuries	No. Empl.	Response
< 50	833	327	360	76	72	349	INCIDENTS (per million man-hours)
50-100	966	336	362	68	199	40	
>100	2678	1437	1122	338	49	162	
< 50	2464	1540	---	263	660	349	DAYS LOST (per million man-hours)
50-100	2278	785	---	---	1492	40	
>100	129	129	---	---	---	162	
< 50	1792	269	90	411	1021	349	DAYS RESTRICTED (per million man-hours)
50-100	2080	---	---	610	1470	40	
>100	2904	140	1419	1203	141	162	
50	4257	1809	90	675	1617	349	DAYS LOST + DAYS RESTRICTED (per million man-hours)
50-100	6362	785	---	610	2962	40	
>100	3034	269	1419	1203	141	162	

is outlined in Table 27. Here the most stressful job would be characterized by heavy loads lifted away from the body, with high frequency. As can be seen, the introduction of "bulk moment" or the horizontal aspects of the job did little to enhance the trends of Table 27 for particular employees.

Additional analyses using predicted job strengths from Chapter IV based on worker stature, body weight, age, and gender in place of demonstrated job position strength showed the same trends as Tables 25 through 27. These are presented in Appendix C. Thus, matching effects are similar whether specific job position strength tests, or predicted job strengths based on standardized arm and torso strengths are used.

ANALYSIS OF MATCHING WITH REFERENCE TO JOB CHARACTERISTICS

Shifting the focus from the individual worker medical behavior to the average worker on a particular job, we may define an index of job matching as a job strength rating:

$$JSR = \frac{\text{Object Weight Lifted on Job}}{\text{Average of Strengths of Workers on the Job}}$$

Using this index one gains an index of relative job physical stress which is not as influenced by a specific worker's strength as was ESR.

Table 28 illustrates the medical experiences of this study as a function of JSR across medical diagnoses. Here, too, interesting trends were found with incidence rates and severity rates. For back injuries, there is an increase in the incidence rates and in the days lost or days lost and restricted with JSR. Moving to the left across the diagnoses one sees a slow reversal of this trend until the left column (nonspecific complaints) which shows the complete reversal. This reversal in trends and the U-shaped function in between (for contact and musculoskeletal injuries) is most interesting.

Weighting this index with frequency of lift or using the predicted average worker strengths as in the preceding section did not show strong trends. The results of these efforts are also summarized in Appendix C.

It is concluded from this analysis that back problems are more frequent and severe when a greater demand is placed on the worker's strength, regardless of the frequency of the exertions. Also, using predicted job position strengths did not improve the correlations with medical incidents.

ANALYSIS OF MATCHING WITH REFERENCE TO MULTIPLE EMPLOYEE JOBS

We would not expect the results of the job level analyses to differ substantially from the employee level analyses (as was the case) since 50 of the 128 jobs were actually one worker jobs. This section considers only those jobs with two or more workers.

In this analysis, the use of employee job position strengths was similar to that found for all jobs. When predicted employee strength was used in a matching index a stronger trend in the severity rates was disclosed. The

Table 27: Medical experience by employee strength rating (HOR x FREQ x ESR)

ESR x in/week	Total Medical	Nonspecific Complaints	Contact Injuries	Musculoskel. Injuries	Back Injuries	No. Empl.	Response
< 500	826	326	358	74	72	331	
500-1000	993	282	421	84	204	45	INCIDENTS (per million man-hours)
>1000	2542	1370	1055	320	45	175	
< 500	2583	1615	---	278	690	331	
500-1000	1736	353	---	---	1373	45	DAYS LOST (per million man-hours)
>1000	223	223	---	---	---	175	
< 500	1880	283	95	429	1072	331	
500-1000	1376	---	---	37	1339	45	DAYS RESTRICTED (per million man-hours)
>1000	2828	130	1314	1253	131	175	
< 500	4463	1898	95	707	1695	331	
500-1000	4893	363	---	37	2712	45	DAYS LOST + DAYS RESTRICTED (per million man-hours)
>1000	3052	353	1314	1253	131	175	

Table 28: Medical experience by job strength rating (JSR)

JSR	Total Medical	Nonspecific Complaints	Contact Injuries	Musculoskel. Injuries	Back Injuries	No. Jobs	Response
< .5	1307	425	709	124	60	27	
.5-1	776	318	287	85	104	60	INCIDENTS (per million man-hours)
> 1	563	62	238	118	143	41	
< .5	9117	8510	---	---	607	27	
.5-1	2390	984	---	---	1405	60	DAYS LOST (per million man-hours)
> 1	1863	326	---	123	1413	41	
< .5	3023	54	202	582	2183	27	
.5-1	1584	341	154	319	767	60	DAYS RESTRICTED (per million man-hours)
> 1	5727	84	244	441	4957	41	
< .5	12141	8564	202	582	2790	27	
.5-1	3974	1326	154	319	2092	60	DAYS LOST + DAYS RESTRICTED (per million man-hours)
> 1	7702	410	244	565	6370	41	

index used is:

$$\text{Pred.MJSR} = \frac{\text{Object Weight on Job}}{\text{Average Predicted Strength of Employees on Job}}$$

In this index, the predicted strengths were derived from the earlier regressions of age, weight, height, and sex to predict job strength. Table 29 shows that this indicator of job/employee match is also quite effective in relating increased susceptibilities to musculoskeletal or back injury losses and restrictions. It is concluded that employee strength, whether predicted or measured in the job position is important in anticipating the severity of musculoskeletal and contact related injuries and illnesses.

Appendix C provides additional combinations of the above indices and their effects on medical experience trends for the interested reader.

Table 29: Medical experience by multiple employee jobs (PRED.JSR)

Predicted JSR	Total Medical	Nonspecific Complaints	Contact Injuries	Musculoskel. Injuries	Back Injuries	No. Jobs	Response
< .5	656	146	331	98	79	14	
.5-1	794	281	360	99	86	47	INCIDENTS (per million man-hours)
> 1	624	207	282	63	67	17	
< .5	278	278	---	---	---	14	
.5-1	1083	784	---	71	227	47	DAYS LOST (per million man-hours)
> 1	3545	1623	---	99	1822	17	
< .5	625	---	470	144	10	14	
.5-1	1651	489	182	680	298	47	DAYS RESTRICTED (per million man-hours)
> 1	3213	142	286	1034	1750	17	
< .5	903	278	470	144	10	14	
.5-1	2734	1273	182	752	526	47	DAYS LOST + DAYS RESTRICTED (per million man-hours)
> 1	7028	1766	286	1134	3286	17	

CHAPTER VI

SUPERVISOR EVALUATIONS OF WORKERS' PHYSICAL PERFORMANCE CAPABILITIES

RELATIONSHIPS AMONG PERFORMANCE CRITERIA

The performance of each employee participating in the study has been evaluated by the line supervisors on two occasions. Please refer to Chapter II, "Variables Under Study - Supervisor Data" for details of the evaluation procedure.

Descriptive statistics for the seven evaluation scores are given in Table 30. In addition, statistics describing the average score of criteria 1-6 are given. Several points are worth noting in this table. Criteria 1-6 rate various aspects of the employee's performance on the job; the higher the rating in each category, the better the job performance. Although the supervisors use the full range of possible scores (0 through 5), most scores are clustered near the high end of the scale. The mean scores for these criteria range from 2.76 to 4.34 while the mean of the scoring scale is set at 2.5. This indicates that supervisors might be hesitant to give a truly "average" rating (i.e., in general they rated all employees better than average). It is possible that most of the employees in the study were better than the average, since many had worked for a number of years, thus having more general experience in industry.

The mean of criterion #7 is only .70, considerably lower than the first six. This apparent inversion is to be expected since this question was scored on a reversed scale (i.e., a low score indicates a high rating).

A matrix showing the correlation coefficients among the 7 evaluation scores and the average score is presented in Table 31.

It is reasonable to predict that the scores on evaluation criteria 1-6 should be highly correlated since each of these scores rates a factor which contributes to the success of an employee in performing his job. A deficiency in any one of these areas is likely to have a detrimental effect on the remaining areas. This prediction is supported by the data with correlation coefficients in the range $.43 < r < .83$. The average scores of the six criteria, as expected, show a high correlation with each of the individual scores with correlation coefficients in the range $.65 < r < .90$. The importance of the above result is that the average score can be used as an overall indicator of an individual's performance instead of using the six individual ratings.

Criterion #7 is negatively correlated with all other factors in the table. Once again, this is to be expected since the question is scored on a reversed scale.

Table 30: Descriptive statistics - final supervisor evaluations

Variables	Minimum	Maximum	Mean	Standard Deviation
1. Physically Capable	0.	5.00	4.22	.964
2. Performed All Duties	0.	5.00	4.19	.976
3. Accepted Lifting Duties	0.	5.00	4.15	1.012
4. Had No Accidents Due to Lifting	0.	5.00	4.34	1.07
5. Maintained Pace	0.	5.00	4.03	1.15
6. Well Matched to Job	0.	5.00	3.76	1.27
7. Absence Due to Lifting	0.	5.00	.70	1.28
8. Average of Criteria (1-6)	.17	5.00	4.12	.912

Table 31: Correlation matrix: final supervisor evaluations

Criterion	1. Capable	2. Performed	3. Accepted	4. No Accidents	5. Pace	6. Matched	7. Absent	8. Average
1. Physically Capable	1.000							
2. Performed All Lifting Duties	.8170	1.000						
3. Accepted Lifting Duties	.6580	.7908	1.000					
4. Had No Accidents Due to Lifting	.4512	.4830	.5261	1.000				
5. Maintained Pace	.7400	.7754	.7165	.4354	1.000			
6. Well Matched to Job	.7738	.7487	.7132	.4679	.8320	1.000		
7. Absence Due to Lifting	-.4276	-.4479	-.4225	-.4483	-.4232	-.4420	1.000	
8. Average of Criteria (1-6)	.8682	.9007	.8618	.6586	.8911	.9010	-.5136	1.000

n = 551

SUPERVISOR EVALUATIONS AS A FUNCTION OF EMPLOYEE CAPABILITIES, JOB DEMANDS, AND JOB/EMPLOYEE MATCH

The supervisor's evaluation is intended to be an indicator of an employee's performance on the job and the effectiveness of the job/employee match. This score should be expected to increase as the employee's capabilities increase and decrease as the demands of the job place increasing stresses on him.

A matrix showing the correlation coefficients between the several rating criteria and the employee and job factors is presented in Table 32. For all entries given in this table, r was found to be significant at the $\alpha < .05$ level.

The results of Table 32 are consistent with expectations. All strengths demonstrated by the employee during his pre-employment test are positively correlated to his supervisor evaluation scores. The job position strength shows a slightly higher correlation than the three standard strengths when considering main employee factors. Job position strength also is significant in several of the interactions. Residual impairment (resulting from a previous medical episode) is negatively correlated with the various performance scores. Age is also negatively correlated with performance scores; as a person grows older his rating goes down. This result is not surprising as age is negatively correlated with strength. (See Chapter IV.)

Looking at job factors, frequency is negatively correlated with performance, both as a main effect and as a component of several interactions. The only other job factor which shows a significant correlation is LSR. Surprisingly, the correlation is positive here. Perhaps the supervisors have an intrinsic appreciation for more difficult jobs and "reward" the employee's filling these jobs with higher evaluations.

The Employee Strength Ratio (ESR) defined as

$$\frac{\text{Object Weight Lifted on Job}}{\text{Employee Strength Demonstrated in Job Position Test}}$$

also was correlated with the performance ratings. As this ratio increases, the worker's strength is stressed to a greater extent by the lifting requirements of the job. Intuitively, one would propose that as this stress rating increases, the worker's performance would decrease. The data supports this prediction with consistantly negative correlations between ESR and evaluation scores. Clearly, many of the factors appearing in Table 32 are correlated among themselves. To overcome the problems of multicollinearity of the independent variables when trying to predict the average evaluation score (column 8 in Table 32) a stepwise, forward least squares regression was performed with inclusion at the $\alpha = .05$ level. The resulting prediction equation is:

$$\begin{aligned}\text{Average Performance Evaluation Score} &= 4.239 - .272 \times \\ &(\text{Resid. Impairment}) + .227 \times 10^{-2} \times (\text{Frequency}) \\ &- .248 \times 10^{-5} \times (\text{Load} \times \text{Horiz.} \times \text{Freq.}) - .335 \times 10^{-6} \\ &\times (\text{Load} \times \text{Vert.}\ X\ \text{Freq}) + .010 \times (\text{LSR}) - .275\ (\text{ESR})\end{aligned}$$

Table 32: Correlation coefficients: supervisor evaluations vs. employee and job characteristics

Variable		1. Physically Capable	2. Performed All Duties	3. Accepted Lifting Duties	4. Had No Accidents Due To Lifting	5. Maintained Pace	6. Well Matched to Job	7. Absence Due To Lifting	8. Average of Criteria (1-6)
Employee Main Factors	Height	.092	---	---	---	---	---	---	---
	Weight	.088	---	---	-.104	---	---	.084	---
	Age	-.112	---	---	---	-.097	-.107	---	---
	Sex (0 = Male; 1 = Female)	---	---	---	.106	---	---	-.091	---
	Prognosis (0 = fair; 1 = excellent)	---	---	---	---	---	---	---	---
	Experience (0 = fair; 1 = excellent)	---	---	---	---	---	---	---	---
	Number of Previous Medical Cases	---	---	---	---	---	---	---	---
	Residual Impairment	-.158	-.116	.093	-.099	-.092	-.102	---	-.129
	Job Position Strength	.288	.180	.149	.084	.098	.145	---	.170
	Torso Strength	.099	---	---	---	---	---	.105	---
	Arm Strength	.115	---	---	---	---	---	---	---
	Leg Strength	.162	.088	---	---	---	.117	---	.090
Employee Interactions	Height x Weight	.097	---	---	-.099	---	---	.0808	---
	Height x Age	-.092	---	---	---	-.087	-.096	---	---
	Height x Job Strength	.226	.176	.143	---	.096	.141	---	.166
	Weight x Job Strength	.212	.163	.129	---	.089	.129	.091	.149
	Experience x Strength	.149	.151	.143	.091	---	.092	---	.130
Job Main Factors	Load	---	---	---	---	---	---	---	---
	Horizontal Distance	---	---	---	---	---	---	---	---
	Vertical Distance	---	---	---	---	---	---	---	---
	Frequency/Week	-.108	-.106	-.141	---	-.120	-.127	---	-.135
	Bulk Moment (Load x Hor.)	---	---	---	---	---	---	---	---
	LSR	---	.087	.103	.121	.091	.096	---	.111
Job Interactions	Load x Frequency	-.147	-.139	-.165	-.125	-.174	-.194	---	-.188
	Load x Hor. x Freq.	-.154	-.151	-.180	-.118	-.182	-.200	---	-.196
	Load x Vert. x Freq.	-.148	-.137	-.163	-.167	-.181	-.196	---	-.198
	Load x Vert. x Hor. x Freq.	-.143	-.139	-.170	-.161	-.186	-.193	---	-.198
	LSR x Freq.	-.160	-.146	-.180	-.120	-.174	-.196	---	-.193
Employee-Job Interaction	ESR	-.204	-.196	-.198	-.130	-.110	-.145	---	-.190

n = 551 employees

Although this prediction is statistically significant, its practical significance is minimal. Only 16.5% of the total variance of the performance score is explained, and the standard error about the mean is 0.84.

SUPERVISOR EVALUATIONS AS A RESPONSE TO MEDICAL INCIDENTS

The question of whether or not the supervisor's performance scores are affected by an employee's medical experience on the job is addressed in this section. To answer this question in the simplest of terms, the population of 551 employees was divided into two categories:

1. Those having no medical incidents, and
2. Those having at least one medical incident.

A student's t test is performed on each of the eight evaluation criteria to test the null hypothesis:

H_0: The means of the two populations are equal; against the alternative hypothesis
H_1: The means of the two populations are different.

The results of the tests are presented in Table 33. In seven of the eight categories a significant decrease in the mean evaluation score is observed between the group with no medical incidents and the group with at least one incident. (The direction of the difference is reversed for criterion #7; however, this is to be expected since the scale runs in the opposite direction.) The greatest difference in means occurs for criterion #4 which rates the worker's performance in terms of freedom from injury. In most cases the difference between means is fairly subtle in practical terms; however, the large sample sizes and small variances allow statistically significant differences to be detected.

Having demonstrated the simple relationship between an employee's medical experience and the evaluation scores, the next question to answer is whether or not the type of medical incident has any effect on the score. To address this issue, employees are classified into five categories depending on their "worst" type of medical incident.

These categories (in increasing order of severity) are:

1. Employees with no incident
2. Employees with only nonspecific complaints (headaches, colds, etc.)
3. Employees with contact injuries (lacerations, bruises, etc.)
4. Employees with musculoskeletal complaints (sprains, strains, fractures, etc.)
5. Employees with back incidents.

An analysis of variance was performed on the average final evaluation and the results are presented in Table 34. Across the five categories, significant differences were found to exist between both means and variances. Looking at the pairwise results, the scores for categories 3 and 4 are significantly lower than the scores for categories 1 and 2. (The mean score for category

Table 33: Supervisor final evaluations: difference between employees experiencing at least one medical incident and employees with no medical incidents

Criteria	Mean Score		Significance Between Means	Variance		Significance Between Variances
	No Medical Incidents (n=311)	At Least One Incident (n=240)		No Medical Incidents (n=311)	At Least One Incident (n=240)	
1. Physically Capable	4.3183	4.1125	.0128	.74028	1.1547	.0001
2. Performed All Tasks	4.2765	4.1000	.0352	.82651	1.1029	.0086
3. Accepted Lifting Tasks	4.2315	4.0625	.0518	.86238	1.2220	.0020
4. Hand No Injuries Due to Lifting	4.5080	4.1333	.0000	.89590	1.4047	.0001
5. Maintained Pace	4.1350	3.9083	.0220	1.1430	1.5480	.0061
6. Well Matched to Job	3.8714	3.6375	.0326	1.4157	1.8722	.0105
7. Absent from Job Due to Lifting	.66881	1.0833	.0016	1.8545	2.9135	.0001
8. Average of Criteria (1-6)	4.2241	3.9932	.0032	.69049	.99072	.0014

Table 34: Analysis of variance - average final supervisor evaluation vs. type of medical incident

Category	N	Mean	Variance
1. No Incidents	292	4.2279	.6879
2. Nonspecific	56	4.2732	.6146
3. Contact	127	3.9300	.9304
4. Musculoskeletal	46	3.8761	1.4943
5. Back	30	4.0273	.9414

Test On Means -

H_0 - Means are Equal

H_1 - Means are Not Equal

ANOVA

Source	DF	Sum of Squares	Mean Sqr.	F-Statistic	Signif.
Between	4	12.287	3.0717	3.7624	.0050
Within	546	445.77	.81642		
Total	550	458.05	(Random Effects Statistics)		

Test on Variance -

H_0 - Variances are Equal

H_1 - Variances are Not Equal

Equality of Variances:	DF	F-Stat.	Signif.
	.12121 + 6	4.3819	.0015

Differences Between Means - Pairwise

Categories to Compare	Significance
1 - vs. - 2	n.s.
3	.0020
4	.0144
5	n.s.
2 - vs. - 3	.0182
4	.0276
5	n.s.
3 - vs. - 4	n.s.
5	n.s.
4 - vs. - 5	n.s.

5 is also lower than the scores for categories 1 and 2; however the small sample size precludes statistical significance.) This indicates that the supervisors tend to regard employee's that display non-specific complaints as performing no differently than those individuals with no complaints. Those employees with contact and musculoskeletal injuries, however, rate a decrease in performance.

GENDER EFFECTS

The issue of gender effects on final supervisor evaluations is discussed in this section. The study population of 551 employees is composed of 446 males and 105 females. Using a person's gender as a stratification factor a student's t-test was performed on the performance evaluation criteria to determine if any mean differences exist. The results of this test are presented in Table 35.

Only two evaluation criteria are found to be significant at the $\alpha < .05$ level. Females scored significantly better on criterion #4, which rates employees on freedom from injuries. Females scored significantly lower on criterion #7, which rates employees based on absences from the job. Considering the direction of these two rating scales (i.e., they are reversed), both of these results indicate that supervisors regard females as better performers. In the remaining six criteria, including the average evalution (criterion #8), no statistically significant differences between the sexes are observed.

A COMPARISON OF THREE WEEK AND FINAL EVALUATIONS

Supervisor evaluations were reported for employees on two occasions--the first one was completed at the end of three weeks exposure to the job and the second one was completed upon leaving. (In actuality, the second evaluation for many employees coincided with the end of the study. This presented no conceptual problem, however, since it is intended to be a performance measure of the employee's attributes after he has learned the job.)

To test for differences in evaluation scores, the statistical tool known as the paired-t test was employed. This test simply tests for differences in mean response when a population is exposed to two different conditions. The results of three such tests are presented in Table 36.

Looking at the total study statistics, it is clear that employees are given slightly lower scores on final evaluations than on three week evaluations. In five of eight criteria, these differences are statistically significant at the $\alpha < .05$ level. A simple explanation for this trend might be that performance scores drop during the time between the evaluation periods due to the fact that some employees will experience medical incidents sometime during the longer exposure. To test this possibility, the paired-t test was repeated for two new populations--those employees with no medical incidents and those employees with one or more incidents. The results of these tests follow much the same trend--final evaluation scores are consistently lower than three week scores. (Statistically significant differences are not as common here due to the smaller sample sizes.) Furthermore, the magnitude of the differences for those employees with at least one incident is greater in all

Table 35: Final supervisor evaluations - gender effects

Criterion	Means			Variance		
	Males n = 446	Females n = 105	Significance	Males n = 446	Females n = 105	Significance
1. Physically Capable	4.2646	4.0762	.0716	.09062	.99414	.2498
2. Performed All Tasks	4.2130	4.1429	.5081	.93655	1.0275	.2616
3. Accepted Lifting Tasks	4.1390	4.2381	.3672	1.0818	.77930	.0216
4. Had No Accidents Due to Lifting	4.2892	4.5810	.0120	1.2173	.80348	.0054
5. Maintained Pace	4.0247	4.0857	.6259	1.3859	1.0984	.0750
6. Well Matched	3.7478	3.8190	.6585	1.6940	1.3419	.0746
7. Absent Due to Lifting	.91704	.56190	.0327	2.5167	1.5755	.0021
8. Average of Criteria (1-6)	4.1151	4.1596	.6531	.86646	.69529	.0865

Table 36: Mean supervisor evaluation scores: three week vs. final

Criterion	Total Study (n - 484)				Employees with At Least One Incident (n - 105)				Employees with No Medical Incidents (n = 309)			
	Three Week	Final	Diff.	Signif.	Three Week	Final	Diff.	Signif.	Three Week	Final	Diff.	Signif.
1. Physically Capable	4.3401	4.2753	.06480	n.s.	4.2452	4.1298	.11538	n.s.	4.4091	4.3811	.02797	n.s.
2. Performed All Tasks	4.3719	4.2692	.05273	n.s.	4.2596	4.1538	.10577	n.s.	4.3671	4.3531	.01398	n.s.
3. Accepted Lifting Tasks	4.3684	4.2389	.12955	.0018	4.3462	4.1490	.19712	.0096	4.3846	4.3042	.08042	n.s.
4. Had No Injuries Due to Lifting	4.5951	4.4049	.19020	.0000	4.4760	4.2067	.24923	.0017	4.6818	4.5490	.13287	.0085
5. Maintained Pace	4.2085	4.0911	.11746	.0101	4.1010	3.9471	.15385	n.s.	4.2867	4.1958	.09090	n.s.
6. Well Matched	3.9774	3.8239	.15352	.0173	3.8462	3.6923	.15385	n.s.	4.0210	3.9196	.10140	n.s.
7. Absent Due to Lifting	.51136	.61281	-.10145	n.s.	.72581	.83871	-.11290	n.s.	.43233	.52632	-.09398	n.s.
8. Average of Criteria (1-6)	4.2991	4.1848	.11430	.0013	4.2154	4.0475	.16788	.0114	4.3600	4.2846	.07538	.0468

cases than the magnitude of the differences for workers with no medical incidents.

In summary, performance scores decrease between the three week and final evaluation. The magnitude of the decrease appears to be directly related to the employee's illness and injury record during his time on the job.

CHAPTER VII

CASE STUDIES OF THE HEALTH AND SAFETY ASPECTS OF MANUAL MATERIALS HANDLING JOBS

During this project, it was realized that further insight into the physical job stresses that could cause injuries and illnesses would be gained by executing in-depth investigations as to the physical requirements of certain selected jobs. The jobs were chosen for such evaluations with reference to the following criteria:

* The injury/severity rates from OHMES for each job were higher than expected (as compared to the total study rates) and were particularly so for musculoskeletal problems.
* At least three employees populated each job.

The specific objectives of these investigations were:

1. To document the specific strength and metabolic requirements of jobs having known high injury and illness rates.
2. To compare the strength requirements of these jobs with the strength capacities of the population of this study as a whole so as to determine the proportion of the population that might be expected to be overstressed by the job demands.
3. To qualitatively compare the types of injuries and illnesses incurred on different manual materials handling jobs with the predicted stresses imposed on the musculoskeletal system.

The procedure used in meeting these objectives was as follows:

1. Review injury/illness frequency and severity data and select candidate jobs.
2. Visit the plants and document the physical job demands as described earlier in the last part of Section III. This required the careful measurement of hand forces, work postures, and work paces comprising each job, (via force gauges, still and motion picture cameras, tape measures, and stopwatches).
3. Analyze the job stress data by using the three dimensional strength simulation model of Chaffin and Garg (1976), (see Chapter III) with population strengths based on values obtained from workers included in this study.
4. Develop a metabolic rate prediction using the methodology described by Garg (1976) (see Chapter III).

Case I

In this job the worker tends several machines used in the manufacturing of wire cable. To do this, the worker lifts and carries wire on supply reels to the machine, strings the wire through the machine, and after processing, lifts and carries the take-up reels of wire to storage racks. Table 37 describes the physical tasks required in the job along with the corresponding strength requiring acts. Each act is further described for the purpose of predicting the strength and metabolic rates in Appendix D, Tables D-1 and D-2.

Also shown in Table 37 is the following:

* The proportion of men and women who are estimated to be able to perform each task from the strength standpoint.
* The corresponding muscle actions that are most highly stressed when performing a high strength task.
* The total eight hour metabolic expenditure predicted for each physical act comprising the job, along with the resulting eight hour average metabolic expenditure rate for the job.

Table 38 presents the types of injuries and illnesses and their severity and frequency rates for this job. The injuries and illnesses for this purpose were grouped into four broad diagnostic classifications.

Inspection of Table 38 indicates that this job is associated with a high number of musculoskeletal and back problems (almost 4x the study average rates), and the musculoskeletal problems were over 13 times more severe than the average severity rates for the project. Further, the severity of the incidents to the lower extremity (particularly knee strain/sprains) was high, while the shoulder incurred more frequent but minor injuries. Contact injuries (cuts, bruises, lacerations) to the hands were high, apparently due to the manipulative actions required when stringing wire through the machines, and cutting and welding the wire ends. There were also recorded a large number of very minor non-specific complaints, such as headaches, indigestions, cramps, eyestrain, etc. which cannot easily be explained on a biomechanical basis.

The biomechanical analysis (summarized in Table 37 and detailed in Appendix Table D-1) indicates that a high strength requirement does exist on this job. Particularly, high strengths in both the legs and arms (especially shoulder and knee strengths) are required. Thus, the comprehensive biomechanical analysis indicates musculoskeletal stresses that correspond with the injury/illness profile.

The metabolic energy expenditure estimate (summarized in Table 37 and detailed in Appendix Table D-2) discloses an expenditure which is not particularly high on an average. Clearly, if a number of machines require tending within a short period of time, the metabolic expenditure rate could become excessive. An analysis of such a variation in work pace scheduling goes beyond the scope of this project, but could be performed with the existing metabolic energy expenditure prediction methodology utilized in this project. The fact that the average expenditure rate is as high as it is raises a question of selection of people based on their aerobic capacities. Probably an many as 10% of the

Table 37: Task/activity analysis for Case I

Task	Task/Activity Description	Peak Load (lbs.)	Freq./ Day	Population Capable from Strength Analysis		Strength Limiting Muscle Group Action	Energy Expended (Kcal/day)
				% Male	% Female		
1	Changing Supply Reel						100.7
	A. Pull Supply Reel	35	206	66	1	Knee Flexion	
	B. Lift Supply Reel	65	206	33	2	Shoulder Abduction	
	C. Push Supply Reel	10	206	99	98	Knee Flexion	
2	Changing Take Up Reel						72.4
	(Push Take Up Reel)	5	103	99	97	Hip Extension	
3	Wiring and Tagging						319.3
	(Arm Work and Squatting)	---	103	---	---	---	
4	Standing (Slow walk)	---	---	---	---	---	923
	A. Erect						
	B. Slightly Stooped						
	Total Metabolic Expenditure (Kcal/day)						1415.4
	Average 8-hour Metabolic Expenditure Rate (Kcal/min)						2.95

Table 38: Frequency and severity of incidents for Case I

Number of Incidents						
	Body Part Involved				Frequency Rate*	
Diagnosis Class	Upper Extremities	Shoulder and Back	Lower Extremities	Head, Neck Abdomen	Case I Only	Total Study
Non-Specific		1		31	960	273
Contact	18		3	1	660	348
Musculo-skeletal	6	4	3	1	420	99.7
Back		4			120	55.8

Days Lost and Days Restricted						
	Body Part Involved				Severity Rate*	
Diagnosis Class	Upper Extremities	Shoulder and Back	Lower Extremities	Head, Neck Abdomen	Case I Only	Total Study
Non-Specific				9	270	984
Contact	10		1		330	280
Musculo-skeletal	34	60	225	2	10535	799
Back		5			150	811

* per million man hours

male working population, and possibly over 40% of the female working population could not perform this job without excessive fatigue and accompanying adverse stress on the cardiovascular system, based on the statistics of Chaffin (1972). As in the case of strength testing, the effectiveness of such a screening procedure for health maintenance needs to be further evaluated, but this case does indicate the potential for such a selection procedure.

In summary, the case demonstrates that certain jobs can create excessive specific stresses on the musculoskeletal system, and that this appears to raise the probability of increased injuries and illnesses of a corresponding nature.

Case II

This job requires the worker to service two machines used to apply insulation on electrical wire. This requires the frequent loading of the machine with empty wire reels and the unloading of reels filled with insulated wire. Periodically wire breaks require the machine to be stopped and re-strung, which involves pulling the wire through various dies and pulleys. Also, the reels of wire are handled on a dolley type pallet which must be manually pushed and pulled into a location in front of the machine.

The biomechanical strength and metabolic analyses are summarized in Table 39 and detailed in Appendix Tables D-3 and D-4. What is evident from the strength analysis is that a couple of physical acts require a high exertion, namely pulling a full pallet of wire reels away from the machine, and pulling wire through the wire draw dies. In particular, because of the hand forces and postures demonstrated when performing these acts, the ankles and hips are highly stressed.

The injury and illness data summarized in Table 40 corresponds to the biomechanical analyses, in that the lower extremity showed a higher frequency and severity rate of musculoskeletal problems for this job than the average rates for the entire study job population. It should also be noted that there are a larger than average number of minor contact injuries, probably due to the manipulating and pulling of the wire required in the process of stringing the wire through the dies. There were also a high number of nonspecific but minor complaints (e.g., headaches, cramps, etc.) on this job.

The metabolic rate predicted (as summarized in Table 39 and detailed in Appendix C-3) for a typical worker on this job is slightly higher than that for Case I. It is not excessive on an average, but could necessitate some screening of workers to assure their aerobic capacity and fitness in general is adequate, as was discussed with regard to Case I.

In summary, this case also confirms that the job has occasionally high peak strength requirements which would limit the population capable of performing it. The injury/illness data indicate that such biomechanical demands are probably excessive for some of the workers, and job redesign or personnel selection would be justified.

Table 39: Task/activity analysis for Case II

Task	Task/Activity Description	Peak Load (lbs.)	Freq./Day	Population Capable		Limiting Muscle Group Action	Energy Expended (Kcal/day)
				% Male	% Female		
1	Push Empty Reel Pallet	45	7	97	60	Hip Extension	2.7
2	Carry Empty Reels						62.1
	A. Pull Empty Reel	10	140	99	98	Hip Extension	
	B. Lift Empty Reel	32	70	96	63	Hip Extension	
3	Push Full Reels Onto Pallet	20	140	97	31	Elbow Extension	15.4
4	Pull Full Reel Pallet	160	7	8	1	Ankle Extension	3.4
	Non-Repetitive						
5	Take Wire Sample and Gauge						31.1
	A. Pull Sample	2	16	99	99	Hip Extension	
	B. Walk to Gauging Machine	--	16	--	--	---	
6	String Wire Through Machine	20	12	99	95	Hip Extension	316.8
7	String Wire Through Wire Gauge	18	0.5	99	75	Hip Extension	6.8
8	Pull Wire Through Wire Draw	100	3	32	1	Ankle Extension	40.1
9	Walking	--	--	--	--	---	15.1
10	Standing						
	A. Erect						222
	B. Slightly Stooped						789.4
	Total Metabolic Expenditure (Kcal/day)						1504.9
	Average 8-hour Metabolic Expenditure Rate (Kcal/min)						3.14

Table 40: Number and frequency of medical incidents for Case II

Number of Incidents						
	Body Part Involved				Frequency Rate*	
Diagnosis Class	Upper Extremities	Shoulder and Back	Lower Extremities	Head, Neck Abdomen	Case II Only	Total Study
Non-Specific				16	791	273
Contact	12	1	2	1	791	348
Musculo-skeletal	1		4		247	99.7
Back		2			98	55.8

Days Lost and Days Restricted						
	Body Part Involved				Severity Rate*	
Diagnosis Class	Upper Extremities	Shoulder and Back	Lower Extremities	Head, Neck Abdomen	Case II Only	Total Study
Non-Specific				3	148	984
Contact					---	280
Musculo-skeletal			32		1582	799
Back		3			148	811

* per million man hours

Case III

In this job several different workers perform a series of spot welding tasks along an assembly line. The object to be welded serves as the housing for an electronic instrument, and is, therefore, a strongly reinforced 18 pound metal assembly. Each worker lifts the housing from a conveyor and moves it to a spot welding machine where several small parts are welded to the assembly. During the welding operation, the housing must be reoriented several times in order to properly position the electrodes. Upon completion of the welding operation, the worker returns the housing to the conveyor. There is also a non-repetitive, infrequent requirement of pulling, carrying and pushing pallets full of housings on and off the conveyor. This involves both high loads and awkward body positions, particularly for the arms and back.

The biomechanical strength and metabolic evaluations are summarized in Table 41. A more detailed breakdown is presented in Appendix Tables D-5 and D-6. The strength analysis indicates the upper extremity and shoulder are highly stressed when carrying and pushing the pallets on the conveyor. It is also noteworthy that the more repetitive tasks when welding an individual housing stress the same general musculoskeletal area as the high load, non-repetitive acts. Even though the average metabolic energy expenditure rate is not exceptionally high, it is clear that this job concentrates the motor requirements on the upper extremities and shoulders. This could create localized muscle fatigue in some workers leading to both complaints of minor "aches and pains" in the stressed muscles, as well as increased contact injuries. The latter could be due to the decreased motor capabilities accompanying muscle fatigue.

Clearly, the above is speculative, but examination of the injury and illness data summarized in Table 42 provides justification for concern over the problem of upper extremity stress in this job. Minor musculoskeletal complaints involving the upper extremity did occur at a rate seven times the expected. Also, a larger number of contact injuries occurred than expected, some of which were severe. The back injury rates and severity rates were also much higher for this job than the average for the study.

In summary, a high musculoskeletal loading of the upper extremity has been documented for this job. The resulting injury and illness data confirms that some people are incurring incidents of a type expected from the biomechanical and metabolic evaluations, and that job resign and/or personnel selection procedures would be justified.

Case IV

In this job, several plastic components of an electronic assembly are bonded together using a special purpose bonding machine. In performing the job, the worker carries a full pan of the assembly units from a pallet to the work bench. Units are then individually fed to the bonding machine. Upon completing the bond, the unit is placed into a storage pan. The procedure is continued until the storage pan is filled. At that time, the filled pan is carried to a pallet where it is stored.

Table 41: Task/activity analysis for Case III

Task	Task/Activity Description	Peak Load (lbs.)	Freq./Day	Population Capable From Strength Average		Strength Limiting Muscle Group Action	Metabolic Expenditure (Kcal/day)
				% Male	% Female		
1	Assemble Two Sections of Housing	7	856	99	87	Shoulder Abduction	158.7
2	Spot Weld the Assembly						333.2
	A. Lift Housing to Weld Machine	18	856	99	92	Elbow Flexion	
	B. Operate Welder	18	856	99	95	Elbow Flexion	
	C. Move Housing to Conveyor	18	856	99	92	Elbow Flexion	
	Non-Repetitive Acts						
3	Remove Empty Pallets						5.2
	A. Pull Pallet	13	8	93	61	Knee Extension	
	B. Carry Pallet	42	8	93	31	Elbow Flexion	
4	Push Full Pallets Down Conveyor	68	8	66	9	Humerus Lateral	7.4
5	Standing						889.4
	Total Metabolic Expenditure (Kcal/day)						1394
	Average 8-hour Metabolic Expenditure Rate (Kcal/min)						2.90

Table 42: Frequency and severity of incidents for Case III

Number of Incidents						
	Body Part Involved				Frequency Rate*	
Diagnosis Class	Upper Extremities	Shoulder and Back	Lower Extremities	Head, Neck Abdomen	Case III Only	Total Study
Non-Specific					----	273
Contact	6			1	1854	348
Musculo-skeletal	3				794	99.7
Back		2			529	55.8

Days Lost and Days Restricted						
	Body Part Involved				Severity Rate*	
Diagnosis Class	Upper Extremities	Shoulder and Back	Lower Extremities	Head, Neck Abdomen	Case III Only	Total Study
Non-Specific					----	948
Contact	26				6886	280
Musculo-skeletal					----	799
Back		21			5561	811

* per million man hours

As in the preceding Case III, the biomechanical strength and metabolic evaluations indicate a high physical load imposed on the upper extremity, and particularly the shoulder, as depicted in Table 43. (The Appendix Tables D-7 and D-8 contain a more detailed analysis of this job.)

The injury and illness data presented in Table 44 confirm the basis for concern, in that the upper extremity and shoulder did incur a number of complaints, some of which were serious in nature. It is, therefore, concluded that this job does present an unusually high load on the shoulder and upper extremity for some individuals, and that the need for job redesign and/or personnel selection is substantiated.

SUMMARY OF CASE ANALYSIS

It is believed that the preceding in-depth case analyses demonstrate a feasible method of proceeding towards the eventual goal of controlling some of the biomechanical hazards of manual materials handling tasks in a job. In all four jobs, a clear pattern of musculoskeletal injuries and illnesses were documented through the use of the Occupational Health Monitoring and Evaluation System. The follow-up, in-depth biomechanical strength and metabolic evaluations documented the physical conditions. More specifically, the biomechanical evaluations illustrated a rational relationship between various manual acts and resulting high stresses on the musculoskeletal system. As such, the analysis identified specific loads and postural conditions in each job that would over-stress a significant proportion of the working population's strength capability. Such information is crucial for good job redesign. Also, the biomechanical analysis indicated what general anatomical area of the musculoskeletal system would be most stressed. This information is necessary for specifying the type of strength testing to be used in employee selection, as well as in achieving an understanding of why certain injuries occur.

The cases presented in this section are valuable in that they demonstrate how the emerging technology of occupational biomechanics can be applied as part of a systems approach to occupational health and safety problem identification and control. By using concepts of occupational biomechanics in the design and implementation of an Occupational Health Monitoring and Evaluation System, it is believed that insights have been documented which are highly related and important to the research necessary to control the physical hazards associated with mismatching people placed on jobs requiring significant manual materials handling.

Table 43: Task/activity analysis for Case IV

Task	Task/Activity Description	Peak Load (lbs.)	Freq./Day	Population Capable From Strength Analysis		Strength Limiting Muscle Group Action	Metabolic Expenditure (Kcal)
				% Male	% Female		
1	Lift Pan of Handsets from Pallet to Bench A. Lift B. Carry	40	80	92	29	Shoulder Abduction	23.2
2	Operate Bonding Machine						759
	A. Bond Handset		1600				
	B. Transfer Empty Pan	5	80	99	87	Shoulder Abduction	
3	Lower Pan of Handsets from Bench to Pallet A. Lift B. Carry	40	80	92	21	Shoulder Abduction	19.2
4	Standing and Sitting						542
	Total Metabolic Expenditure (Kcal/day)						1343.4
	Average 8-hour Metabolic Expenditure Rate (Kcal/min)						2.8

Table 44: Frequency and severity of incidents for Case IV

Number of Incidents						
	Body Part Involved				Frequency Rate*	
Diagnosis Class	Upper Extremities	Shoulder and Back	Lower Extremities	Head, Neck Abdomen	Case IV Only	Total Study
Non-Specific					---	273
Contact	4				222	348
Musculo-skeletal	4	4			444	99.7
Back		3			167	55.8

Days Lost and Days Restricted						
	Body Part Involved				Severity Rate*	
Diagnosis Class	Upper Extremities	Shoulder and Back	Lower Extremities	Head, Neck Abdomen	Case IV Only	Total Study
Non-Specific					---	948
Contact	21				1165	280
Musculo-skeletal	45				2497	799
Back					---	811

* per million man hours

CHAPTER VIII

SUMMARY OF RESULTS AND RECOMMENDATIONS

It is believed that this project has disclosed several major findings regarding the prevention of medical problems associated with physical exertion in industry today. What follows is a brief summary of the results, and recommendations for future needs in this important occupational health and safety field.

For quite a long time a number of different human attributes have been considered as significant when assigning a personal risk level to an individual who is to perform a job requiring some degree of physical exertion, as reviewed in Chapter I. Age, gender, stature and body weight are often mentioned as personal risk factors by different authorities. In this study, however, the practical value for such a claim could not be substantiated since none of these four factors were reasonably correlated with increased incidence or severity rates of later medical problems of any kind, as discussed early in Chapter V. Further, when the physicians were asked to rate each person's capability to safely perform manual material handling activities, based on a total clinical impression from the person's medical history, or in some cases X-rays and/or physical examination, the resulting correlation with later medical incidents was also of little practical value, though such examinations were undoubtedly able to screen-out people who were obviously unable to perform any physical activity. This study also revealed that a person's past physical activity experience did not indicate risk of future injury or illness in materials handling jobs.

It is, therefore, concluded from this project that neither simple physical attributes of an individual, a clinical impression based on more traditional information of personal risk, or past physical activity experience are probably adequate to reasonably explain the types of later medical problems that develop when a reasonably healthy person performs materials handling activities. What appears to be needed is a better measure of what physical stress a healthy person's musculoskeletal system can safely sustain in given controlled exertions. Based on this assumption, strength tests of some type appeared to be justified.

The question of what types of jobs could best utilize strength testing for employee selection was also evaluated in this project. Two earlier studies by this research group, as described in Chapter I, indicated that jobs having high lifting strength ratings LSR (see Chapter III for more precise definitions) were jobs having increased incident rates of low-back pain. This project extended this finding and disclosed that:

- The heavier the loads lifted, even occasionally, the greater the severity of back problems and other types of musculoskeletal problems.

* The more frequent the lifting of maximum loads on a job, the greater the frequency and severity rates of musculoskeletal problems, other than back incidents, and the greater the severity of contact injuries.

* The more remote the load center of gravity (CG) is from the body (due to either the bulk of the object being handled or the workplace layout), the greater the frequency and severity of musculoskeletal problems and contact injuries.

Based on these findings it is concluded that a medical action level is necessary. Such a criterion would designate that people being placed on jobs having known physical exertion requirements intrinsic to the job be examined by medical personnel to determine their capacities to withstand such stresses in the future. A more specific recommendation in this regard is presented at the end of this chapter.

On the question of strength testing, per se, the medical incident data as presented in Chapter V, disclose increased frequency and severity rates of all types of musculoskeletal and contact injuries for weaker workers placed on high strength requiring jobs, especially on those jobs wherein the frequency of the exertions is also high. This result confirms what was shown in the earlier studies of low-back pain described in Chapter I. It substantiates the need for some type of strength testing procedure to be added to the current pre-employment or pre-placement medical examination.

The results of the employee supervisor ratings, presented in Chapter VI, also lend justification for such a recommendation. These indicated that stronger persons were rated better in general than weaker persons employed in jobs requiring manual materials handling.

The question of what type of strength testing would be most effective was also dealt with in this project. Chapter IV describes several methods for using standardized position strength tests to predict a variety of job position strengths. More importantly, a wide variation in lifting strengths in the working population is documented. The effects of age, gender, body weight and stature on the population variation in isometric strength scores are also described. In general, Chapter IV includes findings that reveal:

* Gender and body weight have a highly significant effect on a person's strength capability in industry, with the heavier males scoring much higher than the lighter female employees.
* Stature adds slightly to strength, while age detracts slightly, in the general working population.
* Job position strengths can be reasonably predicted (r^2 with about 65% of the variation being accounted for) if torso and arm strengths are measured in standardized postures, are combined with gender, body weight, stature and age, and different equations are used for grossly different types of lifting, (i.e., from the floor close to the ankles, in front of the torso, or in a location remote from the body).

* Isometric strengths can be obtained with minimum of training of medical personnel in various plants, with acceptable test-retest variations.

If predicted job position strengths or workers are used instead of actual measures of the job position strength, the medical incident data indicate similar results (i.e., the standardized strength tests provide equal levels of personal risk assignment as that derived from a job position strength test).

With both methods of strength testing the medical incident data summarized in Chapter V disclose an increased severity of musculoskeletal problems when a person is asked to perform a job that requires lifting more than about one-half the amount demonstrated in the medical strength tests. In other words, it would appear that personal protection may only be possible if people are able to demonstrate in the isometric tests that they are capable of far greater strength than required by the job they are about to undertake.

RECOMMENDATION REGARDING WHEN MEDICAL PREEMPLOYMENT EXAMINATION IS REQUIRED

Three of the findings of this and previous studies substantiate the need for some type of action level for jobs containing significant physical exertions. These are:

1. Jobs requiring high strengths were associated with higher frequency and more severe incidence of musculoskeletal and contact type injuries.
2. The strengths of the working population vary greatly, and are not well predicted with reference to age, gender, body weight and stature.
3. Jobs populated by weaker persons had higher frequency and more severe incidence of musculoskeletal problems.

An earlier study by this research group (Chaffin and Park, 1973) indicated low-back incidence rates increased with occasional lifting of compact loads as low as about 35 pounds. This study used the 35 pound limit as a lower-bound to define the jobs to be included in the project. Thus more sedentary jobs were not included and hence comparative statistics with jobs having very low physical requirements were not available. This study was able to show that an upward trend exists in the frequency and severity rates of musculoskeletal injuries in jobs requiring greater than 35 pounds lifting. Whether there is an inflection point in such a trend is not as obvious in the data summarized in Chapter V. Of course, these data regarding job conditions that contribute to medical incidents assume an "average" worker, selected without a strength testing procedure for job placement.

If one considers the large variation in worker strengths that exist, and that such an attribute appears to affect a worker's personal risk of later injury, then the level of exertion on a job wherein medical examinations would be necessary to detect the more susceptible worker would need to be lower. From this viewpoint, if arm lifting strengths are used as a limit for occasional lifting, then about 10% of the working women in the study could not be expected to be able to lift compact loads weighing more than about 20 pounds.

There also appears to be some validity for further reduction in such a medical action level if the heavier loads are lifted often on a job or if they are bulky or located in remote positions from the body. In regards to the frequency of lifting, this study showed that maximum loads handled more than about five times a day were associated with increased frequencies and severity of musculoskeletal problems other than back injuries, and in increased contact type injuries. What is possibly being reflected in this statistic is that as the frequency of heavy load lifting increases, so also does the frequency of other submaximal exertions, i.e., the job has more general materials handling requirement. This aspect would require a much more detailed study using a more complete job evaluation than was performed in this project, since the lesser exertions if frequent enough could cause muscle fatigue and increase the probability of contact injuries.

Certainly as many previous biomechanical analyses of lifting indicate, the size of an object and/or its location relative to the worker is an important hazard factor. This study lends some support to this finding.

Thus, conceptually it would appear that stringent medical examinations for job placement would be required on jobs exceeding conditions as expressed in Figure 29.

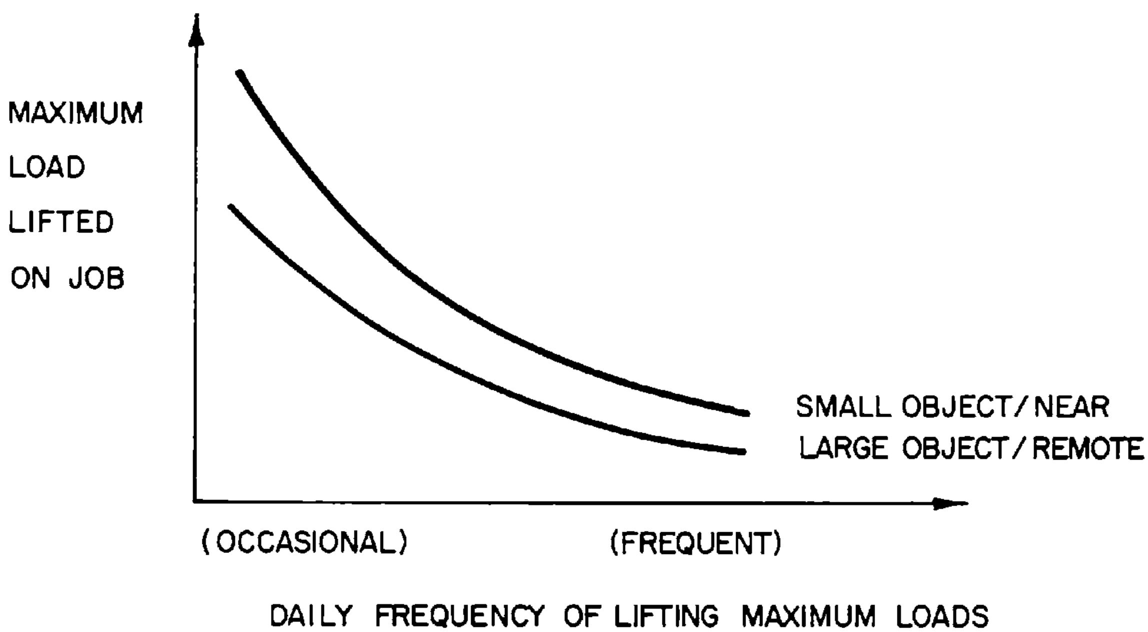


Figure 29: Proposed medical action level

The levels of the parameters described need to be established by combining the results of this research project with those of other projects now underway or recently finished. Such an action level concept, however, appears to be justified by this and other earlier studies. In fact, a similar concept was recently proposed by Snook (1976) at a NIOSH supported Symposium on Materials Handling Safety. NIOSH should now undertake a coordinated program of research in cooperation with industry and labor to establish equitable and effective physical exertion limits to protect the more susceptible workers. It is believed that this study amply demonstrates the enormous gains in the health and safety of the American worker which would be realized by such an approach.

RECOMMENDATION REGARDING STRENGTH TESTING AS A COMPONENT IN PREEMPLOYMENT MEDICAL EXAMINATIONS

Based on earlier studies and the results of this project, the medical incident data and supervisor work performance evaluations substantiate the need for employee strength testing to be incorporated into a systematic program of employee placement. Such an employee testing and placement program needs to be constructed and carefully evaluated in various plants to determine its effectiveness for preventive purposes.

SOME COMMENTS ON FURTHER RESEARCH NEEDS

The biomechanical and metabolic case evaluations comprising Chapter VII indicate the complexity of the issues when dealing with the medical problems associated with manual materials handling activities. It was only when the in-depth studies were performed that a more complete picture of the physical conditions on the job that cause specific stresses and strains were documented. In other words, the gross physical stress can probably be adequately rated by the method used in this study, as described in Chapter II. But to actually improve the job, once the action level has been exceeded, will require the more rigorous kinds of job physical evaluations described in Chapters III and VII. When this is done, it appears that very specific information regarding the causes of many different types of musculoskeletal and contact injuries is obtained. Further, the metabolic energy expenditure predictions could be used to understand the effects of various cardiovascular problems, predict better heat stress allowances, and ascribe better work/rest schedules.

The job evaluation methods described in Chapters III and VII are new developments. Their potential for assisting in the engineering control of the types of occupational health and safety hazards described in this report needs to be further researched and demonstrated. Considering the magnitude of the health problems, however, and the existing technology now available, such development and application should have a high priority within NIOSH.

One final recommendation is in regards to the development of occupational health monitoring systems. This project necessitated the development of such a system. It is effective because it has the following characteristics:

* Easy on-line retrieval and updating of all records (both job and employee).
* Job data and employee medical data are structured to allow easy statistical analysis.
* Supervisor employee performance evaluations are also included.
* Movement between jobs by employees is easily documented and included in computations of exposure data.
* Higher than nominal rates of job related medical occurrences can be detected and reported in order to identify potential problem areas.

The development of such systems should be encouraged in not only the control of toxic agents, but in the control of physical agents of many types as was done in this case. The technology to do so exists. Incentives and assistance to develop such systems should be given high priority within NIOSH.

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APPENDIX A

This appendix contains descriptive statistics (minima, maxima, means, and standard deviations) of 84 study variables for each of the six plants. These statistics are computed on the employee level, i.e., each study subject is weighted equally in the calculations.

An explanation of the abbreviations used for the variable labels is presented following the summary data.

The final page of this appendix is a graph showing the cumulative number of data reporting forms received as a function of time.

Descriptive Measures for Plant 1

VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STD DEV
TOT.HRS	108	22.000	2664.0	1297.3	854.26
HGT	108	57.000	74.000	66.870	3.7369
WGT	108	93.000	252.00	151.33	30.843
AGE	108	18.000	48.000	24.333	5.9058
SEX	108	0.	1.0000	.38889	.48977
PRO	108	0.	1.0000	.53704	.50095
ACT	108	0.	1.0000	.32407	.47021
NO.HIST	108	0.	2.0000	.92593 -1	.32171
NO.ACT	108	0.	2.0000	.38889	.69489
STR	108	14.000	207.00	66.120	41.290
STR1	108	13.000	198.00	63.037	40.519
STR2	108	12.000	198.00	63.963	39.739
STR3	108	14.000	227.00	66.722	44.413
STR4	108	11.000	219.00	70.194	43.902
TOR	108	10.000	204.00	74.630	39.569
ARM	108	10.000	174.00	71.991	35.282
LEG	108	30.000	375.00	159.25	82.278
LOAD	108	11.000	97.000	59.343	18.902
HOR	108	8.0000	30.000	15.694	4.1501
VER	108	4.0000	57.000	19.944	15.135
LSR	108	16.000	95.000	50.787	23.527
NO.SEC	108	0.	3.0000	2.0000	1.2530
NO.NSM	108	0.	0.	0.	
LENGTH	108	0.	46.000	17.778	9.0619
WIDTH	108	10.000	46.000	14.435	5.1324
HEIGHT	108	0.	23.000	10.120	5.3942
MED.INC	108	0.	6.0000	.99074	1.3006
NON.INC	108	0.	1.0000	.37037 -1	.18973

VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STD.DEV.
CON.INC	108	0.	4.0000	.65741	.94880
MUS.INC	108	0.	3.0000	.21296	.51248
BAC.INC	108	0.	3.0000	.83333 -1	.38970
MED.LOST	108	0.	79.000	.76852	7.6042
NON.LOST	108	0.	3.0000	.37037 -1	.30344
CON.LOST	108	0.	0.	0.	
MUS.LOST	108	0.	0.	0.	
BAC.LOST	108	0.	79.000	.73148	7.6018
MED.REST	108	0.	50.000	2.0093	7.2916
NON.REST	108	0.	0.	0.	
CON.REST	108	0.	50.000	1.4444	6.4058
MUS.REST	108	0.	10.000	.23148	1.3916
BAC.REST	108	0.	36.000	.33333	3.4641
MED.TOTL	108	0.	79.000	2.7778	10.386
NON.TOTL	108	0.	3.0000	.37037 -1	.30344
CON.TOTL	108	0.	50.000	1.4444	6.4058
MUS.TOTL	108	0.	10.000	.23148	1.3916
BAC.TOTL	108	0.	79.000	1.0648	8.3244
MED.IRAT	108	0.	6896.6	1005.8	1581.8
NON.IRAT	108	0.	6896.6	75.122	665.90
CON.IRAT	108	0.	5137.0	642.38	1188.9
MUS.IRAT	108	0.	5434.8	191.87	636.37
BAC.IRAT	108	0.	6250.0	96.444	630.17
MED.LRAT	108	0.	43311.	416.25	4168.1
NON.LRAT	108	0.	1245.8	15.222	125.51
CON.LRAT	108	0.	0.	0.	
MUS.LRAT	108	0.	0.	0.	
BAC.LRAT	108	0.	43311.	401.03	4167.6
MED.RRAT	108	0.	42135.	2342.1	7581.4
NON.RRAT	108	0.	0.	0.	

VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STD.DEV.
CON.RRAT	108	0.	42135.	1948.3	7354.5
MUS.RRAT	108	0.	16204.	258.93	1744.9
BAC.RRAT	108	0.	14563.	134.84	1401.3
MED.TRAT	108	0.	43311.	2758.3	8537.1
NON.TRAT	108	0.	1245.8	15.222	125.51
CON.TRAT	108	0.	42135.	1948.3	7354.5
MUS.TRAT	108	0.	16204.	258.93	1744.9
BAC.TRAT	108	0.	43311.	535.88	4384.5
AVG.3WK	100	1.8300	5.0000	4.2752	.78321
AVG.F	108	.33000	5.0000	4.0173	1.0368
CAPAB.3	100	1.0000	5.0000	4.3100	.88415
PERF.3	100	1.0000	5.0000	4.3300	.91071
ACCEPT.3	100	2.0000	5.0000	4.3100	.81271
INJURY.3	100	0.	5.0000	4.5800	.88967
PACE.3	100	0.	5.0000	4.1300	1.0016
MATCH.3	100	0.	5.0000	3.9700	1.0679
ABSENT.3	92	0.	5.0000	.80435	1.3847
CAPAB.F	108	0.	5.0000	4.0926	1.1068
PERF.F	108	0.	5.0000	3.9907	1.1879
ACCEPT.F	108	0.	5.0000	4.0000	1.1520
INJURY.F	108	0.	5.0000	4.4259	.95901
PACE.F	108	0.	5.0000	3.9074	1.3293
MATCH.F	108	0.	5.0000	3.6667	1.3942
ABSENT.F	104	0.	5.0000	.50000	1.0334
ESR	108	.22778	3.6364	1.2176	.81084
PRED.STR	108	17.414	113.98	80.204	18.216

Descriptive Measures for Plant 2

VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STD DEV
TOT.HRS	73	80.000	2920.0	997.93	794.51
HGT	73	60.000	74.000	67.479	3.5905
WGT	73	102.00	235.00	154.92	29.634
AGE	73	25.000	55.000	35.877	7.5239
SEX	73	0.	1.0000	.45205	.50114
PRO	73	0.	1.0000	.31507	.46776
ACT	73	0.	1.0000	.24658	.43400
NO.HIST	73	0.	3.0000	.56164	.78149
NO.ACT	73	0.	2.0000	.90411	.62726
STR	73	19.000	230.00	102.30	60.370
STR1	73	17.000	223.00	95.000	56.576
STR2	73	17.000	233.00	101.14	59.611
STR3	73	15.000	268.00	103.95	64.006
STR4	73	20.000	252.00	108.63	66.280
TOR	73	16.000	211.00	75.603	39.228
ARM	73	11.000	231.00	71.616	39.916
LEG	73	27.000	366.00	153.73	86.308
LOAD	73	41.000	123.00	64.521	19.735
HOR	73	5.0000	18.000	13.274	3.6828
VER	73	3.0000	58.000	20.425	15.623
LSR	73	18.000	77.000	44.288	11.300
NO.SEC	73	0.	3.0000	.75342	.96869
NO.NSM	73	0.	1.0000	.12329	.33104
LENGTH	73	9.0000	36.000	20.233	5.9989
WIDTH	73	5.0000	30.000	13.986	3.9493
HEIGHT	73	0.	17.000	6.5890	3.7448
MED.INC	73	0.	6.0000	.90411	1.3454
NON.INC	73	0.	3.0000	.34247	.67122

VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STD.DEV.
CON.INC	73	0.	4.0000	.47945	.86778
MUS.INC	73	0.	1.0000	.41096 -1	.19989
BAC.INC	73	0.	2.0000	.68493 -1	.30408
MED.LOST	73	0.	20.000	.78082	3.3634
NON.LOST	73	0.	20.000	.78082	3.3634
CON.LOST	73	0.	0.	0.	
MUS.LOST	73	0.	0.	0.	
BAC.LOST	73	0.	0.	0.	
MED.REST	73	0.	120.00	2.2603	14.487
NON.REST	73	0.	120.00	1.7397	14.057
CON.REST	73	0.	2.0000	.68493 -1	.34676
MUS.REST	73	0.	17.000	.24658	1.9915
BAC.REST	73	0.	15.000	.20548	1.7556
MED.TOTL	73	0.	120.00	3.0411	14.751
NON.TOTL	73	0.	120.00	2.5205	14.359
CON.TOTL	73	0.	2.0000	.68493 -1	.34676
MUS.TOTL	73	0.	17.000	.24658	1.9915
BAC.TOTL	73	0.	15.000	.20548	1.7556
MED.IRAT	73	0.	12500.	1146.2	2019.2
NON.IRAT	73	0.	4166.7	349.42	839.08
CON.IRAT	73	0.	12500.	651.49	1861.2
MUS.IRAT	73	0.	4166.7	92.499	531.76
BAC.IRAT	73	0.	2016.1	80.425	354.30
MED.LRAT	73	0.	9387.4	373.12	1513.9
NON.LRAT	73	0.	9387.4	373.12	1513.9
CON.LRAT	73	0.	0.	0.	
MUS.LRAT	73	0.	0.	0.	
BAC.LRAT	73	0.	0.	0.	
MED.RRAT	73	0.	48000.	1543.6	7320.5
NON.RRAT	73	0.	48000.	1057.1	6533.2

VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STD. DEV.
CON.RRAT	73	0.	2941.2	60.820	365.15
MUS.RRAT	73	0.	15625.	236.87	1836.4
BAC.RRAT	73	0.	13787.	188.86	1613.6
MED.TRAT	73	0.	48000.	1916.7	7396.9
NON.TRAT	73	0.	48000.	1430.2	6646.4
CON.TRAT	73	0.	2941.2	60.820	365.15
MUS.TRAT	73	0.	15625.	236.87	1836.4
BAC.TRAT	73	0.	13787.	188.86	1613.6
AVG.3WK	73	2.1700	5.0000	4.3533	.70259
AVG.F	73	2.0000	5.0000	4.3604	.75303
CAPAB.3	73	2.0000	5.0000	4.3699	.75474
PERF.3	73	0.	5.0000	4.2329	.93572
ACCEPT.3	73	2.0000	5.0000	4.5068	.72884
INJURY.3	73	3.0000	5.0000	4.7123	.58877
PACE.3	73	1.0000	5.0000	4.3014	.90806
MATCH.3	73	1.0000	5.0000	3.9726	1.0926
ABSENT.3	67	0.	4.0000	.31343	.65618
CAPAB.F	73	0.	5.0000	4.3288	.95822
PERF.F	73	0.	5.0000	4.3973	.92406
ACCEPT.F	73	2.0000	5.0000	4.4932	.78392
INJURY.F	73	1.0000	5.0000	4.6575	.83698
PACE.F	73	1.0000	5.0000	4.2740	.97554
MATCH.F	73	0.	5.0000	4.0000	1.1902
ABSENT.F	73	0.	5.0000	.34247	.97495
ESR	73	.18222	4.7368	.91041	.74556
PRED.STR	73	70.084	127.14	90.828	16.164

Descriptive Measures for Plant 3

VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STD DEV
TOT.HRS	66	8.0000	3400.0	1106.2	848.32
HGT	66	65.000	75.000	68.939	2.4737
WGT	66	127.00	266.00	173.65	28.881
AGE	66	21.000	44.000	28.758	5.6434
SEX	66	0.	1.0000	.30303 -1	.17273
PRO	66	0.	1.0000	.96970	.17273
ACT	66	0.	1.0000	.93939	.24043
NO.HIST	66	0.	2.0000	.60606 -1	.29762
NO.ACT	66	0.	2.0000	1.5152	.70694
STR	66	17.000	237.00	115.36	44.168
STR1	66	18.000	246.00	110.09	44.876
STR2	66	16.000	213.00	115.38	47.100
STR3	66	17.000	285.00	117.38	48.781
STR4	66	16.000	240.00	118.20	45.084
TOR	66	30.000	273.00	118.47	47.206
ARM	66	18.000	178.00	94.955	30.982
LEG	66	40.000	438.00	232.26	87.653
LOAD	66	36.000	84.000	58.318	12.032
HOR	66	6.0000	17.000	13.985	1.7408
VER	66	2.0000	74.000	41.561	13.375
LSR	66	24.000	70.000	43.394	9.9334
NO.SEC	66	0.	1.0000	.30303	.46309
NO.NSM	66	0.	1.0000	.65152	.48014
LENGTH	66	4.0000	48.000	16.394	5.0410
WIDTH	66	6.0000	144.00	13.333	24.369
HEIGHT	66	0.	30.000	3.0606	7.9341
MED.INC	66	0.	12.000	2.0758	2.4514
NON.INC	66	0.	6.0000	.98485	1.4196

VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STD.DEV.
CON.INC	66	0.	5.0000	.77273	1.0640
MUS.INC	66	0.	3.0000	.27273	.64559
BAC.INC	66	0.	1.0000	.12121	.32887
MED.LOST	66	0.	9.0000	.25758	1.2808
NON.LOST	66	0.	9.0000	.25758	1.2808
CON.LOST	66	0.	0.	0.	
MUS.LOST	66	0.	0.	0.	
BAC.LOST	66	0.	0.	0.	
MED.REST	66	0.	100.00	3.9091	14.855
NON.REST	66	0.	0.	0.	
CON.REST	66	0.	7.0000	.27273	1.2594
MUS.REST	66	0.	100.00	3.3333	14.808
BAC.REST	66	0.	7.0000	.30303	1.2523
MED.TOTL	66	0.	100.00	4.1667	14.881
NON.TOTL	66	0.	9.0000	.25758	1.2808
CON.TOTL	66	0.	7.0000	.27273	1.2594
MUS.TOTL	66	0.	100.00	3.3333	14.808
BAC.TOTL	66	0.	7.0000	.30303	1.2523
MED.IRAT	66	0.	.12500 +6	5044.3	16409.
NON.IRAT	66	0.	.12500 +6	3484.7	15966.
CON.IRAT	66	0.	23256.	1602.3	3848.8
MUS.IRAT	66	0.	11364.	543.31	1829.4
BAC.IRAT	66	0.	1315.8	76.210	227.70
MED.LRAT	66	0.	5000.0	146.91	716.54
NON.LRAT	66	0.	5000.0	146.91	716.54
CON.LRAT	66	0.	0.	0.	
MUS.LRAT	66	0.	0.	0.	
BAC.LRAT	66	0.	0.	0.	
MED.RRAT	66	0.	69686.	4019.5	12424.
NON.RRAT	66	0.	0.	0.	

VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STD.DEV.
CON.RRAT	66	0.	34884.	667.74	4341.7
MUS.RRAT	66	0.	69686.	3202.1	11829.
BAC.RRAT	66	0.	3888.9	149.73	633.35
MED.TRAT	66	0.	69686.	4166.4	12428.
NON.TRAT	66	0.	5000.0	146.91	716.54
CON.TRAT	66	0.	34884.	667.74	4341.7
MUS.TRAT	66	0.	69686.	3202.1	11829.
BAC.TRAT	66	0.	3888.9	149.73	633.35
AVG.3WK	64	.67000	5.0000	3.9295	.93532
AVG.F	66	.83000	5.0000	3.7948	1.0506
CAPAB.3	64	0.	5.0000	4.1250	.96773
PERF.3	64	0.	5.0000	4.1250	.95119
ACCEPT.3	64	1.0000	5.0000	4.1406	.87045
INJURY.3	64	1.0000	5.0000	4.1094	.97780
PACE.3	64	1.0000	5.0000	3.7031	1.2431
MATCH.3	64	1.0000	5.0000	3.3281	1.2978
ABSENT.3	55	0.	5.0000	1.3091	1.4513
CAPAB.F	66	0.	5.0000	4.1061	1.0688
PERF.F	66	0.	5.0000	4.0303	1.0950
ACCEPT.F	66	0.	5.0000	3.8485	1.2679
INJURY.F	66	0.	5.0000	3.8788	1.1834
PACE.F	66	0.	5.0000	3.5909	1.4248
MATCH.F	66	0.	5.0000	3.3182	1.4693
ABSENT.F	62	0.	5.0000	1.2097	1.5272
ESR	66	.18848	3.8235	.63410	.49830
PRED.STR	66	74.473	122.75	87.708	7.6409

Descriptive Measures for Plant 4

VARIABLE	#	MINIMUM	MAXIMUM	MEAN	STD DEV
TOT.HRS	48	80.000	1720.0	757.54	427.23
HGT	48	61.000	78.000	69.167	3.2112
WGT	48	122.00	232.00	168.44	26.328
AGE	48	24.000	58.000	40.833	9.6631
SEX	48	0.	1.0000	.10417	.30871
PRO	48	0.	1.0000	.20833	.41041
ACT	48	0.	1.0000	.27083	.44909
NO.HIST	48	0.	3.0000	.64583	.88701
NO.ACT	48	0.	2.0000	.77083	.62704
STR	48	38.000	212.00	96.417	44.675
STR1	48	36.000	207.00	89.875	41.405
STR2	48	39.000	216.00	97.563	45.390
STR3	48	41.000	222.00	98.438	48.166
STR4	48	37.000	216.00	99.667	47.074
TOR	48	50.000	216.00	113.13	41.745
ARM	48	35.000	105.00	68.833	17.424
LEG	48	76.000	300.00	175.17	61.077
LOAD	48	40.000	150.00	80.000	34.952
HOR	48	8.0000	22.000	11.896	3.3596
VER	48	4.0000	43.000	31.292	15.297
LSR	48	25.000	99.000	57.813	24.027
NO.SEC	48	0.	3.0000	2.2083	1.0306
NO.NSM	48	0.	0.	0.	
LENGTH	48	0.	54.000	15.833	13.146
WIDTH	48	0.	33.000	9.5000	7.8361
HEIGHT	48	0.	15.000	4.5833	3.6486
MED.INC	48	0.	2.0000	.58333	.76724
NON.INC	48	0.	2.0000	.27083	.53553

VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STD. DEV.
CON.INC	48	0.	2.0000	.10417	.37129
MUS.INC	48	0.	2.0000	.14583	.41203
BAC.INC	48	0.	1.0000	.62500 -1	.24462
MED.LOST	48	0.	79.000	5.3750	14.826
NON.LOST	48	0.	54.000	3.4375	9.4078
CON.LOST	48	0.	0.	0.	
MUS.LOST	48	0.	7.0000	.14583	1.0104
BAC.LOST	48	0.	62.000	1.7917	9.2021
MED.REST	48	0.	61.000	4.3333	12.891
NON.REST	48	0.	7.0000	.20833	1.0907
CON.REST	48	0.	0.	0.	
MUS.REST	48	0.	42.000	2.0417	7.8793
BAC.REST	48	0.	61.000	2.0833	10.349
MED.TOTL	48	0.	140.00	9.7083	24.538
NON.TOTL	48	0.	54.000	3.6458	9.8575
CON.TOTL	48	0.	0.	0.	
MUS.TOTL	48	0.	42.000	2.1875	8.2916
BAC.TOTL	48	0.	113.00	3.6667	17.741
MED.IRAT	48	0.	5208.3	889.02	1321.4
NON.IRAT	48	0.	4166.7	412.89	881.42
CON.IRAT	48	0.	1785.7	126.43	427.46
MUS.IRAT	48	0.	1785.7	164.26	459.45
BAC.IRAT	48	0.	5208.3	185.44	832.54
MED.LRAT	48	0.	.22500 +6	12011.	41429.
NON.LRAT	48	0.	.22500 +6	7425.6	32891.
CON.LRAT	48	0.	0.	0.	
MUS.LRAT	48	0.	5912.2	123.17	853.35
BAC.LRAT	48	0.	.13778 +6	4462.2	21475.
MED.RRAT	48	0.	.20313 +6	9324.4	35479.
NON.RRAT	48	0.	5912.2	215.08	1053.8

VARIABLE	N	MIMIMUM	MAXIMUM	MEAN	STD.DEV.
CON.RRAT	48	0.	0.	0.	
MUS.RRAT	48	0.	50000.	2053.5	8294.3
BAC.RRAT	48	0.	.20313 +6	7055.8	34900.
MED.TRAT	48	0.	.31111 +6	21335.	65483.
NON.TRAT	48	0.	.22500 +6	7640.7	32995.
CON.TRAT	48	0.	0.	0.	
MUS.TRAT	48	0.	50000.	2176.6	8571.4
BAC.TRAT	48	0.	.26042 +6	11055.	51648.
AVG.3WK	48	2.1700	5.0000	4.1179	.70705
AVG.F	48	1.5000	5.0000	4.0512	.82252
CAPAB.3	48	2.0000	5.0000	4.0833	.79448
PERF.3	48	3.0000	5.0000	4.2083	.71335
ACCEPT.3	48	2.0000	5.0000	4.2917	.68287
INJURY.3	48	3.0000	5.0000	4.6042	.60983
PACE.3	48	1.0000	5.0000	3.9167	1.0280
MATCH.3	48	0.	5.0000	3.6042	1.2332
ABSENT.3	48	0.	3.0000	.35417	.60105
CAPAB.F	48	2.0000	5.0000	4.2083	.87418
PERF.F	48	1.0000	5.0000	4.2708	.86884
ACCEPT.F	48	3.0000	5.0000	4.2292	.77842
INJURY.F	48	0.	5.0000	4.1875	1.3314
PACE.F	48	0.	5.0000	3.8542	1.3367
MATCH.F	48	0.	5.0000	3.5625	1.3194
ABSENT.F	48	0.	5.0000	.58333	1.1267
ESR	48	.30660	2.6316	.98205	.57996
PRED.STR	48	52.527	113.98	96.877	14.746

Descriptive Measures for Plant 5

VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STD DEV
TOT.HRS	32	104.00	2784.0	1085.6	771.47
HGT	32	60.000	75.000	67.406	2.9387
WGT	32	130.00	233.00	176.19	25.651
AGE	32	23.000	51.000	34.656	7.6099
SEX	32	0.	0.	0.	
PRO	32	0.	1.0000	.43750	.50402
ACT	32	0.	1.0000	.59375	.49899
NO.HIST	32	0.	2.0000	.25000	.50800
NO.ACT	32	0.	2.0000	.59375	.61484
STR	32	31.000	181.00	79.906	33.709
STR1	32	25.000	193.00	76.906	33.456
STR2	32	31.000	170.00	78.563	33.773
STR3	32	30.000	187.00	79.750	35.415
STR4	32	29.000	184.00	84.125	35.555
TOR	32	35.000	189.00	89.688	33.353
ARM	32	31.000	105.00	63.844	18.056
LEG	32	46.000	270.00	145.53	58.878
LOAD	32	45.000	105.00	90.625	14.185
HOR	32	7.0000	25.000	10.344	3.9481
VER	32	4.0000	77.000	44.188	14.003
LSR	32	39.000	99.000	62.438	8.4546
NO.SEC	32	0.	3.0000	1.1250	.55358
NO.NSM	32	0.	0.	0.	
LENGTH	32	1.0000	19.000	6.1875	2.5201
WIDTH	32	6.0000	16.000	14.719	2.9864
HEIGHT	32	0.	36.000	5.5938	10.348
MED.INC	32	0.	6.0000	1.0000	1.3678
NON.INC	32	0.	4.0000	.34375	.78738

VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STD.DEV.
CON.INC	32	0.	2.0000	.46875	.67127
MUS.INC	32	0.	1.0000	.62500 -1	.24593
BAC.INC	32	0.	3.0000	.12500	.55358
MED.LOST	32	0.	41.000	1.7188	7.5273
NON.LOST	32	0.	13.000	.43750	2.2992
CON.LOST	32	0.	0.	0.	
MUS.LOST	32	0.	0.	0.	
BAC.LOST	32	0.	41.000	1.2813	7.2478
MED.REST	32	0.	147.00	6.1875	26.085
NON.REST	32	0.	23.000	.84375	4.1044
CON.REST	32	0.	7.0000	.21875	1.2374
MUS.REST	32	0.	9.0000	.43750	1.7949
BAC.REST	32	0.	147.00	4.6875	25.974
MED.TOTL	32	0.	188.00	7.9063	33.233
NON.TOTL	32	0.	23.000	1.2813	4.6228
CON.TOTL	32	0.	7.0000	.21875	1.2374
MUS.TOTL	32	0.	9.0000	.43750	1.7949
BAC.TOTL	32	0.	188.00	5.9688	33.221
MED.IRAT	32	0.	12500.	1580.6	3175.9
NON.IRAT	32	0.	6250.0	355.17	1131.5
CON.IRAT	32	0.	12500.	1122.7	2662.2
MUS.IRAT	32	0.	905.80	40.063	171.39
BAC.IRAT	32	0.	1200.0	62.702	251.74
MED.LRAT	32	0.	16400.	676.22	2996.1
NON.LRAT	32	0.	4879.9	163.72	862.94
CON.LRAT	32	0.	0.	0.	
MUS.LRAT	32	0.	0.	0.	
BAC.LRAT	32	0.	16400.	512.50	2899.1
MED.RRAT	32	0.	58800.	2950.0	10798.
NON.RRAT	32	0.	19525.	710.95	3480.1

VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STD.DEV
CON.RRAT	32	0.	2514.4	78.574	444.48
MUS.RRAT	32	0.	4529.0	247.34	984.05
BAC.RRAT	32	0.	58800.	1913.1	10389.
MED.TRAT	32	0.	75200.	3626.2	13555.
NON.TRAT	32	0.	19525.	874.67	3551.8
CON.TRAT	32	0.	2514.4	78.574	444.48
MUS.TRAT	32	0.	4529.0	247.34	984.05
BAC.TRAT	32	0.	75200.	2425.6	13287.
AVG.3WK	25	2.0000	5.0000	3.9668	.87969
AVG.F	32	.17000	5.0000	3.7400	1.1932
CAPAB.3	25	0.	5.0000	3.9600	1.1719
PERF.3	25	2.0000	5.0000	4.1200	.83267
ACCEPT.3	25	3.0000	5.0000	4.2800	.73711
INJURY.3	25	1.0000	5.0000	4.3200	1.1075
PACE.3	25	2.0000	5.0000	3.8400	1.0279
MATCH.3	25	0.	5.0000	3.2800	1.4000
ABSENT.3	21	0.	5.0000	1.6667	1.7416
CAPAB.F	32	0.	5.0000	3.8438	1.3225
PERF.F	32	0.	5.0000	3.9063	1.0883
ACCEPT.F	32	1.0000	5.0000	4.0000	1.1072
INJURY.F	32	0.	5.0000	4.0000	1.4591
PACE.F	32	0.	5.0000	3.5938	1.4780
MATCH.F	32	0.	5.0000	3.0938	1.5731
ABSENT.F	30	0.	5.0000	1.3000	1.7449
ESR	32	.30488	3.0645	1.3342	.57499
PRED.STR	32	39.360	118.37	103.69	17.329

Descriptive Measures for Plant 6

VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STD DEV
TOT.HRS	224	48.000	2887.0	1361.2	786.85
HGT	224	58.000	80.000	69.768	3.2956
WGT	224	118.00	290.00	168.86	30.255
AGE	224	18.000	62.000	25.661	6.5620
SEX	224	0.	1.0000	.10268	.30422
PRO	224	0.	1.0000	.40625	.49223
ACT	224	0.	1.0000	.64286	.48023
NO.HIST	224	0.	3.0000	.22321	.48677
NO.ACT	224	0.	2.0000	1.3170	.70391
STR	224	15.000	348.00	84.786	54.808
STR1	224	7.0000	370.00	83.951	55.103
STR2	224	12.000	360.00	83.455	55.106
STR3	224	10.000	340.00	84.656	55.917
STR4	224	13.000	320.00	86.540	56.560
TOR	224	19.000	325.00	136.94	59.427
ARM	224	15.000	145.00	80.290	24.236
LEG	224	47.000	389.00	213.16	76.928
LOAD	224	36.000	145.00	79.545	24.233
HOR	224	6.0000	29.000	14.286	5.0919
VER	224	0.	61.000	32.621	18.044
LSB	224	29.000	99.000	67.406	20.453
NO.SEC	224	0.	3.0000	1.4286	1.1460
NO.NSM	224	0.	1.0000	.66964 -1	.25052
LENGTH	224	0.	48.000	18.129	12.302
WIDTH	224	0.	480.00	61.076	89.867
HEIGHT	224	0.	98.000	7.4509	10.431
MED.INC	224	0.	6.0000	.62054	1.0646
NON.INC	224	0.	6.0000	.29464	.75926

VARIABLE	N	MINUMUM	MAXIMUM	MEAN	STD.DEV.
CON.INC	224	0.	3.0000	.24107	.53144
MUS.INC	224	0.	1.0000	.44643 -1	.20698
BAC.INC	224	0.	2.0000	.35714 -1	.20871
MED.LOST	224	0.	83.000	1.7321	8.1163
NON.LOST	224	0.	43.000	.98661	4.0440
CON.LOST	224	0.	0.	0.	
MUS.LOST	224	0.	79.000	.65625	6.9057
BAC.LOST	224	0.	10.000	.89286 -1	.76999
MED.REST	224	0.	10.000	.44643 -1	.66815
NON.REST	224	0.	10.000	.44643 -1	.66815
CON.REST	224	0.	0.	0.	
MUS.REST	224	0.	0.	0.	
BAC.REST	224	0.	0.	0.	
MED.TOTL	224	0.	83.000	1.8884	8.3554
NON.TOTL	224	0.	43.000	1.0313	4.2388
CON.TOTL	224	0.	0.	0.	
MUS.TOTL	224	0.	79.000	.65625	6.9057
BAC.TOTL	224	0.	10.000	.89286 -1	.76999
MED.IRAT	224	0.	8771.9	646.54	1384.1
NON.IRAT	224	0.	6250.0	293.60	842.71
CON.IRAT	224	0.	5263.2	256.87	784.64
MUS.IRAT	224	0.	4464.3	53.427	359.95
BAC.IRAT	224	0.	2544.5	39.988	258.44
MED.LRAT	224	0.	56081.	1305.0	5272.3
NON.LRAT	224	0.	24862.	847.51	3172.3
CON.LRAT	224	0.	0.	0.	
MUS.LRAT	224	0.	53378.	384.75	4110.7
BAC.LRAT	224	0.	6250.0	72.735	614.48
MED.RRAT	224	0.	6422.6	28.672	429.13
NON.RRAT	224	0.	6422.6	28.672	429.13

VARIABLE	N	MIMIMUM	MAXIMUM	MEAN	STD. DEV.
CON.BRAT	224	0.	0.	0.	
MUS.BRAT	224	0.	0.	0.	
BAC.BRAT	224	0.	0.	0.	
MED.TRAT	224	0.	80128.	1691.4	7491.9
NON.TRAT	224	0.	24862.	876.18	3273.6
CON.TRAT	224	0.	0.	0.	
MUS.TRAT	224	0.	53378.	384.75	4110.7
BAC.TRAT	224	0.	6250.0	72.735	614.48
AVG.3WK	184	2.1700	5.0000	4.5116	.64522
AVG.F	224	1.8300	5.0000	4.2647	.77128
CAPAB.3	184	2.0000	5.0000	4.5380	.67643
PERF.3	184	2.0000	5.0000	4.4783	.74626
ACCEPT.3	184	0.	5.0000	4.4565	.85460
INJURY.3	184	0.	5.0000	4.7609	.60723
PACE.3	184	1.0000	5.0000	4.5163	.77513
MATCH.3	184	1.0000	5.0000	4.3207	.94690
ABSENT.3	179	0.	5.0000	.20112	.69815
CAPAB.F	224	1.0000	5.0000	4.3571	.78503
PERF.F	224	2.0000	5.0000	4.3125	.80949
ACCEPT.F	224	2.0000	5.0000	4.2232	.91534
INJURY.F	224	0.	5.0000	4.4241	.98124
PACE.F	224	2.0000	5.0000	4.2545	.82694
MATCH.F	224	1.0000	5.0000	4.0179	1.0286
ABSENT.F	219	0.	4.0000	.72603	1.3125
ESR	224	.20089	4.8667	1.3682	.96113
PRED.STR	224	21.803	122.75	86.387	22.349

DEFINITION OF LABELS

Employee Variables:

Tot. Hrs. - Total hours of exposure to the job
Hgt - Height (inches)
Wgt - Weight (pounds)
Age - Age (years)
Sex - Gender (0 = male, 1 = female)
Pro - Medical Prognosis (1 = excellent, 0 = other)
Act - Experience rating in physical activities (1 = excellent, 0 = other)
No. Hist - Number of medical history cases documented on Form 3
No. Act - Number of previous physical activities documented on Form 3
Str - Average of four strength tests in job position (lbs.)
Str 1 - Result of 1st strength test in job position (lbs.)
Str 2 - Result of 2nd strength test in job position (lbs.)
Str 3 - Result of 3rd strength test in job position (lbs.)
Str 4 - Result of 4th strength test in job position (lbs.)
Tor - Result of standard position test of torso strength (lbs.)
Arm - Result of standard position test of arm strength
Leg - Result of standard position test of leg strength

Job Variables:

Load - Weight lifted in primary task (lbs.)
Hor - Horizontal distance from ankle to object (inches)
Ver - Vertical Distance from floor to object (inches)
LSR - LSR x 100
No. Sec - Number of secondary tasks documented on Form 1
No. Nsm - Number of non-symmetrical tasks documented on Form 1
Length - Object length (inches)
Width - Ojbect width (inches)
Height - Object height (inches)

Medical Variables:

Med. Inc - Total number of on the job medical incidents
Non. Inc - Total nonspecific incidents
Con. Inc - Total contact incidents
Mus. Inc - Total musculoskeletal incidents
Bac. Inc - Total back incidents
Med. Lost - Total days lost - all incident categories
Non. Lost - Total days lost - nonspecific incidents
Con. Lost - Total days lost - contact incidents
Mus. Lost - Total days lost - musculoskeletal incidents
Bac. Lost - Total days lost - back incidents
Med. Rest - Total days restricted - all incident categories
Non. Rest - Total days restricted - nonspecific incidents
Con. Rest - Total days restricted - contact incidents
Mus. Rest - Total days restricted - musculoskeletal incidents
Bac. Rest - Total days restricted - back incidents
Med. Total - (Days lost + days restricted) all incident categories

Non. Total - (Days lost + days restricted) nonspecific incidents
Con. Total - (Days lost + days restricted) contact incidents
Mus. Total - (Days lost + days restricted) musculoskeletal incidents
Bac. Total - (Days lost + days restricted) back incidents
Med. Irat - Incidence rate per million man-hours - all incident categories
Non. Irat - Incidence rate per million man-hours - nonspecific incidents
Con. Irat - Incidence rate per million man-hours - contact incidents
Mus. Irat - Incidence rate per million man-hours - musculoskeletal incidents
Bac. Irat - Incidence rate per million man hours - back incidents
Med. Lrat - Days lost per million man-hours - all incident categories
Non. Lrat - Days lost per million man-hours - nonspecific incidents
Con. Lrat - Days lost per million man-hours - contact incidents
Mus. Lrat - Days lost per million man-hours - musculoskeletal incidents
Bac. Lrat - Days lost per million man-hours - back incidents
Med. Rrat - Days restricted per million man-hours - all incident categories
Non. Rrat - Days restricted per million man-hours - nonspecific incidents
Con. Rrat - Days restricted per million man-hours - contact incidents
Mus. Rrat - Days restricted per million man-hours - musculoskeletal incidents
Bac. Rrat - Days restricted per million man-hours - back incidents
Med. Trat - Days lost + days restricted per million man-hours - all incident categories
Non. Trat - Days lost + days restricted per million man-hours - nonspecific incidents
Con. Trat - Days lost + days restricted per million man-hours - contact incidents
Mus. Trat - Days lost + days restricted per million man-hours - musculoskeletal incidents
Bac. Trat - Days lost + days restricted per million man-hours - back incidents

Supervisor Evaluation Variables:

Avg. 3wk - Average three week evaluation score
Avg. F - Average final evaluation score
Capab. 3 - Physical capability rating - three week
Perf. 3 - Performance rating - three week
Accept. 3 - Acceptance of lifting rating - three week
Injury 3 - Freedom from injury rating - three week
Pace 3 - Working pace rating - three week
Match 3 - Job/employee match rating - three week
Absent. 3 - Absence rating - three week
Capab. F - Physical capability rating - final
Perf. F - Performance rating - final
Accept. F - Acceptance of lifting rating - final
Injury F - Freedom from injury rating - final
Pace F - Working pace rating - final
Match F - Job/employee match rating - final
Absent. F - Absence rating - final

Other Variables:

ESR - Employee strength ratio = object weight lifted on the job/employee strength demonstrated in job position test.
Pred. Str - Predicted strength in job position using regression equation of Chapter IV.

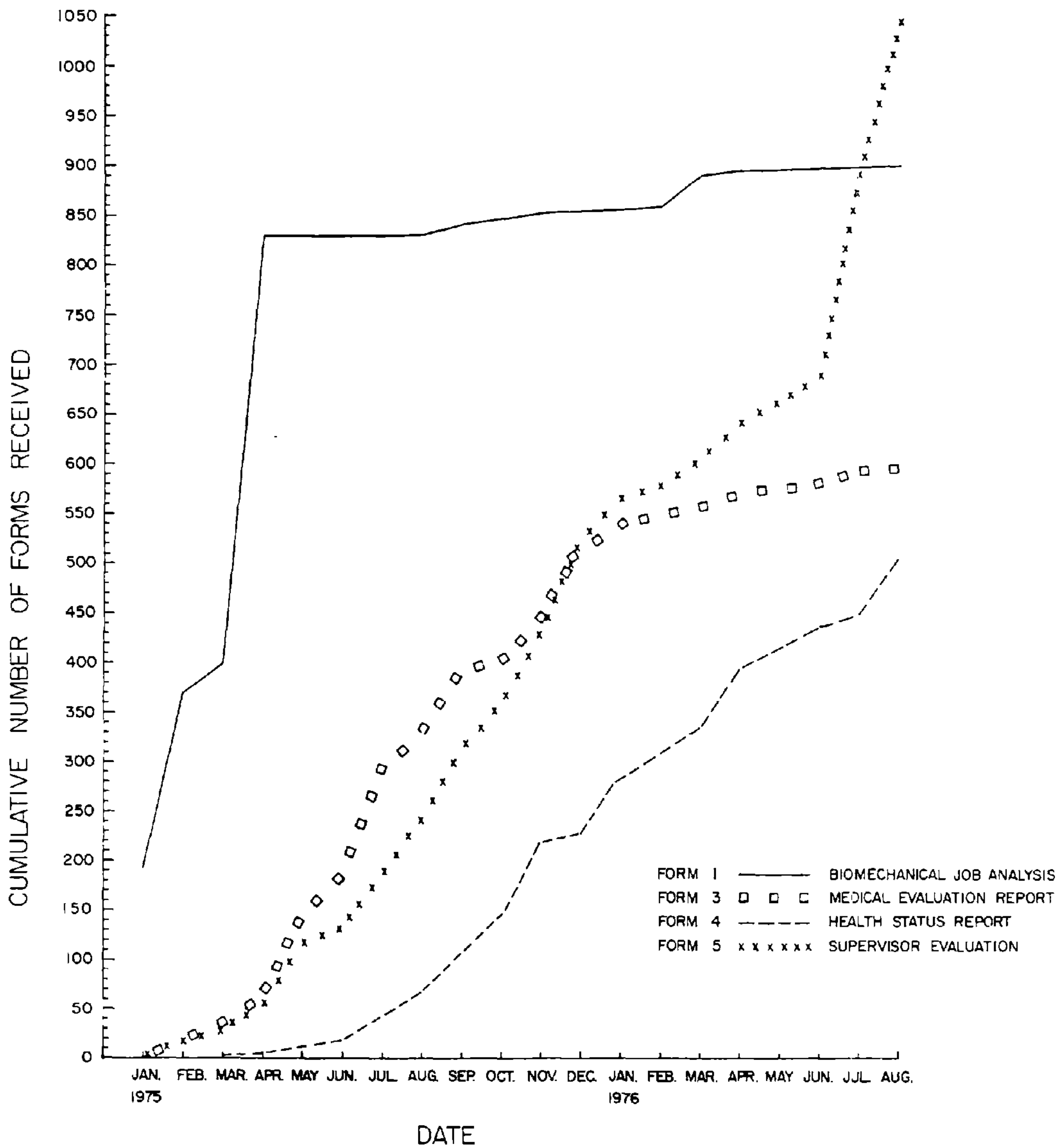

Figure A-1: Cumulative number of forms received January 1975 through end of study

APPENDIX B

This appendix summarizes the types of incidents encountered in this study along with the frequency and severity statistics for the classifications utilized in the various analyses.

Table B-1

PRE-EMPLOYMENT STRENGTH TESTING EXPERIMENT -- SUMMARY OF MEDICAL INCIDENTS
MEDICAL COMPLAINTS CLASSIFIED BY BODY MEMBER AFFECTED
COMPILED AUG 17, 1976 FOR ALL PLANTS

BODY MEMBER	NUMBER OF INCIDENTS	PERCENTAGE OF TOTAL
HEAD	76	10.5
NECK	10	1.4
SHOULDER	22	3.0
ELBOW	13	1.8
ARM	31	4.3
WRIST	25	3.4
HAND	160	22.0
UPR BACK	18	2.5
LOW BACK	37	5.1
ABDOMEN	75	10.3
CHEST	36	5.0
THIGH	8	1.1
KNEE	22	3.0
LOWR LEG	12	1.7
ANKLE	11	1.5
FOOT	28	3.9
OTHER	142	19.6

$$$ THIS TABLE IS BASED ON A TOTAL OF 728 BODY MEMBERS

Table B-2

PRE-EMPLOYMENT STRENGTH TESTING EXPERIMENT -- SUMMARY OF MEDICAL INCIDENTS
MEDICAL COMPLAINTS CLASSIFIED BY DIAGNOSIS
COMPILED AUG 17, 1976 FOR ALL PLANTS

DIAGNOSIS	NUMBER OF INCIDENTS	PERCENTAGE OF TOTAL
INFECTIVE/PARASITIC DISEASE	8	1.3
CHEMICAL BURN	1	0.2
DISEASE OF BLOOD	1	0.2
MENTAL DISORDERS	1	0.2
NERVOUS SYSTEM DISORDER	5	0.9
CIRCULATORY DISEASE	4	0.6
RESPIRATORY DISEASE	76	12.0
DIGESTIVE DISORDER	50	7.9
GENITOURINARY DISORDER	8	1.3
SKIN DISORDER (DERMATITIS)	19	3.0
MUSCULO-SKELETAL DISORDER	23	3.6
ILL-DEFINED SYMPTOMS/CAUSES	58	9.2
FRACTURE -- UPPER LIMB	8	1.3
FRACTURE -- LOWER LIMB	3	0.5
SPRAIN/STRAIN WITHOUT WOUND	60	9.5
LACERATION AND OPEN WOUND	93	14.7
SPINAL FRACTURE	1	0.2
BACK- SPRAIN OR STRAIN	24	3.8
ABRASION/BLISTER/SCRATCH	77	12.2
CONTUSION OR BRUISE	67	10.6
EFFECTS OF FOREIGN BODY	14	2.2
EXTERNAL BURN(S)	21	3.3
ADVERSE EFFECTS OF CHEMICALS	2	0.3
ADVERSE ENVIRONMENTAL EFFECT	8	1.3

$$$ THIS TABLE IS BASED ON A TOTAL OF 633 REPORTED DIAGNOSES

PRE-EMPLOYMENT STRENGTH TESTING EXPERIMENT -- SUMMARY OF MEDICAL INCIDENTS
BODY MEMBER VS. DIAGNOSIS MATRIX
COMPILED AUG 17, 1976 FOR ALL PLANTS

Table B-3

BODY MEMBER

DIAGNOSIS	HEAD	NECK	SHDR	ELBO	ARM	WRST	HAND	UBAC	LBAC	ABDM	CHST	THIG	KNEE	LLEG	ANKL	FOOT	OTHR
INFECTIVE/PARASITIC DISEASE	2									1							5
CHEMICAL BURN						1	1										
DISEASE OF BLOOD																	1
MENTAL DISORDERS																	1
NERVOUS SYSTEM DISORDER	2																4
CIRCULATORY DISEASE																	4
RESPIRATORY DISEASE	22	2								13	26						28
DIGESTIVE DISORDER	4									39	3						10
GENITOURINARY DISORDER								1	1								7
SKIN DISORDER (DERMATITIS)	1				4	2	3	1			2	1				1	10
MUSCULO-SKELETAL DISORDER		1	1	1	2	1	2		9		1		2			3	1
ILL-DEFINED SYMPTOMS/CAUSES	20	2		1	1	1	2	3	3	18	2				1		17
FRACTURE -- UPPER LIMB						2	5										2
FRACTURE -- LOWER LIMB									1				1		1	1	
SPRAIN/STRAIN WITHOUT WOUND	1	3	15		5	11	5	2	2	2	2	2	10	1	4	4	2
LACERATION AND OPEN WOUND	3			1	5	4	65					2	1	2		5	7
SPINAL FRACTURE									1						1		
BACK- SPRAIN OR STRAIN			3					7	15							1	
ABRASION/BLISTER/SCRATCH	6			2	4	2	42	1	2			1	6	5	1	1	16
CONTUSION OR BRUISE	5	2	3	7	7	1	23	2	3			1	2	3	3	10	9
EFFECTS OF FOREIGN BODY	3						1					1					11
EXTERNAL BURN(S)	1			1	3		11	1		2						2	2
ADVERSE EFFECTS OF CHEMICALS	1													1			1
ADVERSE ENVIRONMENTAL EFFECT	1																4
TOTAL	75	10	22	13	31	25	160	18	37	75	36	8	22	12	11	28	142

Table B-4: Medical incidents by class of incident (employee level)

ITEM	No Incidents (n=311)		One or More (n=240)		Nonspecific (n=115)		Contact (n=160)		Musculoskeletal (n=53)		Back (n=30)	
	$\bar{X}$	S	$\bar{X}$	S	X	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S
Number of Incidents	---	---	2 60	1.60	2.55	1.94	2.29	1.74	2.62	2.13	3.03	2.49
Days Lost	---	---	2.96	10.53	5.53	13.23	1.35	7.39	3.52	14.99	9.03	21.00
Days Restricted	---	---	4.35	16.29	4.15	16.23	3.30	12.43	8.90	18.38	14.80	33.61
Total Days	---	---	7.32	21.28	9.68	22.2	4.65	14.19	12.43	23.09	23.83	45.58
Incident Rate*	---	---	3035	8835	3893	12370	2798	4559	2941	3394	2696	2.33
Severity Rate*	---	---	3601	19398	6995	27219	743	3904	2303	9338	12474	34124
Lost Rate*	---	---	8488	31643	11290	37059	3803	9552	10575	17612	30117	72745

*per million man hours

APPENDIX C

This appendix summarizes the medical experiences of the study population as a function of employee/job match. Each table represents a rating index based upon one of three levels of analysis:

1. employee level (n = 551 employees)
   ESR = employee strength rating as defined in Chapter V with one data entry per employee

2. job level (n = 128 jobs)
   JSR = job strength rating as defined in Chapter V with one data entry per study job

3. multiple employee jobs level (n = 78)
   MJSR = job strength rating as defined in Chapter V with one data entry per job with more than one employee

In deriving each of these rating indices, two measures of employee strengths were examined: actual observed strengths as demonstrated in the isometric tests or predicted job position strengths based on anthropologic and job descriptors as described in Chapter IV. In the latter case, the ratings are prefixed with PRED to indicate use of predicted strengths in place of observed strengths, i.e., Pred.ESR, Pred.JSR, and Pred.MJSR.

Each of these indices are further examined multiplicatively with frequency of exertion, FREQ, and horizontal distance to object, HOR, and FREQ times HOR, FREQ x HOR.

The combinations of variables and table references are as follow:

Table C-1: Medical Experience by Employee Strength Rating (HOR x ESR)

ESR x in.	Total Medical	Nonspecific Complaints	Contact Injuries	Musculoskel. Injuries	Back Injuries	No. Empl.	Response
< 5	1070	378	544	133	48	63	
5-15	1633	639	809	216	125	280	INCIDENTS (per million man-hours)
>15	1146	757	294	80	13	208	
< 5	4090	3830	---	---	260	63	
5-15	1997	844	---	197	955	280	DAYS LOST (per million man-hours)
>15	747	540	---	176	30	208	
< 5	1493	---	75	462	956	63	
5-15	3155	372	470	971	1340	280	DAYS RESTRICTED (per million man-hours)
>15	969	59	600	297	11	208	
< 5	5584	3830	75	462	1217	63	
5-15	5439	1216	470	1169	2217	280	DAYS LOST + DAYS RESTRICTED (per million man-hours)
>15	1716	599	600	474	41	208	

Table C-2: Medical Experience by Employee Strength Rating (PRED x ESR).

Pred. ESR	Total Medical	Nonspecific Complaints	Contact Injuries	Musculoskel. Injuries	Back Injuries	No. Empl.	Response
<.5	1192	400	477	241	74	79	INCIDENTS (per million man-hours)
.5-1	1853	947	765	202	86	309	
≥ 1	592	222	295	18	53	163	
<.5	3307	3100	---	---	207	79	DAYS LOST (per million man-hours)
.5-1	1304	612	---	279	413	309	
≥ 1	1890	958	---	36	896	163	
<.5	1561	---	380	419	763	79	DAYS RESTRICTED (per million man-hours)
.5-1	2462	338	345	995	784	309	
≥ 1	1811	76	766	138	832	163	
<.5	4869	3100	380	419	971	79	DAYS LOST + DAYS RESTRICTED (per million man-hours)
.5-1	3766	949	345	1274	1197	309	
≥ 1	4193	1033	766	174	1592	163	

Table C-3: Medical Experience by Employee Strength Rating (FREQ x PRED.ESR)

Pred. ESR/ Week	Total Medical	Nonspecific Complaints	Contact Injuries	Musculoskel. Injuries	Back Injuries	No. Empl.	Response
< 50	774	302	329	61	85	348	INCIDENTS (per million man-hours)
50-100	1306	441	624	192	47	46	
>100	2762	1496	1139	345	58	157	
< 50	2504	1583	---	264	656	348	DAYS LOST (per million man-hours)
50-100	1376	389	---	---	986	46	
>100	238	133	---	---	104	157	
< 50	1666	269	90	286	1019	348	DAYS RESTRICTED (per million man-hours)
50-100	1523	---	---	1491	31	46	
>100	3371	144	1464	1241	520	157	
< 50	4171	1853	90	550	1612	348	DAYS LOST + DAYS RESTRICTED (per million man-hours)
50-100	4641	389	---	1491	1018	46	
>100	3610	278	1464	1241	625	157	

Table C-4: Medical Experience by Employee Strength Rating (HOR x PRED.ESR)

ESR x in.	Total Medical	Nonspecific Complaints	Contact Injuries	Musculoskel. Injuries	Back Injuries	No. Empl.	Response
< 5	807	179	315	114	197	52	
5-15	1731	878	709	199	67	367	INCIDENTS (per million man-hours)
>15	650	216	345	40	47	132	
< 5	1791	374	---	---	1417	52	
5-15	1643	1200	---	234	208	367	DAYS LOST (per million man-hours)
>15	2090	986	---	44	1059	132	
< 5	7973	923	485	1262	5302	52	
5-15	1132	153	196	749	33	367	DAYS RESTRICTED (per million man-hours)
>15	2643	93	1242	169	1137	132	
< 5	9764	1297	485	1262	6719	52	
5-15	2995	1353	196	984	242	367	DAYS LOST + DAYS RESTRICTED (per million man-hours)
>15	4734	1079	1242	214	2028	132	

Table C-5: Medical Experience by Employee Strength Rating (FREQ x HOR x PRED.ESR)

Pred. ESR x in./week	Total Medical	Nonspecific Complaints	Contact Injuries	Musculoskel. Injuries	Back Injuries	No. Empl.	Response
< 500	759	280	332	66	84	323	
500-1000	1255	547	517	123	66	63	INCIDENTS (per million man-hours)
>1000	2659	1426	1103	335	59	165	
< 500	2562	1570	---	285	707	323	
500-1000	993	960	---	---	33	63	DAYS LOST (per million man-hours)
>1000	496	134	---	---	361	165	
< 500	1795	290	97	308	1098	323	
500-1000	724	---	---	701	23	63	DAYS RESTRICTED (per million man-hours)
>1000	3356	137	1393	1329	495	165	
< 500	4358	1861	97	593	1737	323	
500-1000	2990	960	---	701	56	63	DAYS LOST + DAYS RESTRICTED (per million man-hours)
>1000	3853	272	1393	1329	857	165	

Table C-6: Medical Experience by Job Strength Rating (FREQ x JSR)

JSR/week	Total Medical	Nonspecific Complaints	Contact Injuries	Musculoskel. Injuries	Back Injuries	No. Jobs	Response
< 50	886	280	413	94	113	90	
50-100	573	177	134	124	136	17	INCIDENTS (per million man-hours)
>100	733	232	318	128	60	21	
< 50	4323	3172	---	56	1094	90	
50-100	4288	749	---	---	3538	17	DAYS LOST (per million man-hours)
>100	188	188	---	---	---	21	
< 50	3431	270	134	385	2641	90	
50-100	4152	---	---	693	3458	17	DAYS RESTRICTED (per million man-hours)
>100	1525	48	605	310	560	21	
< 50	7755	3443	134	442	3681	90	
50-100	8710	749	---	693	6997	17	DAYS LOST + DAYS RESTRICTED (per million man-hours)
>100	1713	236	605	310	560	21	

Table C-7: Medical Experience by Job Strength Rating (HOR x JSR)

JSR x in.	Total Medical	Nonspecific Complaints	Contact Injuries	Musculoskel. Injuries	Back Injuries	No. Jobs	Response
< 5	941	352	349	163	76	21	
5-15	991	309	428	104	169	70	INCIDENTS (per million man-hours)
>15	426	110	238	69	8	37	
< 5	11676	10895	---	---	780	21	
5-15	2820	759	---	35	2026	70	DAYS LOST (per million man-hours)
>15	630	547	---	70	12	37	
< 5	4872	861	225	871	2914	21	
5-15	4230	70	2168	413	3529	70	DAYS RESTRICTED (per million man-hours)
>15	353	65	131	156	---	37	
< 5	16548	11756	225	871	3695	21	
5-15	7116	829	216	448	5485	70	DAYS LOST + DAYS RESTRICTED (per million man-hours)
>15	984	613	131	227	12	37	

Table C-8: Medical Experience by Job Strength Rating (FREQ x HOR x JSR)

JSR x in./ week	Total Medical	Nonspecific Complaints	Contact Injuries	Musculoskel. Injuries	Back Injuries	No. Jobs	Response
< 500	817	252	365	94	121	83	
500-1000	1082	296	478	164	142	17	INCIDENTS (per million man-hours)
>1000	667	256	274	96	45	23	
< 500	4686	3438	---	61	1187	83	
500-1000	3705	166	---	---	3538	17	DAYS LOST (per million man-hours)
>1000	500	500	---	---	---	23	
< 500	3660	293	145	358	2862	83	
500-1000	4451	---	---	984	3467	17	DAYS RESTRICTED (per million man-hours)
>1000	1144	36	454	233	420	23	
< 500	8346	3732	145	420	3990	83	
500-1000	8426	166	---	984	7006	17	DAYS LOST + DAYS RESTRICTED (per million man-hours)
>1000	1644	537	454	233	420	23	

Table C-9: Medical Experience by Job Strength Rating (PRED.JSR)

Pred. JSR	Total Medical	Nonspecific Complaints	Contact Injuries	Musculoskel. Injuries	Back Injuries	No. Jobs	Response
< .5	854	328	317	97	110	21	
.5-1	917	272	410	125	127	81	INCIDENTS (per million man-hours)
> 1	489	162	239	41	44	26	
< .5	11681	10900	---	---	780	21	
.5-1	1980	564	---	41	1374	81	DAYS LOST (per million man-hours)
> 1	2318	1061	---	64	1191	26	
< .5	3442	---	538	96	2807	21	
.5-1	3513	283	106	412	2710	81	DAYS RESTRICTED (per million man-hours)
> 1	2101	93	187	676	1144	26	
< .5	15123	10900	538	96	3588	21	
.5-1	5493	848	106	454	4084	81	DAYS LOST + DAYS RESTRICTED (per million man-hours)
> 1	4595	1154	187	741	2148	26	

Table C-10: Medical Experience by Job Strength Rating (FREQ x PRED.JSR)

Pred. JSR/ week	Total Medical	Nonspecific Complaints	Contact Injuries	Musculoskel. Injuries	Back Injuries	No. Jobs	Response
< 50	812	237	387	86	115	91	INCIDENTS (per million man-hours)
50-100	901	396	249	202	53	15	
> 100	796	253	324	111	112	22	
< 50	4293	3155	---	55	1082	91	DAYS LOST (per million man-hours)
50-100	3662	744	---	---	2917	15	
> 100	924	179	---	---	745	22	
< 50	3338	268	132	327	2610	91	DAYS RESTRICTED (per million man-hours)
50-100	1125	---	---	1115	9	15	
> 100	4128	46	577	296	3207	22	
< 50	7631	3423	132	383	3639	91	DAYS LOST + DAYS RESTRICTED (per million man-hours)
50-100	5092	744	---	1115	2927	15	
> 100	5053	226	577	296	3952	22	

Table C-11: Medical Experience by Job Strength Rating (HOR x PRED.JSR)

Pred. JSR x in.	Total Medical	Nonspecific Complaints	Contact Injuries	Musculoskel. Injuries	Back Injuries	No. Jobs	Response
< 5	813	97	222	134	360	21	
5-15	937	337	438	117	62	78	INCIDENTS (per million man-hours)
>15	508	165	251	45	45	29	
< 5	3775	266	---	---	3509	21	
5-15	4207	3467	---	43	696	78	DAYS LOST (per million man-hours)
>15	2018	902	---	58	1058	29	
< 5	14551	861	313	795	12580	21	
5-15	598	62	82	391	61	78	DAYS RESTRICTED (per million man-hours)
>15	2043	83	405	199	1354	29	
< 5	18326	1127	313	795	16089	21	
5-15	4864	3530	82	434	757	78	DAYS LOST + DAYS RESTRICTED (per million man-hours)
>15	4062	985	405	257	2245	29	

Table C-12: Medical Experience by Job Strength Rating (FREQ x HOR x PRED.JSR)

Pred. JSR x in./week	Total Medical	Nonspecific Complaints	Contact Injuries	Musculoskel. Injuries	Back Injuries	No. Jobs	Response
< 500	838	237	401	93	123	84	INCIDENTS (per million man-hours)
500-1000	793	398	213	160	21	19	
>1000	776	228	336	97	121	25	
< 500	4593	3359	---	60	1172	84	DAYS LOST (per million man-hours)
500-1000	850	826	---	---	23	19	
>1000	2560	171	---	---	2388	25	
< 500	3616	290	143	354	2827	84	DAYS RESTRICTED (per million man-hours)
500-1000	888	---	---	880	7	19	
>1000	3633	41	508	261	2822	25	
< 500	8209	3650	143	415	3942	84	DAYS LOST + DAYS RESTRICTED (per million man-hours)
500-1000	1979	826	---	880	31	19	
>1000	6193	213	508	261	5211	25	

Table C-13: Medical Experience by Multiple Employee Job Strength Rating (MJSR)

MJSR	Total Medical	Nonspecific Complaints	Contact Injuries	Musculoskel. Injuries	Back Injuries	No. Jobs	Response
< .5	1138	315	722	90	42	10	
.5-1	773	284	299	100	114	46	INCIDENTS (per million man-hours)
> 1	464	116	243	72	30	22	
< .5	477	477	---	---	---	10	
.5-1	1983	1091	---	---	891	46	DAYS LOST (per million man-hours)
> 1	868	607	---	230	30	22	
< .5	1809	146	74	1573	14	10	
.5-1	1982	445	201	385	949	46	DAYS RESTRICTED (per million man-hours)
> 1	1440	156	455	823	5	22	
< .5	2287	624	74	1573	14	10	
.5-1	3965	1537	201	385	1735	46	DAYS LOST + DAYS RESTRICTED (per million man-hours)
> 1	2517	764	455	1054	35	22	

Table C-14: Medical Experience by Multiple Employee Job Strength Rating (FREQ x MJSR)

MJSR/week	Total Medical	Nonspecific Complaints	Contact Injuries	Musculoskel. Injuries	Back Injuries	No. Jobs	Response
< 50	753	272	345	74	86	52	
50-100	457	156	192	62	64	9	INCIDENTS (per million man-hours)
>100	807	189	393	158	75	17	
< 50	2054	1163	---	97	792	52	
50-100	480	430	---	---	50	9	DAYS LOST (per million man-hours)
>100	232	232	---	---	---	17	
< 50	1868	469	141	640	618	52	
50-100	1310	---	---	1310	---	9	DAYS RESTRICTED (per million man-hours)
>100	1884	60	747	384	692	17	
< 50	3923	1632	141	737	1317	52	
50-100	2299	430	---	1310	50	9	DAYS LOST + DAYS RESTRICTED (per million man-hours)
>100	2116	292	747	384	692	17	

Table C-15: Medical Experience by Multiple Employee Job Strength Rating (HOR x MJSR)

MJSR x in.	Total Medical	Nonspecific Complaints	Contact Injuries	Musculoskel. Injuries	Back Injuries	No. Jobs	Response
< 5	1195	364	633	139	57	7	INCIDENTS (per million man-hours)
5-15	766	238	343	103	110	51	
>15	484	204	221	43	15	20	
< 5	541	541	---	---	---	7	DAYS LOST (per million man-hours)
5-15	1725	868	---	48	808	51	
>15	1166	1013	---	130	22	20	
< 5	5541	2583	---	2613	344	7	DAYS RESTRICTED (per million man-hours)
5-15	1747	96	297	539	814	51	
>15	654	121	243	289	---	20	
< 5	6082	3124	---	2613	344	7	DAYS LOST + DAYS RESTRICTED (per million man-hours)
5-15	3562	964	297	587	1527	51	
>15	1820	1134	243	420	22	20	

Table C-16: Medical Experience by Multiple Employee Job Strength Rating (FREQ x HOR x MJSR)

MJSR x in./ week	Total Medical	Nonspecific Complaints	Contact Injuries	Musculoskel. Injuries	Back Injuries	No. Jobs	Response
< 500	715	266	324	63	87	50	
500-1000	852	223	354	176	96	7	INCIDENTS (per million man-hours)
>1000	733	185	365	128	60	21	
< 500	2133	1207	---	101	824	50	
500-1000	469	404	---	---	64	7	DAYS LOST (per million man-hours)
>1000	244	244	---	---	---	21	
< 500	1841	487	146	566	640	50	
500-1000	2411	---	---	2390	21	7	DAYS RESTRICTED (per million man-hours)
>1000	1525	48	605	310	560	21	
< 500	3975	1695	146	668	1367	50	
500-1000	3533	404	---	2390	85	7	DAYS LOST + DAYS RESTRICTED (per million man-hours)
>1000	1770	293	605	310	560	21	

Table C-17: Medical Experience by Frequency of Lift for Multiple Employee Jobs

Lifts/Week	Total Medical	Nonspecific Complaints	Contact Injuries	Musculoskel. Injuries	Back Injuries	No. Jobs	Response
< 200	699	249	316	71	84	59	
200-400	1116	232	573	205	104	6	INCIDENTS (per million man-hours)
> 400	708	204	329	127	57	13	
< 200	1881	1089	---	85	706	59	
200-400	41	41	---	---	---	6	DAYS LOST (per million man-hours)
> 400	296	296	---	---	---	13	
< 200	1871	413	124	737	542	59	
200-400	3025	---	1147	263	1613	6	DAYS RESTRICTED (per million man-hours)
> 400	1201	78	448	502	171	13	
< 200	3776	1502	124	823	1166	59	
200-400	3066	41	1147	263	1613	6	DAYS LOST + DAYS RESTRICTED (per million man-hours)
> 400	1497	375	448	502	171	13	

Table C-18 : Medical Experience by Multiple Employee Job Strength Rating (FREQ x PRED.MJSR)

MJSR/week	Total Medical	Nonspecific Complaints	Contact Injuries	Musculoskel. Injuries	Back Injuries	No. Jobs	Response
< 50	693	259	310	59	89	54	
50-100	809	194	398	185	31	8	INCIDENTS (per million man-hours)
> 100	827	200	402	153	80	16	
< 50	2007	1150	---	93	763	54	
50-100	343	287	---	---	56	8	DAYS LOST (per million man-hours)
> 100	246	246	---	---	---	16	
< 50	1705	451	135	524	592	54	
50-100	2110	---	---	2091	18	8	DAYS RESTRICTED (per million man-hours)
> 100	2002	64	794	408	735	16	
< 50	3712	1601	135	618	126	54	
50-100	3025	2874	---	2091	74	8	DAYS LOST + DAYS RESTRICTED (per million man-hours)
> 100	2249	311	794	408	735	16	

Table C-19: Medical Experience by Multiple Employee Job Strength Rating (HOR x PRED.MJSR)

Pred. MJSR x in.	Total Medical	Nonspecific Complaints	Contact Injuries	Musculoskel. Injuries	Back Injuries	No. Jobs	Response
< 5	669	169	316	86	95	12	
5-15	730	253	334	95	77	50	INCIDENTS (per million man-hours)
>15	788	256	367	82	82	16	
< 5	465	465	---	---	---	12	
5-15	1019	732	---	67	219	50	DAYS LOST (per million man-hours)
>15	3658	1634	---	105	1918	16	
< 5	3636	1506	548	1392	188	12	
5-15	762	98	34	582	47	50	DAYS RESTRICTED (per million man-hours)
>15	3703	151	734	361	2455	16	
< 5	4102	1972	548	1392	188	12	
5-15	1873	830	34	649	267	50	DAYS LOST + DAYS RESTRICTED (per million man-hours)
>15	7362	1786	734	467	4069	16	

Table C-20: Medical Experience by Multiple Employee Job Strength Rating (FREQ x HOR x PRED.MJSR)

Pred. MJSR x in./week	Total Medical	Nonspecific Complaints	Contact Injuries	Musculoskel. Injuries	Back Injuries	No. Jobs	Response
< 500	693	250	309	65	95	49	INCIDENTS (per million man-hours)
500-1000	702	244	311	115	30	13	
>1000	878	208	446	152	80	16	
< 500	2112	1167	---	103	841	49	DAYS LOST (per million man-hours)
500-1000	560	525	---	---	34	13	
>1000	268	268	---	---	---	16	
< 500	1879	497	149	578	653	49	DAYS RESTRICTED (per million man-hours)
500-1000	1298	---	---	1287	11	13	
>1000	2002	64	794	408	735	16	
< 500	3992	1665	149	682	1395	49	DAYS LOST + DAYS RESTRICTED (per million man-hours)
500-1000	2210	525	---	1287	46	13	
>1000	2270	332	794	408	735	16	

APPENDIX D

This appendix contains the detailed metabolic and strength evaluations of the four case studies reported in Chapter VII.

Table D1: Detailed task analysis for metabolic energy expenditure prediction for Case I

Task #	Activity	Technique	Load (lbs.)	Freq. of Acts (day)	Task Description	Estimated Cost Per Task (KCal)
1	Pull	at 38" or 60"	29	206	distance = 5"	14.8
	Lift	arm	60	206	34" to 38"	14.56
	Lateral arm work (180°)	Both hands	60	206	-------------	57.68
	Push	at 38°, lean	10	206	distance = 5"	6.44
	Pull	at 40"	29	25	distance = 20"	7.19
2	Lower	Squat	0	103	-------------	32.96
	Lateral arm work (180°)	Both hands	4	103	-------------	10.3
	Walk	Stand	--	103	at 3 mph	29.14
3	Light arm work	Both arms	--	103	0.3 min./act	37.08
	Heavy arm work	Both arms	--	103	1.1 min./act	249.26
	Lower	Squat	0	103	-------------	32.96
4	Stand	Erect			380 min.	704
	Stand	Semi-bent			100 min.	219
	Total Expenditure (Kcal/day)					1415.4
	Average 8-hour Metabolic Expenditure Rate (Kcal/min)					2.95

Table D2: Output from three-dimensional biomechanical human strength simulation model for Case I

TASK#	TASK	POST.	DEPT. OBJECT	REP. #HD	NON-REP. FORCE	R H LOCATION			L H SEPARA.			MALES % CAPABLE	MALES MUSCLE LIM.	FEMALES % CAPABLE	FEMALES MUSCLE LIM.
1	PULL	LEAN	SUP. REEL	2	35	ORIG 38	0	10	0	-6	10	99	HUM. MED. R	44	KNEE FLEX R
1	PULL	LEAN	SUP. REEL	2	35	DEST 38	0	5	0	-6	10	99	HIP EXTN R	35	HUM. MED. R
1	PULL	STAND	SUP. REEL	2	35	ORIG 60	0	10	0	-6	10	66	KNEE FLEX R	1	KNEE FLEX R
1	PULL	STAND	SUP. REEL	2	35	DEST 60	0	5	0	-6	10	94	KNEE FLEX R	3	KNEE FLEX R
1	LIFT	STOOP	SUP. REEL	2	55	ORIG 34	0	6	0	-6	5	54	ELB. FLEX L	9	ELB. FLEX L
1	LIFT	STOOP	SUP. REEL	2	65	DEST 38	10	10	0	-6	5	33	SHLD ABD. L	2	SHLD ABD. L
1	PUSH	LEAN	SUP. REEL	2	10	ORIG 38	0	24	0	-5	0	99	KNEE FLEX R	98	SHLD ABD. L
1	PUSH	LEAN	SUP. REEL	2	10	DEST 38	-5	24	0	-5	0	99	KNEE FLEX R	99	SHLD ABD. L
1	PULL	STOOP	SUP. REEL	1	35	ORIG 40	0	30	0	0	0	96	ANKL EXTN R	POSTURE	
1	PULL	STOOP	SUP. REEL	1	35	DEST 38	0	10	0	0	0	90	HUM. MED. R	47	HUM. MED. R
2	PUSH	STOOP	TAKE REEL	2	5	ORIG 18	6	12	0	-6	0	99	HIP EXTN R	97	HIP EXTN R
2	PUSH	STOOP	TAKE REEL	2	5	DEST 18	6	12	0	-6	0	99	HIP EXTN R	97	HIP EXTN R
2	PUSH	SQUAT	TAKE REEL	2	5	ORIG 18	0	17	0	-11	0	99	HIP EXTN R	97	HIP EXTN R
2	PUSH	SQUAT	TAKE REEL	2	5	DEST 18	6	17	0	-11	0	99	HIP EXTN R	97	HIP EXTN R

FOR TASKS WITH SPECIFIC MODEL PREDICTIONS:

LIMITING TASKS (MAXIMUM OF FIVE ELEMENTS CHOSEN)

TASK#	%MALE	TASK#	%FEMALE
1 DEST	94	1 DEST	35
1 DEST	90	1 ORIG	9
1 ORIG	66	1 DEST	3
1 ORIG	54	1 DEST	2
1 DEST	33	1 ORIG	1

AVERAGE OF PERCENTS CAPABLE ACROSS TASKS

%MALE	%FEMALE
87	55

Table D3: Detailed task analysis for metabolic energy expenditure prediction for Case II

Task #	Activity	Technique	Load (lbs.)	Freq. of Acts (day)	Task Description	Estimated Cost Per Task (KCal)
1	Walk & Push	Hand in front	30	7	15' @ 3 mph	2.69
2	Pull	At 20.5"	8	140	17" displacement	12.83
	Lower	Stoop	8	140	25" to 16"	15.55
	Lift	Stoop	32	70	16" to 30"	14.99
	Carry	Both hands at sides	32	70	5' @ 3 mph	8.96
	Lateral arm work (90°)	Both hands	32	70	Standing	9.80
3	Push	Stoop	18	140	7" displacement	9.20
	Lift	Stoop	0	140	25" to 32"	6.24
4	Walk & Pull	In front	50	7	15' @ 3 mph	3.38
5	Pull	At bench height	1	16	8"	0.40
	Lift	Stoop	1	16	25" to 35"	0.71
	Carry	At the sides	1	16	75' @ 3 mph	18.86
	Heavy arm work	-------------	--	--	------------	11.1
6	Heavy arm work	-------------	--	--	------------	316.8
7	Pull	In front	10	12	8" displacement	0.6
	Lift	Stoop	16	0.5	8" to 55"	0.2
	Heavy arm work	-------------	--	--	------------	6.0
8	Pull	At bench height	90	3	8" displacement	.47
	Heavy arm work	At bench height	--	--	------------	39.6
9	Walk	Stand	0	12.5	80' @ 3 mph	15.09
10	Stand	Erect			2 hours	222
	Stand	Semi-bent			6 hours	789.4
	Total Expenditure (Kcal/day)					1504.9
	Average 8-hour Metabolic Expenditure Rate (Kcal/min)					3.14

Table D4: Output from three-dimensional biomechanical human strength simulation model for Case II

TASK#	TASK	POST.	DEPT. OBJECT	REP. #HD	NON-REP. FORCE	R H LOCATION				L H SEPARA.			MALES % CAPABLE	MALES MUSCLE LIM.	FEMALES % CAPABLE	FEMALES MUSCLE LIM.
1	PUSH	STOOP	EMPTY PALL	2	45	ORIG	29	5	28	0	-5	0	98	HIP EXTN R	POSTURE	
1	PUSH	STOOP	EMPTY PALL	2	45	DEST	29	5	28	0	-5	0	98	HIP EXTN R	POSTURE	
1	PUSH	STOOP	EMPTY PALL	2	45	ORIG	29	5	25	0	-5	0	99	HIP EXTN R	61	SHLD BACK L
1	PUSH	STOOP	EMPTY PALL	2	45	DEST	29	5	20	0	-5	0	97	HIP EXTN R	60	SHLD BACK L
2	PULL	STOOP	EMPTY REEL	2	10	ORIG	25	5	27	0	-5	0	99	HIP EXTN R	POSTURE	
2	PULL	STOOP	EMPTY REEL	2	10	DEST	16	5	10	0	-5	0	99	HIP EXTN R	98	HUM. MED. L
2	LIFT	STOOP	EMPTY REEL	2	32	ORIG	30	10	6	0	-20	0	99	HIP EXTN R	66	ELB. FLEX L
2	LIFT	STOOP	EMPTY REEL	2	32	DEST	16	10	10	0	-20	0	96	HIP EXTN R	63	ELB. FLEX L
2	DOWN	STAND	EMPTY REEL	2	32	ORIG	30	10	6	0	-20	0	99	ELB. EXTN R	40	ELB. EXTN L
2	DOWN	STAND	EMPTY REEL	2	32	DEST	16	10	10	0	-20	0	99	ELB. EXTN L	41	ELB. EXTN R
3	PUSH	STOOP	FULL REELS	2	20	ORIG	25	5	11	27	-10	0	98	ELB. EXTN L	51	ELB. EXTN L
3	PUSH	STOOP	FULL REELS	2	20	DEST	25	5	18	27	-10	0	97	ELB. EXTN L	31	ELB. EXTN L
4	PULL	STOOP	FULL PALLE	2	160	ORIG	29	5	27	0	-10	0	8	ANKL EXTN R	1	KNEE FLEX R
4	PULL	STOOP	FULL PALLE	2	160	DEST	29	5	27	0	-10	0	8	ANKL EXTN R	1	KNEE FLEX R
4	PULL	STOOP	FULL PALLE	2	100	ORIG	29	5	20	0	-10	0	80	ANKL EXTN R	3	KNEE FLEX R
4	PULL	STOOP	FULL PALLE	2	100	DEST	29	5	20	0	-10	0	80	ANKL EXTN R	3	KNEE FLEX R
5	PULL	STOOP	WIRE SAMPL	1	2	ORIG	25	5	11	0	0	0	99	HIP EXTN R	99	HIP EXTN R
5	PULL	STOOP	WIRE SAMPL	1	2	DEST	35	5	3	0	0	0	99	KNEE EXTN R	99	KNEE EXTN R
5	DOWN	STAND	WIRE SAMPL	1	2	ORIG	25	5	11	0	0	0	99	HIP EXTN R	99	HIP EXTN R
5	DOWN	STAND	WIRE SAMPL	1	2	DEST	35	5	6	0	0	0	99	ELB. FLEX L	99	ELB. FLEX L
6	PULL	STOOP	WIRE STRIN	2	20	ORIG	36	5	16	0	-5	0	99	HIP EXTN R	95	HIP EXTN R
6	PULL	STOOP	WIRE STRIN	2	20	DEST	36	5	16	0	-5	0	99	HIP EXTN R	95	HIP EXTN R
7	LIFT	STOOP	WIRE GUIDE	2	18	ORIG	8	5	10	0	-10	0	99	HIP EXTN R	92	HIP EXTN R
7	LIFT	STOOP	WIRE GUIDE	2	18	DEST	55	5	12	0	-10	0	99	HIP EXTN R	75	SHLD ABD. L
8	PULL	LEAN	WIRE DRAW	2	100	ORIG	43	5	15	-4	-8	-2	32	ANKL EXTN R	1	KNEE FLEX R
8	PULL	LEAN	WIRE DRAW	2	100	DEST	43	5	15	-4	-8	-2	32	ANKL EXTN R	1	KNEE FLEX R

FOR TASKS WITH SPECIFIC MODEL PREDICTIONS:

LIMITING TASKS (MAXIMUM OF FIVE ELEMENTS CHOSEN)

TASK#	%MALE	TASK#	%FEMALE
4 ORIG	80	4 ORIG	3
8 DEST	32	8 DEST	1
8 ORIG	32	8 ORIG	1
4 DEST	8	4 DEST	1
4 ORIG	8	4 ORIG	1

AVERAGE OF PERCENTS CAPABLE ACROSS TASKS

%MALE	%FEMALE
85	55

Table D5: Detailed task analysis for metabolic energy expenditure prediction for Case III

Task #	Activity	Technique	Load (lbs.)	Freq. of Acts (day)	Task Description	Estimated Cost Per Task (KCal)
1	Lift	Standing	7	856	30" to 38"	19.9
	Lateral arm work (90°)	Standing	7	856	-----------	49.4
	Lift	Standing	7	856	30" to 38"	19.9
	Lateral arm work (90°)	Standing	7	856	-----------	49.4
	Horizontal arm work	Standing	7	856	distance = 10"	20.1
2	Lateral arm work (180°)	Standing - both hands	18	856		123.6
	Lateral arm work (90°)	Standing - both hands	18	856		82.4
	Lateral arm work (180°)	Standing - both hands	4	856		84.1
	Heavy arm work	Standing				43.1
3	Lower	Squat	13	8	14" to 4"	2.3
	Lower	Squat	0	8	32" to 4"	2.2
	Lateral arm work (90°)	Squat	13	8		0.7
4	Carry	In front	42	8	10' @ 3 mph	2.4
	Walk			8	40' @ 3 mph	5.0
5	Standing				980 min.	889.4
	Total Expenditure (Kcal/day)					1394
	Average 8-hour Metabolic Expenditure Rate (Kcal/min)					2.90

Table D6: Output from three-dimensional biomechanical human strength simulation model for Case III

TASK#	TASK	POST.	DEPT. OBJECT	REP. X #HD	NON-REP. FORCE	R H LOCATION				L H SEPARA.			MALES % CAPABLE	MALES MUSCLE LIM.	FEMALES % CAPABLE	FEMALES MUSCLE LIM.
1	LIFT	STAND	BACK HOUSE	1	7	ORIG	38	20	9	0	0	0	99	SHLD ABD. R	88	SHLD ABD. R
1	LIFT	STAND	BACK HOUSE	1	7	DEST	32	3	8	0	0	0	99	ELB. FLEX R	97	ELB. FLEX R
1	LIFT	STAND	BACK HOUSE	1	7	ORIG	38	15	18	0	0	0	99	HIP EXTN R	87	SHLD ABD. R
1	LIFT	STAND	BACK HOUSE	1	7	DEST	38	3	8	0	0	0	99	ELB. FLEX R	97	ELB. FLEX R
2	LIFT	STAND	BACK HOUSE	2	16	ORIG	38	6	6	0	-18	0	99	ELB. FLEX L	92	ELB. FLEX L
2	LIFT	STAND	BACK HOUSE	2	18	DEST	38	6	6	0	-18	0	99	ELB. FLEX L	92	ELB. FLEX L
2	LIFT	STAND	BACK HOUSE	2	15	ORIG	32	6	6	0	-18	0	99	HIP EXTN R	95	ELB. FLEX L
2	LIFT	STAND	BACK HOUSE	2	18	DEST	32	6	6	0	-18	0	99	HIP EXTN R	95	ELB. FLEX L
3	PULL	SQUAT	EMP PALLET	2	13	ORIG	14	6	3	0	-12	0	97	KNEE EXTN R	61	KNEE EXTN R
3	PULL	SQUAT	EMP PALLET	2	13	DEST	4	6	6	0	-12	0	93	KNEE EXTN R	37	KNEE EXTN R
3	PUSH	SQUAT	EMP PALLET	2	13	ORIG	4	6	6	0	-12	0	98	KNEE EXTN R	74	KNEE EXTN R
3	PUSH	SQUAT	EMP PALLET	2	13	DEST	4	20	6	0	-12	0	POSTURE		POSTURE	
4	HOLD	STAND	EMP PALLET	2	42	ORIG	36	12	12	0	-30	0	93	ELB. FLEX L	31	HIP EXTN R
4	HOLD	STAND	EMP PALLET	2	42	DEST	36	12	12	0	-30	0	93	ELB. FLEX L	31	HIP EXTN R

FOR TASKS WITH SPECIFIC MODEL PREDICTIONS:

LIMITING TASKS (MAXIMUM OF FIVE ELEMENTS CHOSEN)

TASK#	%MALE	TASK#	%FEMALE
3 ORIG	98	3 ORIG	74
3 ORIG	97	3 ORIG	61
4 DEST	93	3 DEST	37
4 ORIG	93	4 DEST	31
3 DEST	93	4 ORIG	31

AVERAGE OF PERCENTS CAPABLE ACROSS TASKS

%MALE	%FEMALE
97	75

Table D7: Detailed task analysis for metabolic energy expenditure prediction for Case IV

Task #	Activity	Technique	Load (lbs.)	Freq. of Acts (day)	Task Description	Estimated Cost Per Task (KCal)
1	Lift	Stoop	40	80	28" to 36"	7.9
	Carry	In front	40	80	5' @ 3 mph	10.6
	Walk			80	5' @ 3 mph	4.7
2	Medium arm work	Both hands				751
	Lateral arm work (90°)	Sitting	5	160		8.1
3	Lower	Stoop	40	80	26" to 28"	3.9
	Carry	In front	40	80	5' @ 3 mph	10.6
	Walk			80	3' @ 3 mph	4.7
4	Sitting				260 min.	294
	Standing				220 min.	248
	Total Expenditure (Kcal/day)					1343.3
	Average 8-hour Metabolic Expenditure Rate (Kcal/min)					2.8

Table D8: Output from three-dimensional biomechanical human strength simulation model for Case IV

TASK#	TASK	POST.	WGHT. OBJECT	REP. X #HR	NON-REP. FORCE	R H LOCATION				L H SEPARA.			MALES % CAPABLE	MALES MUSCLE LIM.	FEMALES % CAPABLE	FEMALES MUSCLE LIM.
1	LIFT	STOOP	PAN OF SET	2	40	ORIG	24	11	10	0	-28	0	92	HIP EXTN R	40	ELB. FLEX L
1	LIFT	STOOP	PAN OF SET	2	40	DEST	36	11	10	0	-28	0	93	ELB. FLEX L	40	ELB. FLEX L
1	LIFT	STOOP	PAN OF SET	2	40	ORIG	48	11	10	0	-26	0	95	HIP EXTN R	29	SHLD ABD. L
1	LIFT	STOOP	PAN OF SET	2	40	DEST	36	11	10	0	-28	0	93	ELB. FLEX L	40	ELB. FLEX L
2	LIFT	SIT	EMPTY PAN	1	5	ORIG	36	18	6	0	0	0	99	SHLD ABD. R	67	SHLD ABD. R
2	LIFT	SIT	EMPTY PAN	1	5	DEST	36	-18	6	0	0	0	POSTURE		POSTURE	
3	LIFT	STAND	PAN OF SET	2	40	ORIG	36	11	10	0	-28	0	96	SHLD ABD. L	28	SHLD ABD. L
3	LIFT	STAND	PAN OF SET	2	40	DEST	24	11	10	0	-28	0	93	KNEE FLEX R	12	KNEE FLEX R
3	LIFT	STAND	PAN OF SET	2	40	ORIG	36	11	10	0	-26	0	96	SHLD ABD. L	28	SHLD ABD. L
3	LIFT	STAND	PAN OF SET	2	40	DEST	48	11	10	0	-28	0	92	SHLD ABD. L	21	SHLD ABD. L

FOR TASKS WITH SPECIFIC MODEL PREDICTIONS:

LIMITING TASKS (MAXIMUM OF FIVE ELEMENTS CHOSEN)

TASK#	%MALE	TASK#	%FEMALE
3 DEST	93	1 ORIG	29
1 DEST	93	3 ORIG	28
1 DEST	93	3 ORIG	28
3 DEST	92	3 DEST	21
1 ORIG	92	3 DEST	12

AVERAGE OF PERCENTS CAPABLE ACROSS TASKS

%MALE	%FEMALE
94	36

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