IDENTIFICATION AND ANALYSIS OF MANUAL MATERIALS HANDLING TASKS WITHIN A COMMERCIAL WAREHOUSE IN SOUTH AFRICA

BY

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ABSTRACT

Lifting and overstraining are major causative factors related to musculoskeletal injuries and low back pain. A great number of work-related injuries arise from the handling and/or mishandling of materials. Hence there is a need to quantify risk factors in situ and develop guidelines for safe lifting practises in industry. The aim of this study was to make appropriate in situ quantification, within a commercial warehouse, of the stresses and physical demands imposed on the worker when performing two-handed lifts in the sagittal plane.

The performance of employees was assessed under normal working conditions through an observational methodology of data collection. Task performance evaluation was based on detailed measurement of all containers handled, an activity and time analysis, and the 'Work Practices Guide to Manual Lifting' (NIOSH, 1981) which was used as the primary guide to developing theoretical recommendations to probable MMH risk factors for the workers involved.

Of the 191 tasks analysed 103 were deemed unsuitable. Appropriate task factor adjustments were made where necessary to both the frequency and H-factors (horizontal distance between the centre of gravity of the container and that of the worker) in order to reduce the risk factor for the workers.

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CONTENTS

CONTENTS (Continued)

APPENDICES (Cont.) *PAGE*

LIST OF FIGURES

LIST OF FIGURES *(Continued)*

LIST OF FIGURES *(Continued)*

LIST OF TABLES

CHAPTER I

INTRODUCTION

The interdisciplinary field of ergonomics has manifested itself in the optimization of human performance within the working environment, with particular emphasis on comfort, efficiency, safety and reliability pertaining to the workforce. Recognition of sub-optimal performance conditions is essential in order to alleviate such problems as injuries, compensation costs, absenteeism, high turnover and poor productivity that prevail in industries world-wide. In other words, the objectives of ergonomics are twofold: firstly, to enhance the effectiveness with which work and other human activities are carried out, and secondly, to maintain or enhance certain desirable human values such as health, safety and satisfaction in the process (McCormick and Sanders, 1982). The approach of ergonomics in the field of Manual Materials-Handling (MMH), is the systematic application of relevant information about human abilities, characteristics, actual behaviour and the motivational aspects behind the activity (i.e. operator qualities) when considering the job demands implicit in any task performance.

The causes, frequency, severity and costs of MMH injuries have been well recorded in the literature (Chaffin and Andersson, 1984; Liles *et al.*, 1984; David, 1985; Metzler, 1985; Nicholson, 1985). Garg *et al.* (1983) state that an estimated 30% of the total workforce is exposed to hazardous manual materials-handling tasks, with overexertion accounting for 27% of all compensable injury and illness. Two-thirds of these incidents are reported to be caused by lifting activities (Garg *et al.*, 1983; Chaffin and Andersson, 1984). Of major concern to industries world-wide is the prevalence of lumbar back disorders. Due to the increasing evidence that lifting and overstraining are major causative factors related to lower back pain (Frankel and Nordin, 1980; Garg *et al.*, 1983; Sperryn, 1983; Andersson, 1985; Biering-Sorenson, 1985; Metzler, 1985; Nicholson, 1985), there is a need to quantify risk factors and develop guidelines for acceptable lifting loads in industry within the South African milieu. To date, little research has been carried out in this field within South African Industry, with all the values cited above pertaining to North American and European industries. Nevertheless, it is reasonable to assume that the MMH and overexertion injuries that are reported in other countries are prevalent also in this society which is, in general, less technologically advanced than America and Europe and as such, methods of assessing potential risk are required.

The technological advancement of the industrialised nations, with automation on the uptrend, results in a decrease in the number of workers performing MMH tasks, particularly where the tasks are highly structured and repetitive (Chaffin, 1984). In other words, increased mechanisation makes labourers redundant, as improved methods of working and more sophisticated technology require less labour. Many heavy work operations have been wholly or partly mechanised and replaced by tasks which place fresh demands on the individual's physical working capacity (Svedberg, 1987). However, manual labour is still extensive in the technologically underdeveloped countries and in those nations where the population of unskilled manpower vastly exceeds that of the skilled manpower.

The above situation is prevalent in South Africa where it is difficult to draw comparisons with other industrialised nations as both 1st- and 3rd-world cultures co-exist. The "1st-world" is recognised in those sectors that have major financial institutions, and the "3rd-world" pertains to the developing sectors such as homelands and subsistance farming where there is no financial institution (Roux, 1987 - personal communication). Some economists are led to believe that South Africa has a dual economy due to the fact that first world factors of the affluent West co-exist with those of the third world underdeveloped countries (Walton, 1984). Other economists believe that there is only one economy, with most of the capital in the hands of a small wealthy class, and most of the labour provided by the larger, poorer class (Walton, 1984). Nevertheless, as MMH is still prevalent in the majority of South African Industries, relevant guidelines need to be developed or adapted with respect to the target workforces within South African Industries (refer to Appendix A for a break-down of the South African situation with respect to population and occupational distribution).

If a worker's physical attributes (e.g. strength, endurance, size) are not sufficient to meet the demands of the job, then exertion related injuries of various types are more likely. In order to reduce the severity of any injury, it is essential to define the capacity limits of individuals, and to operate within them (Ayoub *et al.*, 1983; Nicholson and Legg, 1986). In this way, by matching the capabilities of the worker with the requirements of a MMH job, or by designing such jobs on the basis of the capabilities of a certain population group, the risk and severity of manual handling overexertion injuries is decreased (Chaffin *et al.*, 1978; Garg and Saxena, 1980; Yates *et al.*, 1980; Mital, 1984a; Dul and Hildebrandt, 1987; Van Wely, 1987). This preventative measure has been associated with reductions in work-related injuries and illnesses, as well as improvements in both job performance and job satisfaction (Snook, 1987). Therefore, in order to determine the likelihood of personal injury to an operator, it is desirable to develop guidelines for safe MMH practise.

According to Ayoub *et al.* (1983) there are two basic determinants as to whether or not a MMH task is injurious to the operator:

1) The occupational requirements, which refer to task characteristics such as the mass of lift for a given frequency and duration, with certain container sizes and configurations (all task variables being highly interactive).

2) Particular capabilities of the operator, in this instance lifting ability, as based on physiological, biomechanical and psycho-physical criteria (NIOSH, 1981; Ayoub *et al.*, 1983).

Drury and Brill (1983) infer that human behaviour is related to 80 - 85% of all accidents. However, it should be borne in mind that this is invariably due to the mismatch between individual capabilities and the demands of the job.

While the focus is on the physical attributes of the worker, it is important to take cognizance of the fact that any measure of physical workload is influenced by an individual's perception of the stresses placed upon him, as well as social and environmental factors. Ultimately, lack of motivation may be a major limiting factor to physical performance, as in the case of boring, monotonous jobs. On the other hand, if appropriate and realistic task goals are set, based on the individual's present standard of performance and performance capabilities (Firth, 1976), performance may be optimized and potential recognised. In this way the individuals can perform their respective tasks efficiently and safely. These are important factors assisting in the improvement of job satisfaction and/or personal commitment, and they decrease the chance of errors and possible injury. It is important to bear in mind that overly motivated workers may become susceptible to injury through striving to achieve better goals or targets than have been established for the workforce. This emphasises the need for constant contact and communication between managerial staff or co-ordinators of the respective tasks performed, and the workers themselves.

In the assessment of task requirements, it is difficult to simulate conditions and employee involvement in a laboratory setting. Therefore, wherever possible *in situ* evaluation should be conducted. However, on-site evaluation of the physical workload is also fairly limited as the investigator should aim to intervene as little as possible with the performance of the worker. It is therefore unlikely that many direct measurements can be taken while individuals are actually performing the required job, without interfering with their routine by making them hold a certain position while relevant measurements are taken, unless a systematic approach to data collection is utilised. Fortunately a data collection methodology was selected for the purposes of this research which enabled extensive measurements to be obtained without interference with the working routine of the Bulkstoremen.

Valuable tools in the assessment of the demands of a particular task are the several computerised mathematical models that have been developed over the past decade and which are now frequently used. These lifting and biomechanical models provide an objective means of evaluating the physical demands of specific tasks in relation to norms established for other industrial populations (Celentano and Nottrodt, 1984). Accordingly, safe lifting guidelines may be established for each respective task analyzed. It must be borne in mind that there are a multitude of MMH tasks performed within the industrial setting and that the particular focus of this study was centred around lifting tasks identified as being representative of a particular workforce.

STATEMENT OF THE PROBLEM

Due to the potential mismatch between job requirements and individual capabilities, many industrial tasks (such as MMH activities) may prove to be hazardous to the 'worker'. The aim of this investigation was to make appropriate endogenous or on-site quantification of stresses and demands imposed on the individual by lifting MMH activities within a selected manual labour force of South Africa. This evaluation was based on the NIOSH (1981) model. In other words, the specific objectives of this study were:

1) To perform a comprehensive analysis of particular lifting task elements in order to determine their suitability to the capabilities of the workers involved (determined by the "Action Limit" and "Maximal Permissible Limit" of the NIOSH model).

2) To identify stressful situations and make appropriate ergonomically-based recommendations for consideration in the alleviation of potential risk factors for the workers.

A detailed evaluation of lifting tasks within the Receivings section of a Supermarket (W1) was carried out, using the "Work

Practices Guide to Manual Lifting" (NIOSH, 1981) as the primary guide to developing theoretical recommendations for potential manual handling risk areas. The model focuses on task and container aspects that best define a hazardous lifting act. In other words, the NIOSH (1981) guidelines were used to assess the situations whereby a worker is likely to be overstressed and suffer injury: injury which could result in higher turnover, time-off, compensation costs and poor productivity for the company concerned, not to mention job dissatisfaction and physical discomfort for the 'worker'. Tasks were analyzed and problem areas identified with respect to:

- object mass
- object size
- height of lift
- distance of centre of gravity of the object to the centre of gravity of the body
- task frequency
- task duration

Consequently, all of these and other task-related factors were examined with respect to the tolerance limits and recommended values for the specific tasks, as reported in the literature and defined by the guidelines. Finally, ergonomic interventions were recommended where necessary, in order to indicate areas in the working situation that may be improved, to the benefit of the 'worker' and ultimately of the organization. One altered task factor, with minimal, if any, cost to the company for redesign of containers and/or work layout, may make the difference between a particular working situation rendering the worker susceptible to injury, or being ralatively injury-free.

RESEARCH HYPOTHESIS

This study was designed to determine whether or not the task characteristics, specifically container mass (kg), exceeded the recommended load limits as specified by the NIOSH mathematical model, based on individual capabilities (Physiologically, biomechanically, psychologically and epidemiologically) built into the model. For the purposes of this research the cut-off recommendation limit used from the NIOSH model was the MPL (Maximal Permissible Limit) with respect to demand placed on the workforce. This was based on the fact that the workforce considered was of a generally fit appearance, had continual 'in-house' training due to repeated MMH activities undertaken, and the individuals were not performing the lifting activities continually for their entire workshift, but rather appeared to enjoy acceptable task diversification.

The following research hypothesis was developed for investigation ($p < 0.05$ level of significance):

There are no differences between the actual load masses lifted and the recommended load masses (Maximal Permissible Limit, or MPL) of the selected MMH Tasks, as a function of lift height, reach distance and frequency as established using NIOSH, for:

1) Basic task performance as observed at Worksite 1.

2) Hypothetically optimised tasks (i.e. task factors adjusted to ensure that the Actual Load Mass is less than the MPL).

STATISTICAL HYPOTHESES

1) Ho: $\mu_{Alm1} = \mu_{Rlm1}$

Ha: $\mu_{Alm1} \neq \mu_{Rlm1}$

2) Ho: $\mu_{Alm2} = \mu_{Rlm2}$

Ha: $\mu_{Alm2} \neq \mu_{Rlm2}$

Where Alm = Actual load mass, and Rlm = Recommended load mass limit (MPL) for (1) Basic task performance, and
(2) Hypothetically optimised performance.

DELIMITATIONS

Two Supermarkets (W1 and W2) agreed to be testing sites for the purposes of this study. The particular department utilised was termed the Bulkstore Depot. Consignments of goods arrived at the Receivings Depot and were transferred and stored in the Bulkstores section. Due to the similarity of the shelving layout and container sizes and masses between W1 and W2, detailed analysis was only performed at W1.

The Subject-Matter-Expert (SME) who was the managerial member of staff in charge, was interviewed and it was ascertained that the MMH activity of lifting containers from the trolley to the shelves, within the Bulkstores, was performed on a frequent basis, and in the sagittal plane , or as close to it as possible, thus impling that the lifting was performed with minimal twisting or turning action.

Direct measurements of task related factors were taken *in situ*, and it is important to note that the subjects' performances were not intentionally interrupted at any stage. Extensive measurements were carried out on the majority of cartons within the Bulkstores, with respect to object dimensions, mass and height of lift (based on shelf heights). A detailed Activity and Time Analysis was carried out, which enabled an identification of all the tasks performed by the respective workforce under investigation, with particular attention to the lifting of containers from the trolleys onto the shelves. Representative sub-tasks were identified, defined by the stages of lifting containers from the trolley to the shelves. Due to the great number of cartons handled by the Bulkstoremen, they were consequently categorised with respect to volume (cm^3) into four main groups. The average rate of lift per minute, and average duration (minutes), were identified for each group of cartons.

During the working periods, and immediately after a sub-task had been performed, the Bulkstore-assistants were requested, at random, to rate their activities on a Ratings of Perceived Exertion (RPE) scale as developed by Borg (1970). Toward the end of the working day, the workers were required to identify, demarcate and quantify (using the RPE scale) the sites on their bodies that were fatigued and/or painful, using a human-form diagram.

On completion of all *in situ* data collection, the relevant measurements were then applied to the NIOSH computer software package as developed by the Department of Human Movement Studies, Rhodes University (and adapted by F.C. Walraven for use on an IBM (MS-DOS) computer). This package was based on the NIOSH (1981) guideline formulae, and facilitated a relatively quick and simple, yet objective, analysis of the lifting tasks performed.

LIMITATIONS

A problem in the development of any guidelines is that they are sample specific with respect to the related or intended target workforce. In a single sample of this nature there are great morphological differences between individuals and presumably cross-cultural and cross-population differences are bound to be extensive. It can therefore be assumed that a large individual variability in lifting performance capability and risk of injury exists in any population. Notwithstanding, as there is a general lack of anthropometric and normative data for the South African Industrial population at present, research has been based on guidelines whose limits may not be wholly appropriate for the SA workforce. Garg and Badger (1986) compared the maximum acceptable weights and static strengths in the sagittal plane obtained from their investigations with the action limit (AL) and maximum permissible limit (MPL) recommended by the Work Practices Guide for Manual Lifting (NIOSH, 1981). The comparison suggested that with psychophysical data, the AL and MPL were conservative for occasional lifting from floor level. Guidelines may tend to be conservative by not being truly specific to the target workforce under investigation, but being so designed that any individual can work without health risk (Dul and Hildebrandt, 1987).

A factor that could be viewed as limiting to this research is that only one Supermarket was analysed. Justification for this lies in the fact that a second Supermarket was considered, but due to the great similarities in carton size and shelf heights (as established through random sample data collection and comparison) and relative inaccessability of the worksite for data collection, further investigation was deemed unnecessary as it would prove to be repetitive, based on the scope and time-constraints of this research. It was assumed that due to the basic similarities in task characteristics, the findings of the one area could apply to the other and in many respects to the nationwide chains these two represent. It must also be borne in mind that numerous assumptions had to be made pertaining to the tasks performed, some of which may be regarded as limits to a study of this nature. It was therefore pertinent herein to list these assumptions:

- on average, a similar quantity of cartons are handled per day/shift;

- the cartons are always put on the same shelves (unless space is limited due to a great stock intake, and they are temporarily put elsewhere);

- that the cartons are always picked up from the trolley with the same orientation as identified over the three-day observation period for the purposes of establishing the H-value required for the NIOSH guidelines;

- that the bulkstore-assistants are involved in lifting from the trolley to the shelf for the same duration of one hundred and five minutes (approximately 1 3/4 hours) or 25.1% of their total working time each day/shift;

- that sub-task frequency may be defined by the volume of the cartons and the size of the trolley (which limits how many cartons may be handled during performance of each sub-task) and therefore the smaller cartons would elicit a greater rate of lift than the larger cartons - this ultimately influences the absolute time spent on each sub-task;

- that the bulkstore-assistants were healthy and of good physical condition;

- that the physical ambient environment was relatively constant and seldom hostile in terms of temperature, humidity and lighting;

- that the social environment pertaining to working ambience and competition or motivation was relatively stable and beneficial for the workers;

- that, when lifting to shelves 1 and 2, the sequence undertaken in transferring the carton is from trolley to waist, and then waist to shelf, with a limited carrying element of fewer than 8 natural walking strides;

- that, when lifting to shelves 3 and 4, out of the normal reach range for the individual, the sequence is from trolley to shoulder and then from shoulder to full-reach, as the carton is passed on to a co-worker who places the carton on the respective shelf - once more with a limited carrying element of fewer than 8 natural walking strides.

CHAPTER II

REVIEW OF LITERATURE

INTRODUCTION

Attempts to 'fit the man to the task' have been fraught with problems in the past. Often individuals have had to adopt postures unsuited to their structures, or work in sub-optimal conditions in order to perform a task. Man's morphology is, predominantly, genetically predetermined and therefore relatively unchangeable within the brief expanse of a life-time. "Biological and cultural heritage interact to set limits upon the genetic potentiality and actuality of human movement" (Charteris *et al.*, 1976). It is the tasks, equipment and working environment that are created and developed and therefore adjustable. It is increasingly evident that working conditions need to be adapted to the psycho-physical nature of man. In other words, the demands of work need to be fitted to the efficiency of man in order to reduce stress (Grandjean, 1980). This may be accomplished by identifying problem areas through task analysis (Celentano and Nottrodt, 1984), modifying the working environment with respect to task related characteristics, and ensuring that the task may be carried out efficiently and safely for the target workforce, under optimal conditions.

It is possible for research to be carried out in the full spectrum of working conditions, extending from why the storeman develops backache to a full examination of the manual operations within an industry with the aim of reducing the physical stress of manual materials handling (MMH) tasks. In this way, trends may be established, and comparison of data from various industries can highlight differences in working methods and aid in the process of determining a means of preventing manual handling injuries which hamper industries world-wide.

Lower back pain is reported to be the most frequent cause of temporary or permanent decrease in working capacity of the individual (Andersson, 1981). The findings of Snook (1978) reveal that designing the job to the worker can reduce up to one-third of these debilitating industrial back injuries. However, if task design does not prove to be cost-efficient, and jobs can not be designed to match human capabilities, then people need to be screened holistically in the sense of task-related factors in order to match job demands with individual capacities (Griffin *et al.*, 1984; Mital, 1984a). A further alternative is the adequate education and training of employees.

There is a need to understand the etiology of manual materials handling accidents before any solutions may be developed. For this purpose, a task analysis approach is useful. Such analyses of lifting, which is one of the major MMH activities causing distress, have proven effective in identifying and assessing operator workload requirements and hazards associated with various occupations (Snook, 1978; Drury *et al.*, 1982; Celentano and Nottrodt, 1984; Nottrodt, 1986a)

"DEVELOPED" VS "DEVELOPING" COUNTRIES

As Daftuar (1975) points out, it is not easy to make a clear-cut classification of a country as being "developed" or "underdeveloped". In general, the development of a country is related to it's economic progress. The developing countries have had a much higher annual rate of growth in manufacturing, rail traffic and electric energy consumption than have the industrialized countries (Chapanis, 1975), with the percentage of gross national product increasing from 27.4% in 1965 to 35.1% in 1980 (Chapanis, 1975). Ferrara and Nordin (1987) maintain that all nations undergo evolutionary changes in their economic bases and in their characteristic work patterns, and specific work injury patterns are concomitant with these economic phases. Workplace injuries should be viewed on a continuum, and as the economy changes, so does the workplace epidemiology (Frankel, 1987). In this way it is implied that countries should not be viewed as developed or developing, but as having an economy that is changing. It should be borne in mind that some underdeveloped countries have the "material requisites, human potentiality, and willingness to make economic progress, but they suffer from mismanagement of resources" (Pepelasis *et al.*, 1961). Consequently, the workers in developing countries are poorly protected against risk situations arising in the workplace due to a lack of education, safety standards and appropriate legislation (Romer, 1987).

Alexander (1962) has identified seven conditions that hinder the rate of economic growth in a country:

- Low per capita income
- An unbalanced economy
- Untapped natural resources
- A tradition-orientated culture
- A large but untrained labour force
- A small amount of capital equipment
- Chronic underemployment

In other words, broad social programmes are required for a country to industrialize successfully (Daftuar, 1975), however, none of the above-mentioned factors considers the individual. In the past, work accidents have been considered as inevitable and the unfortunate consequences of work, but workers are a vital component in the economic and social development of the community and their health is therefore important (Nordin, 1987). Although there have been significant improvements in working conditions in many nations, as reported in the literature (Chapanis, 1975; Jardel, 1987; Svedberg, 1987; Veturi *et al.*, 1987), it can be said that there is virtually no occupation that is free from potential health and safety risks.

At the International Conference on Primary Health Care, held in Alma-Ata, USSR in 1978, the "Health for All by the year 2000" movement evolved, and it was recommended that high priorities be given to the special needs of vulnerable and high-risk groups (Jardel, 1987). One such group would be the working population, and the prevention of occupational injuries has become part of the World Health Organization's global programme on worker health, which has three main components (Jardel, 1987):

i] Identification of the severity of occupational accidents and injuries, and the development of standard occupational safety reporting systems due to the lack of coherent and comparable statistics on occupational injuries.

ii] Research into the human aspects of safety, development of educational material and pre-employment health examinations to enhance matching worker's capacities to job demands and type of work performance. "Human behaviour, training, and psychological and physical status play an important role in the causation of occupational accidents and consequently in controlling them" (Jardel, 1987).

iii] It is necessary to understand the cause and effect relationships in occupational injuries through epidemiological investigation of the environmental and human risk factors.

Accidents resulting in death are among the causes for which the difference between socio-economic groups is most significant (Jardel, 1987). In developed countries, the number of accidental deaths and injuries has declined over recent years, with the annual rate of reported occupational accidents at 6 per 100 working people in highly industrialized countries (Jardel, 1987). This could be accounted for by the fact that in industrialized countries there has been a trend towards the reduction of the amount of work regarded as 'heavy'. Many heavy work operations have been wholly or partly mechanized and replaced by jobs which place other demands on the physical working capacity of the individual, requiring a greater use of other human attributes such as eyesight, precision and stamina (Svedberg, 1987). Looking to the other end of the scale, the number of accidental deaths and injuries are a serious and growing problem in developing countries (Asogwa, 1987; Jardel, 1987), thus constituting a public health challenge (Romer, 1987). One of the major problems in attempting to assess the situation in such countries is that the numbers of injuries and deaths are often underestimated as records and statistics are inadequate.

One of the characteristics of industrialization in Third-World countries is the fact that largely illiterate and impoverished individuals are becoming wage-earning industrial workers (Asogwa, 1987) presumably falling under Alexander's (1962) condition of the large, untrained labour workforce. Throughout the world many workers are dying each year as a result of workplace-related accidents and occupational diseases (Jardel, 1987; Mohan, 1987; Nordin, 1987; Romer, 1987) while some 110 million people suffer from non-fatal musculoskeletal injuries, of which probably 50% could have been prevented with properly designed intervention programmes (Ferrara and Nordin, 1987). According to NIOSH (1981), musculoskeletal disorders rank first among disease groups in both frequency and effect.

In industry, a multi-disciplinary approach to the prevention of musculoskeletal injuries is required, along with rehabilitation of the injured person (Nordin, 1987). Co-operative effort is essential among management, labour, and all others involved with occupational health, which has now become an integral part of most major company activities in industrialized countries (Shahnavaz, 1987; Stamper, 1987), as it should become in countries with the higher risk of injury and disease. At the same time it is necessary that the need is met for an exchange of preventative data and techniques between industry and scientists, and between developed and developing countries on a practical level (Nordin, 1987). In other words, a multi-disciplinary intersector approach is required to increase the awareness of the individual, social, economic and international impact of workplace injuries among individuals, communities, industries, and governments. This may be initiated by bringing together industries and scientific research groups, and exploring the transference of practical prevention means from developed to developing countries (Ferrara and Nordin, 1987).

Although developing countries require the benefits of modern technology, they cannot fill the need for such advancement and depend on products, methods and the technical skills of their more advanced neighbours (Chapanis, 1975). The less developed countries have neither the trained manpower nor the knowledge to do the job themselves. Therefore, with adequate understanding and interpretation of the situation, the opportunity exists for the adaptation and modification of modern technologies to suit the requirements of the less developed countries.

Psychologist Alphonse Chapanis acknowledged that his original ideas that science and technology could be applied universally, with no geographic boundaries, were naive from a cross-cultural viewpoint. He maintained that ethnic and national differences in basic anthropometric measurements, such as height and weight, in languages and in cognitive and cultural styles present an important challenge to the human factors engineer or ergonomist (Chapanis, 1975). These variables must be taken account of in a world in which the use of complex technology is becoming increasingly international.

Until recently the majority of ergonomic research has been geared towards westernised populations, and it has been recognised that problems arise when western engineering and industrial technology are introduced to the less developed areas of the world (Chapanis, 1975; Shahnavaz, 1987). Transfer of such knowledge without consideration of the characteristics of the local users and the environmental conditions of recipient countries has proved to be both socially destructive and economically expensive in terms of human suffering and material losses (Shahnavaz, 1987).

STANDARDS

Before any international standards in the design of equipment and working styles may be established, the needs of the target workforce have to be accounted for and understood on the basis of national and cultural variables. Norms that have been established for safe lifting practises in American and North European countries may not be wholly applicable to the South African situation, but they do provide a means of assessing a potentially hazardous situation.

The International Labour Organization (ILO) developed safety and health standards in the form of recommendations and conventions on accident prevention, labour inspection and occupational health and safety, in addition to technical standards, codes and guides to enable standards to be drafted in other countries (Veturi *et al.*, 1987). Most industrially developed countries have some form of standards according to their requirements (both statutory and non-statutory), with respect to occupational diseases and injuries, which form the basis of prevention programmes for musculoskeletal injuries (Veturi *et al.*, 1987). It is not immediately apparent that such extensive programmes are fully operational within Southern Africa, although steps toward optimising human performance and safety in industry may already be, or should be, put into motion.

A heavy engineering industry in India illustrated how the frequency rates of injuries has declined from 36 in 1962 to 0.77 in 1983, against an overall national increase in the rate of injuries (Veturi *et al.*, 1987). This was accounted-for by their accident prevention scheme based on national non-statutory standards, supplemented by firm-level standards. Also contributing to the decline in accidents in this instance has been the involvement of workers in prevention activities, departmental training and education programmes as well as a personal approach to worker's problems by management.

Veturi *et al.* (1987) conclude that concerted efforts must be made in developing international and national standards and guidelines for the prevention of musculoskeletal injuries. Existing standards may even be adapted, particularly in the case of developing countries where the economy is changing. The development of compatible international data would be welcomed, to enable valid comparisons between different countries (Edwards, 1987), but the process is slow and problems have yet to be overcome. Five main constraints have been outlined with respect to legislation of recommended standards (Veturi *et al.*, 1987):

- The general lack of awareness of health and safety among workers, workers' representatives, professional organizations and Government agencies inhibits the process of adopting recommended standards.

- Apathy on the part of the employers, mainly due to financial constraints, lack of awareness, lack of pressure from employees and their representatives, and weak Government controls.

- The lack of trained manpower to implement the additional responsibilities envisaged by the recommended standards, both at a governmental and plant level.

- The weak economic situation of developing countries and consequent lack of resources is possibly the greatest obstacle to the adoption of any recommended standards.

- Prevention of musculoskeletal injuries does not rank high on the list of national priorities due to the low cost of human resources, lack of development of basic health care facilities and the need for quicker economic growth.

Developing countries strive for an overall improvement in the quality of working life, to be achieved through economic growth (Shahnavaz, 1987). However, more often than not, the rapid rate of change is not suited to the individual or society and many social functions are incompatible with the demands of rapid industrial progress.

OCCUPATIONAL HEALTH AND ACCIDENT PREVENTION

It has been the case in the past that injuries resulting from accidents have been treated, with no particular attention being paid to the circumstances leading up to the accident. Due to the cost and loss of working hours as a result of workplace injuries, it is necessary to formulate effective procedures for accident prevention. These procedures should not only look at the etiology of the accident, but also be able to assess situations that have the probability of producing accidents.

The aim of occupational health services should be to adapt work to man, and to create optimum working conditions and environments for the promotion and maintenance of well-being and satisfaction in all occupations (Shahnavaz, 1987). In order to achieve this goal, prevention of disease and injury, consideration of the problems associated with both the worker and his environment is necessary. In reviewing the circumstances surrounding the accidental situation, it must be borne in mind that manual lifting usually occurs in combination with other task-related factors (carrying, lowering, pushing, pulling). When looking at any MMH activity, the possible limitations to such work must be considered in order to evaluate the situation accurately, and determine the compatibility of the task demands and the capabilities of the individual. (Refer to Appendix B for the comprehensive list of Herrin *et al.*, (1974) detailing the characteristics of major components affecting MMH).

The basic human limitations rendering the individual physically unsuited to the task would take the form of:

- Musculoskeletal strength: related to state of training
- Biomechanical tolerance of the back to stress
- Psychophysical stress: improper attitude (lazy, impatient, and/or uncooperative), lack of knowledge (insufficiently informed, misunderstanding) related to state of education, and lack of incentive/motivation
- Fatigue: both mental and physical
- Cardiovascular capacity - metabolic endurance
- Age and sex

Shahnavaz (1987) maintains that poverty, chronic ill-health, low motivation levels, increased physical and mental stress, coupled with high absenteeism and turnover are additional problems of the individual that need attention. Often salary and social benefits are low because productivity is well below capacity, in turn resulting in worker malnutrition and low efficiency, rendering the worker more vulnerable to accidents. There is a need to break this vicious cycle of failure by creating satisfactory working conditions (Elgstrand, 1985) and by promoting the health of the workers by preventing occupational diseases and problems associated with unnecessary fatigue.

On the other hand the worker may be at risk as a result of inappropriate workplace design and limitations imposed by the design of the task itself. When considering MMH lifting/lowering activities the important causative factors of musculoskeletal injuries (Herrin, 1978) are as follows:

- Loads: measures of the vector forces and moments acting on the body during MMH

- Dimensions: measures of size, shape and form of objects handled

- Distribution of loads: measures of the location of the object's centre of gravity with respect to the worker (NIOSH H-factor)

- Couplings: measures of the interface between the worker and the load

- Stability of load: measures of the consistency of the load's centre of gravity, as when handling liquids and bulky materials

- Workplace geometry: measures of the spatial properties of the task, such as movement distances, obstacles and the nature of the destination (each influencing working posture). Design, layout and organization of the work-station, including tool design and equipment used influence working technique (Melin, 1987)

- Temporal factors: measures of frequency and duration of work activities over the short and long term

- Complexity: measures of manipulation requirements, the objectives of the activity and the tolerances for motion error

- Environment: measures such as temperature, humidity, lighting, noise, vibration, foot traction, toxic agents and so on

- Organization: measures of such administrative factors as the use of teamwork, machine pacing, work incentives, extended work shifts, job rotations, personal protective devices and so on

There is often a disregard for the workload aspects of actual layout (referring to working posture) and organization (in the form of repetition and monotony) of working routine. The way in which the effects of unnecessary fatigue and boredom may be reduced is by introducing regular work breaks, providing variation in the actual tasks performed to create diverstiy in workload, improving working positions. and by increasing the individual's awareness of possible hazards in the working environment.

Healthy employees are better motivated, more enthusiastic and more productive, working in both a safer and more alert manner (Stamper, 1987). An organization of healthy people, who are satisfied with their working situation, contributes to a positive working ambience. Resultant rewards would, in most cases, be lower health care costs, less absenteeism, improved productivity and fewer accidents. Prevention of injury is a cost-effective tool, and as such, those in charge have a responsibility and the opportunity to encourage their employees to take better care of themselves. "By motivating, training and assisting people to stay well, we can provide quality health care for all, at costs we all can afford" (Stamper, 1987). Kilbom and Persson (1987) advise employees against working at a very high pace, and state that management should attempt to reduce the level of perceived stress and be on the look-out for employees with a high occurrence of sick leave.

The prevention of low back injuries which prevail in industry extends beyond the bounds of any guideline, and into the management and organisation of the worksite itself. The recommendations themselves, based on a guideline, will not bring about any positive results or the desired reduction in injuries, until they are put into action and maintained. For this reason, industry needs to be made aware of the ergonomic solutions that may be implemented where necessary in order to put the recommendations into action.

Careful pre-employment screening and selection of the workers for jobs entailing MMH is one method of alleviating the risk of back pain (Griffin *et al.*, 1984), and other work related injuries. However, there is no general agreement about the content of such screening tests, and little epidemiological evidence exists for the predictive values of such tests. The key here lies in identifying the "real" requirements of the task and then including these elements in the screening tests. Selection of employees has become an important issue in Canada in times of increasing technological advancement, high training costs, and with women entering into non-traditional employment sectors and human rights legislation making it necessary to ensure that individuals are suited to the jobs they are performing (Celentano and Nottrodt, 1984). Self-selection is a general rule when people apply for jobs which they feel capable of performing. This, however, does not necessarily indicate that they are suited for those jobs, and one factor rendering individuals unfit for manual work is the prevalence of back pain. The basis for developing selection standards is to match the physical capabilities (morphology, strength, and endurance) of the potential worker population with the actual job demands, in order to reduce the risk and severity of overexertion injuries (Chaffin *et al.*, 1978; Garg and Saxena, 1980; Yates *et al.*, 1980; Ayoub *et al.*, 1983; Mital, 1984a; Nicholson and Legg, 1986; Dul and Hilderbrandt, 1987; Van Wely, 1987). Employee screening and selection is an alternative solution to task redesign, whereby man must fit the task, provided the occupational demands do not greatly exceed the normal range of physical capabilities as depicted by the workforce.

Pre-employment screening methods for jobs involving heavy physical work include general "medicals", low-back X-rays and lordosimetry, clinical and cardiovascular fitness tests, height, weight and strength tests (Norman *et al.*, 1983; Bishu *et al.*, 1984), based on the premise that it is possible to detect an individual who has the potential to obtain low back pain (Rowe, 1969). Chaffin *et al.* (1978) revealed that susceptability to, and the frequency and severity of musculoskeletal injuries increases as the load lifting demands approach, or exceed, the maximal strength capabilities of the worker, as established during an isometric strength test (in relation to the forces required for work). Garg *et al.* (1980) maintain that standard isometric measures can not be confidently used as a worker selection tool, as they are not sufficiently related to the performance of dynamic tasks such as lifting. A high correlation is required between strength as measured in a test and strength as employed to perform an industrial task (Norman *et al.*, 1983), taking into consideration that human strength is the result of many different motivational and physiological processes (Chaffin, 1975).

Good training, conditioning through simple exercise methods, and education in safe lifting procedures not only gives the employees confidence in what they are doing, but may also reduce the potential risk of injury. The following should be included in a complete education/training programme to prepare personnel both mentally and physically for manual handling tasks:

- increase employee awareness of potential hazards associated with manual materials handling
- instruct employees in approproate handling procedures, and
- improve the physical capabilities of the employees as related to the job requirements

Cain and Pettry (1984) studied the potential effect of training as a means of reducing injury in the coal industry and the results, not yet conclusive at the time of writing, were promising. Specific training of subjects for 2 hours per day, 3 days per week for 6 weeks (a period deemed adequate by Garg and Saxena, 1981; Asfour *et al*, 1983) produced significant increases in the maximum acceptable frequency of lift for a 4-minute period, for both males and females (Mital and Asfour, 1983). These results, however, are not conclusive as the effects of the training were not consistent. Only so much can be done by training personnel in proper lifting techniques and encouraging regular exercise habits, and this solution should only be relied upon and utilized after selection and job design/redesign have been instituted (Ayoub *et al.*, 1984). The employees themselves must be made aware of the benefits of such selection procedures and training programmes.

If the job design itself is good, based on a working knowledge of the capabilities and limitations of the workforce, it will reduce the worker's exposure to the hazards of manual materials handling. This consequently decreases the medical and legal problems of selecting the workers for the job, as well as finding replacements for absent workers (Snook, 1978). Effective design also places less emphasis on the workers lifting technique as a causative factor for injury (Snook, 1978). According to Ayoub *et al.* (1984) task design/redesign is the optimal solution to a hazardous situation and may be implemented by eliminating or reducing the need for lifting and carrying activities, thus decreasing the physical demands of the task and minimising stressful movements and postures. These design effects may be brought about by (Ayoub, 1982):

- introducing mechanical aids (trolleys and fork-lifts)
- modifying the work layout (lower storage shelf heights)
- adjusting actual task characteristics (work rates, distances moved)
- modifying load or container characteristics (addition of handles)
- adapting movement patterns (reducing bending,twisting)

Designing the job to fit the worker (Snook and Ciriello, 1972) is preferred by the Liberty Mutual Insurance Company because it represents a more permanent engineering solution to low back injury problems (Snook, 1978). In some instances, task redesign may not be cost effective, but the NIOSH guidelines provide the basis for theoretical recommendations to be made with respect to modification of worksite, task and load characteristics.

The effectiveness of job design, selection and training procedures was evaluated by Loss Prevention Representatives of the Liberty Mutual Insurance Company in the United States in terms of the reduction of low back injuries (Snook *et al.*, 1978). The results indicated that approximately one quarter of the policyholders' jobs involved manual handling tasks that were acceptable to <75% of the workers, and half of the low back injuries were associated to these jobs. Therefore a worker was three times more susceptible to low back injury if performing a task that was acceptable to <75% of the working population. Also apparent was that two out of three of the low back injuries incurred during heavy manual handling tasks could be prevented if the tasks were designed to fit at least 75% of the working population. The third injury would occur regardless of the job. However, proper design can reduce up to one third of the existing industrial back injuries (Snook *et al.*, 1978). No significant reductions in low back injuries were found when such factors as medical histories and examinations and low back X-rays were included in the selection process, or when the individuals were trained to lift properly. Job design is not the total solution, but appears to be significantly more effective than either selection or training (Snook *et al.*, 1978).

Industrial fatigue

A factor related to the mismatch between the worker and his job is fatigue, as identified by Heinrich (1959) when outlining rules for industrial fatigue reduction. Apart from employees being examined regularly, careful attention should be made of the environment, which includes both the work environment and leisure and recreation activities when off the job. Other factors to be considered are the length of the working shift and the requirements placed upon the worker during this period, usually an 8-hour a day shift. As has been noted in a project carried out by Charteris *et al.* (1987), if the workers work to task (in other words, are told that they can leave once they have completed a certain amount of work), this quota is likely to be carried out as quickly as possible to allow the worker more free time to pursue other interests, or even another job for more money. It can thus give rise to a greater amount of cumulative fatigue than would ordinarily be experienced if the work quota was allocated and distributed evenly over the entire 8-hour shift for which workers are being paid. Working to task could consequently increase the risk of injury through greater carelessness, or pure inability to continue performing effectively, due to fatigue.

Accordingly, care should be taken in establishing the working hours for a particular trade, and in situations where the work is monotonous and repetitive, regular rest periods have proved to be effective (Heinrich, 1959) in that they allow the worker to recuperate sufficiently to continue work effectively. These breaks provide for a change of focus of attention and in general revitalise the body. Rest periods may be active (e.g. following specific exercise programmes such as aerobics in a Company gymnasium, playing racket sports or jogging) or simply a time to relax and take a break. Heinrich (1959) concludes that "the workman with a fatigued mental, nervous, or muscular system is a 'bad risk' for himself and his employer". By removing or minimising the sources of fatigue, the incidence of accidents can be greatly reduced.

MANUAL MATERIALS HANDLING (MMH)

Manual labour is still prevalent in most industries world-wide, despite advanced sophistication in technology and increased mechanisation. It has become possible to replace the human being with 'robots' in tasks that are straightforward, continuous and monotonous, providing greater reliability, accuracy and consistency in performance. Mechanisation, however, rarely allows for variability of and adaptability to the task at hand, and there are some tasks in which it is impossible to remove the human element. Shipping and major warehouse operations use mechanical assistance in loading and unloading their cargo, but the distribution of goods and stock to the various smaller outlets requires manual labour. In these smaller industries, aisles between shelves in storage rooms are often made very narrow as a means of maximising the available space for storage. This eliminates the possibility of machines doing the work and therefore there are still significant requirements for manual work in many areas industry wide.

MMH activities include the common task elements of lifting, lowering, pushing, pulling, holding, carrying and walking (Snook *et al.*, 1970) which often occur in combination in industry (Jiang *et al.*, 1986) depending on the nature of the task, available space or spatial constraints and obstructions. Each of these components contributes to the physical demand of a particular task, and occurs with varying frequency during the execution of tasks. In 1984, Celentano and Nottrodt reported on the Canadian Forces approach to analyzing physically demanding jobs. The authors identified the need for an objective system to match the physical abilities of individuals to the physical requirements of occupations, in order to develop physical selection standards for each individual military occupation as a means of alleviating the risk of injury.

A task-analysis methodology was utilised by Celentano and Nottrodt (1984) with the aim of creating better utilization and increased productivity of its personnel. Of the 1163 tasks that were identified as physically demanding, lifting and carrying comprised approximately 70% (Saunders *et al.*, 1982). Once the tasks were categorised according to trade, the number was eventually reduced to 126 separate trade-specific tasks, and five common tasks (with more than ten trades involved) (Celentano and Nottrodt, 1984). With this further breakdown, the lift/lower component comprised 77.9% of the activities, which increased to 95% when the carrying component was included. From this task analysis approach, it was established that the vast number of tasks within a trade may be described by a small set of common task elements. Inter-trade differences are determined by varying object configurations and task requirements (such as distance carried or lifted, and frequency) as established by the specific trade. Nevertheless, as stated previously, lifting/lowering and carrying still constitute a major proportion of the tasks elements in industry to date, and as such must be considered in conjunction with the object configuration and task stipulations as causative factors in many manual handling injuries and accidents as reported in the literature.

Lifting

In industry today approximately 30% of all jobs involve some degree of manual lifting (NIOSH, 1981). Most tasks included in this category consist of two-handed lifting of boxes or containers from floor to knuckle or waist height. Evidence suggests that these types of activities may be causal factors in low back pain, musculoskeletal injuries and related compensation costs (Haber, 1971; Akeson and Murphy, 1977; Kelsey *et al.*, 1979). Monod and Zerbib (1985) state that a load-carrying task can be characterized by the weight and shape of the load, the distance involved and the work-rate (frequency of the operation if the task is repetitive).

It can be stated that lifting is an activity of daily living, occuring in the home as well as in industry. Occasional lifting is found throughout industry, even in various types of office work, with repetitive lifting being more prevalent in such occupations as shipping rooms, warehouses, construction work and manufacturing operations which all involve the manual handling of materials (AIHA, 1970). Lifting as such may be described as the act of manually grasping an object and raising it from a lower to a higher position. In the process, the weight of the object is for some time either wholly or partly supported by the lifter. It can therefore be seen that manual lifting involves both static and dynamic work (Tang, 1987), with static work putting greater strain on the body, particularly when additional load is being lifted and held in a certain position.

In order to justify the costs of ergonomically designed workplaces, it is necessary to relate improved posture and working techniques with improved performance (Bhatnager *et al.*, 1985). The ergonomic design of any worksite should allow workers to maintain efficient postures, which increases perceived comfort while reducing postural complaints. The general prescription for "good" posture (Bhatnager *et al.*, 1985) is to 'design for minimum constraint and minimum use of static contraction of postural muscles'. In the absence of these guidelines, neck, back, shoulder and arm pains can result.

Prolonged maintenance of any body position requires static muscular activity, during which blood vessels are compressed and blood-flow to muscle is reduced (Astrand and Rodahl, 1977). Therefore fatigue and discomfort are common complaints during activities that require some form of static effort, and recovery can take as long as twelve times the original period of activity (Grandjean, 1980). Periods of dynamic work, interrupted with brief periods of rest constitutes the ideal way to perform physical activity (Astrand and Rodahl, 1977). These rest periods provide a means of avoiding fatigue and postural discomfort, given an adequate worksite. Chaffin (1973) demonstrated that prolonged forward flexion of the trunk caused extreme levels of local fatigue in the lower back.

Leaning the trunk forward increases the compressive load on the lumbar spine, a condition known to be associated with increased frequency of back complaints. McCormick and Sanders (1982) maintain that the most important possible physical consequence of improper posture is with respect to spinal problems, the main reason being pathological degeneration of the intervertebral discs. It has been found that in either a standing of sitting position, the intradiscal pressure increases with increasing degrees of bending of the back (McCormick and Sanders, 1982).

THE BACK AND INTERVERTEBRAL (IV) DISCS

The curvature of the vertebral column provides the spine with elasticity to absorb shocks, with the greatest loading in the lower lumbar region. A functional unit or motion segment of the spine consists of two vertebrae (V) and a disc (D), known as the V-D-V unit (Frankel and Nordin, 1980). Each intervertebral

(IV) disc acts as a pivot joint and cushion between adjacent vertebral bodies (Jacob *et al.*, 1982) and is made up of an inner gelatinous nucleus pulposus, surrounded by a fibrous ring, termed the annulus fibrosis (Hay and Reid, 1982; Sperryn, 1983). In order for the spinal column to function adequately these functional units need to work in a synchronous manner, with the discs absorbing additional stresses imposed on the body during activity.

Discs lose their elasticity, becoming more fibrous with age (Hay and Reid, 1982), and gradually become brittle and more susceptible to rupture. In association with disc deterioration, pain and stiffness are experienced in the back due to infiltration of nuclear pulp through the annulus fibrosis and into the surrounding tissues. Discs are not pain sensitive themselves, due to the absence of any innervation, but they are susceptible to wear and tear. Lifting, classified as heavy work (Grandjean, 1980), imposes this problem of wear and tear on the IV discs.

The effectiveness of the disc as a shock absorber is almost entirely dependent upon the nature and direction of the stresses imposed on it. It must be borne in mind that the greatest loading on the vertebral column occurs in the lower region of the lumbar vertebrae 3, 4, and 5 (L_3, L_4 and L_5). Due to this greater stress being imposed on the lumbar region (Grandjean, 1980), the lumbar vertebrae are larger (Hay and Reid, 1982), having a greater surface area. There is a respective increase in size of the vertebral body from the cervical to lumbar regions. The surface area of the vertebrae reflects the stress that has to be withstood and consequently $L_5 > L_4 > L_3$.

BIOMECHANICS OF LIFTING

Forces and moments acting on the lumbar spine result from the weight of body segments, bodily movements and external loads. These forces need to be equilibrated by internal forces (muscular contractions, soft tissue resistance, truncal pressures) (Andersson, 1985). Newton's Third Law states that for every action there is an equal and opposite reaction. (Hay and Reid, 1982). Therefore, when moments are created about the lumbar vertebrae when lifting loads, the appropriate musculature exerts a counteractive force to maintain the integrity of the structure. One internal force resisting the external stressor is provided by the erector spinae muscle group which exerts force approximately 5cm posterior to the centres of rotation in the spinal IV discs (Chaffin and Andersson, 1984). During load lifting, gravitational forces acting on the load held in the hands, and the individual's body masses, create rotational moments or torques at various articulations of the body (Chaffin and Park, 1973).

Figures 1a and 1b illustrate the forces that prevail in the lumbar region which are both shear (F_s) and compressive (F_c). The superimcumbent weight of the body (F) acts vertically downwards, and is transported down the spine through the vertebral bodies. The lumbar-sacral angle (L_5 on S_1) is generally 30-40° from the horizontal when standing erect (Chaffin and Andersson, 1984). Resolution of forces in this region indicate that with an increase in the lumbar sacral angle (as when bending forward), there is a resultant increase in F_s, as the force acting vertically down (F) remains constant (be it the weight of the body unloaded, or with the additional load when manually handling an object). The shear force tends to push the vertebral body into the abdominal cavity and is initially absorbed by the soft tissues surrounding the joint, i.e. the structures preventing an anterior slippage of the vertebral body (such as the ligaments) which can maintain the integrity of the structure for a certain time. As ligaments have a lower modulus of elasticity than bones, they eventually deform under the stress and the vertebral body moves until the boney facets meet. This prevents any further slippage unless severe trauma results in a fracture of the pars interarticularis (spondylolysis, or defective vertebral arch) (Peterson and Renstrom, 1986).

The amount of torque (forward bending moment) at any one joint is dependent on the amount of force tending to rotate the segments, multiplied by the perpendicular (normal) distance from the joint to the force vector, known as the moment arm (refer to Figure 1b). That is, torque = force x perpendicular distance (Chaffin and Park, 1973).

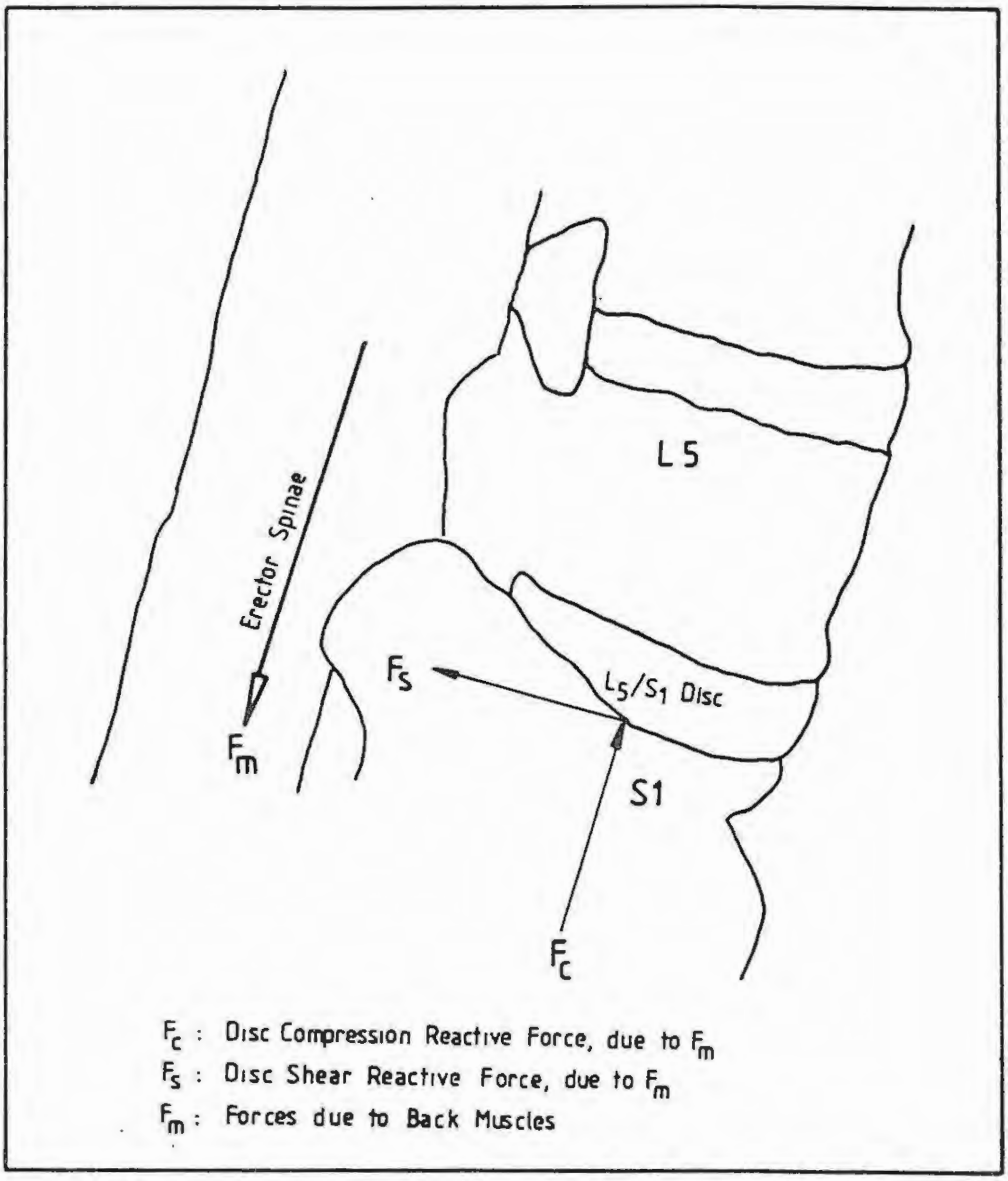


FIGURE 1a: Forces and moments acting on the L_5S_1 disc in a simplified spinal model of load lifting. (Modified from: Chaffin and Andersson, 1984 p.196)

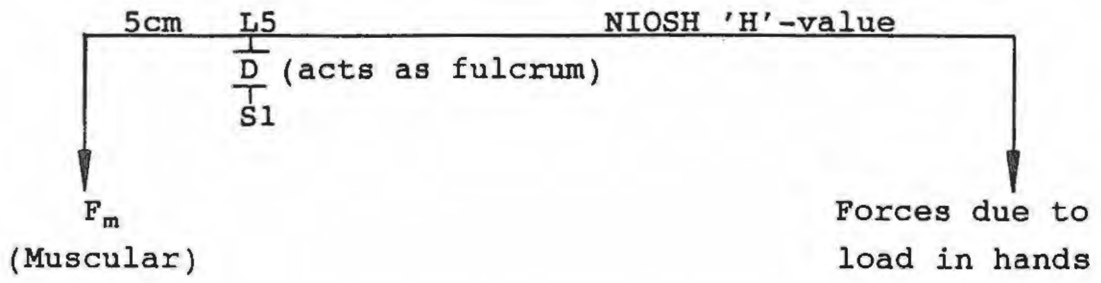
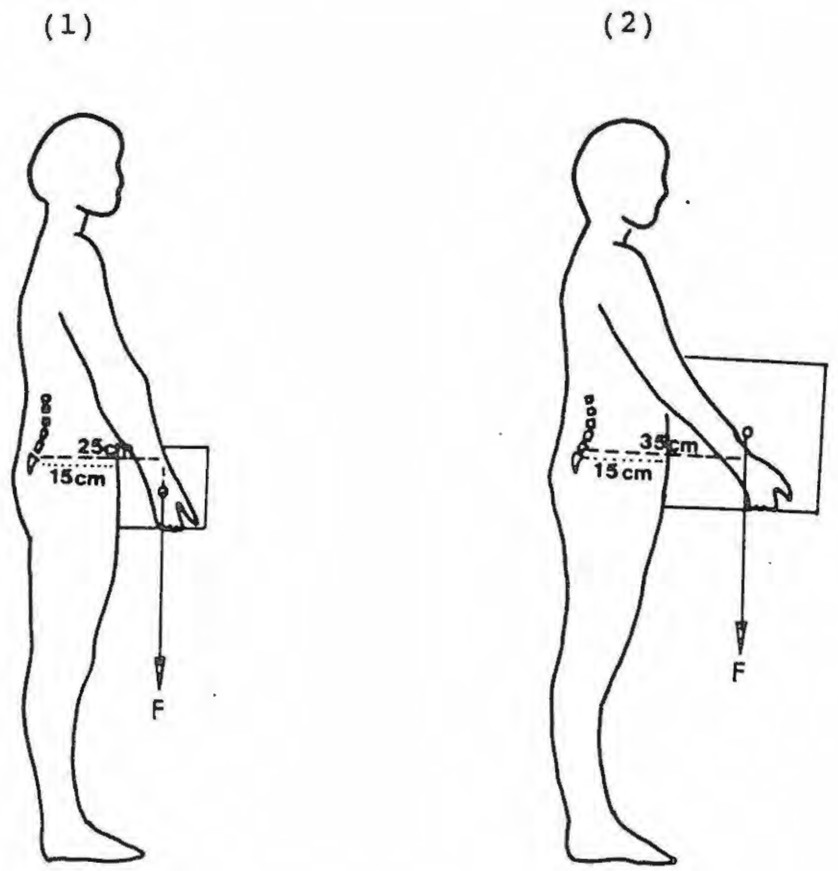


FIGURE 1b: Diagramatic resolution of the forces/torques (bending moments) in Figure 1a, about the disc (D) between the fifth lumbar vertebra (L_5) and the first sacral vertebra (S_1), illustrating the the stressors placed upon it.

It must be borne in mind that the force vector is usually taken at the centre of mass of the object and therefore the moment arm varies with the individual's lifting posture, and the size of the load. When the load is lifted or held close to the body, the moment arms are small, therefore the resultant torque at the joints are small. On the other hand, larger moment arms that result from lifting/holding the load further away from the body cause larger torques or forward bending moments.

For example, it is generally accepted in the NIOSH (1981) guidelines that the distance from the centre of mass of the body (acting through the spinal column) to the front of the abdomen is 15cm in an erect-standing individual. Consequently, the closest that an object may be held to the centre of mass of the body is 15cm. A situation will be outlined (refer to Figure 2) whereby two objects of equal mass (20kg, or about 200N), but different size are held. In the first case, where the object is 20cm wide (front to back), the centre of mass of the object is 10cm from the abdomen, which creates a moment arm of 25cm (15 + 10 cm = 0.25m) between the joint of articulation in the lumbar region and the force vector (mass of the object). In the second case, the object is 40cm wide, creating a moment arm of 0.35m (15 + 20cm). In the first case, the forward bending moment (torque) acting on the lowest lumbar disc is

50Nm. In the second case, where the object is held further away from the body, it's centre of mass is further away from that of the body creating a larger forward bending moment of 70 Nm (Figures 1a and 1b).



Torque = force x distance

(1) Torque = 200N x 0.25Nm
= 50 Nm

(2) Torque = 200N x 0.35Nm
= 70 Nm

Figure 2: The resultant forward bending moments (torques during lifting/holding objects of different sizes (modified from Frankel and Nordin 1980, p274).

During load lifting, the bending moment at the lumbosacral joint can become quite large and to counteract this torque, the muscles (in particular the erector spinae group) have to exert correspondingly high forces due to the fact that they act over much smaller moment arms (approximately 5cm - Chaffin and Moulis, 1969).

These high forces generated by the lower back muscles are the primary source of compression on the lumbosacral disc. Chaffin and Park (1973) established a graph (see Figure 3) for the prediction of compression forces at the L_5/S_1 (a range of values which has been confirmed by Nachemson and Elfstrom, 1970). Incremental loads were used that were held in a standardised position, reasonably close to the body. An important inference that may be drawn from this graph is that even when the 'reasonable' lifting posture is used, high compression forces are created in the disc.

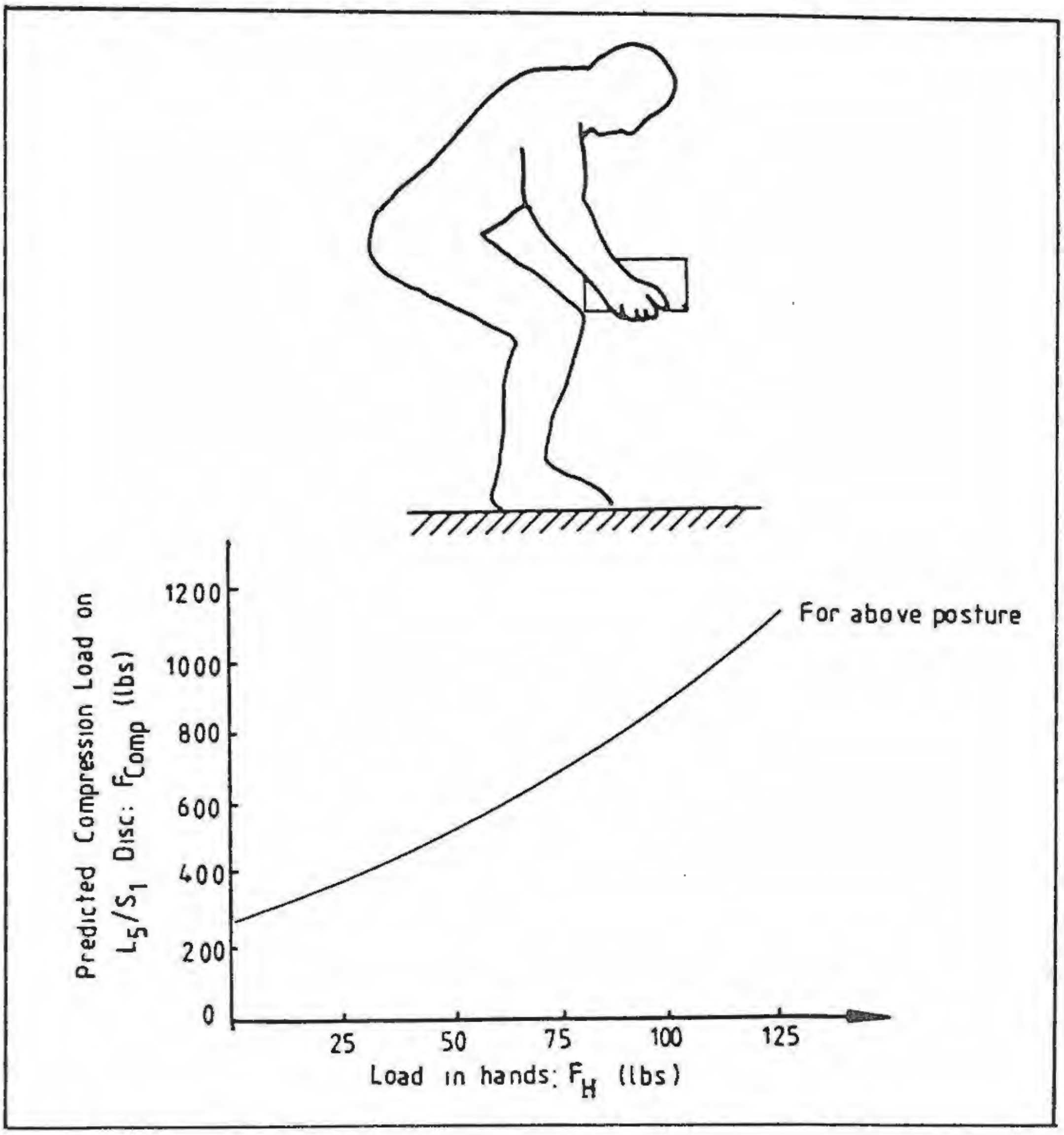


Figure 3: Predicted compression forces acting on the L_5S_1 disc when lifting loads of various magnitudes. (adapted from: Chaffin and Park, 1973, p.516)

Many models have been outlined by Chaffin and Andersson for the quantification of forces about the lumbar spine and hip joints. "Since the lumbar spine is anatomically close to the hip joints, a similar effect occurs about the joints of the lumbar spine, which in flexion and extension can be considered to be near the centre of the spinal discs" (Chaffin and Andersson, 1984). Along this line, Tichauer (1971) proposed that the load moment about the lumbosacral disc (L_5/S_1) be used as a criterion for setting limits for lifting and carrying loads. In this way unnecessary fatigue in the lumbar extensors (erector spinae) may be avoided, and risk of injury reduced. This is because this pivot point incurs the greatest moment in lifting activities, and between 85-95% of all disc herniations occur with relatively equal frequencies at L_4/L_5 and L_5/S_1 (Chaffin and Andersson, 1984).

Lifting technique is also important in order for the mechanics of the spine not to be upset, due to the fact that a rounded back causes curvature of the lumbar spine with subsequent heavy, asymmetrical loads being placed on the IV discs in the frontal plane (Grandjean, 1980). This unequal increase in pressure tends to squeeze the discal fluid towards the posterior portion of lower pressure. The danger in this is that the fluid may leak towards the spinal nerve cord. However, if the spine is kept straight during lifting, the joints are held by the vertebral shape and supporting muscles and ligaments (Sperryn, 1983). Nachemson and Elfstrom (1970) reveal how flexing the back with straight knees while lifting puts a much greater stress on the discs in the L_3/L_4 region, than when keeping the back as straight as possible and flexing the knees (see Figure 4).

Flexing the knees enables the individual to get closer to the object, thus reducing the horizontal distance factor (H) and moment arm between the body and object, creating a lower torque. As has been shown, a correct lifting technique is essential to reduce the risk of injury. The recommended ways of lifting loads are outlined by Grandjean (1980) as follows:

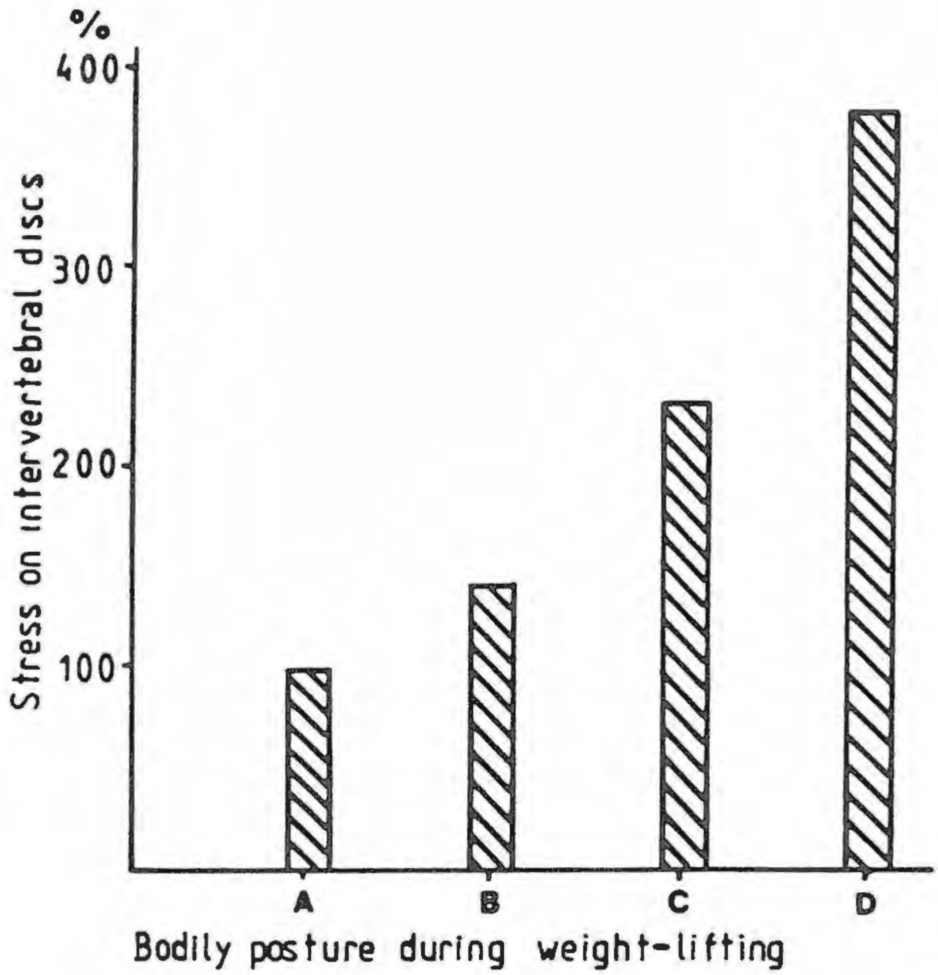


FIGURE 4: The effect of body posture on the intervertebral disc pressure between L3 and L4 when lifting weights.
A = upright stance (pressure on discs taken as 100%)
B = upright stance with 10 kg in each hand
C = lifting a load of 20kg with knees flexed and back straight (the correct stance for weight lifting)
D = lifting 20 kg with knees straight and back flexed
(From Grandjean, 1980, p95: after Nachemson and Elfstrom, 1970)

- Take a firm hold of the load and lift it with a straight back (to evenly distribute the loads imposed on the disc). Ideally, loads should be handled in such a manner as to maintain the body as erect as possible, and the knees should be flexed.

- The maximum power for lifting a load is obtained when the object is gripped 40-50 cm above ground level (Grandjean, 1973), it is advised that loading ramps be positioned at this height, or other methods should be considered for loads with no handles, to allow them to be gripped at the optimal position.

- Loads should be lifted as close to the body as possible to reduce the resultant shear and compressive forces on the lumbar spine.

MANUAL MATERIALS HANDLING INJURIES

In a survey carried out in 1985, involving 83 industries in Singapore, it was established that manual lifting occurred in 66% of them, although only approximately 6% of the total workforce were involved (Tang, 1987). In the reports relating to injuries incurred in the workplace, the majority of musculoskeletal injuries were as a result of manual materials handling. Particular attention is now given to overexertion injuries, 60% of which, over the last five years in the United States, were incidents involving manual lifting. The pushing, pulling, handling or throwing of objects accounted for 18% of the overexertion injuries, and 22% involved strenuous movements (Tang, 1987). Overexertion in these instances would relate to exercising beyond one's capabilities for that particular situation, as injury results, and these are all injuries which could have been alleviated if adequate preventative measures had been utilized.

MMH is the principal source of compensable work injuries in the United States, amounting to 23% of all injuries, 79% of which are injuries to the lower back (Snook, 1978). Low back pain is a major cause of industrial disability, with one million back injuries occurring in the United States per year, accounting for 20% of all work-related injuries (Bureau of Labour Statistics, 1972). Between 1938 and 1965, compensable back injuries increased from 7.7% to 19.1% of all compensable injuries in Wisconsin, USA (Snook and Ciriello, 1972). Lower back injuries are not usually serious, with four out of five injured workers returning to work within three weeks (White, 1966). However, even though they may not be serious, back injuries occur frequently, affecting more than half of the working population at some stage during their working career (Rowe, 1971), and this exacerbates the number of man hours lost to the company.

It is generally the cumulative effect of wear and tear on the IV discs in the lumbar region, due to a life-style that repeatedly places great demands on the lower back through continual loading and stressing and that causes the inevitable recurring discomfort preventing the individual from working satisfactorily unless appropriate action is taken. Initially no pain or discomfort may be felt, but as the situation continues, so the integrity of the lumbar system is gradually worn down until it finally gives way. Consequently, serious injury may result and this generally needs no great traumatic event to occur. Lower back pain simply becomes unbearable, and hence MMH is rendered temporarily or even permanently unsuitable and a change of job may be required. Grandjean (1973) postulated that more than 50% of adults suffer from backache during their lives. Lundgren (1960) claims that 60% of the Swedish population are affected, with Hirsch (1966) citing a similar estimate of 65%. In the United States of America, Rowe (1971) found that 56% of long-term male employees suffered back pain sufficient to warrant medical treatment, and this would be as a result of the accumulative strain due to MMH.

Lifting and handling of loads involves a great deal of static effort, whereby part of the body exerts a continuous force of more than 15% of its maximum possible effort, even momentarily, and is sufficient to be classified as heavy work (Grandjean, 1980). This creates the problem of wear and tear on the intervertebral discs, which increases the risk of back pain and reduces the worker's mobility and ability to do work efficiently. Back pain as such is not a simple phenomenon, and Pope (1987) maintains that at least 50% of LBP is idiopathic (its cause is obscure). There is considerable disagreement as to the cause of lower back pain in industry. However in most cases it is reasonable to assume that LBP occurs as a result of mechanical overload to one of the tissues of the back (Pope, 1987). Frymoyer *et al.* (1980) list activities at risk for low back pain, illustrating that there is a greater incidence of LBP in those men involved in MMH activities, particularly lifting and carrying. Chaffin and Park (1973) found that those who lift heavy objects have eight times the number of LBP injuries. Work posture also relates to LBP and to neck and shoulder pain (Grandjean, 1980).

Mennel (1960) lists six major theories of low back pain (LBP) causation, stating that "none of these theories ever lived up to the claims made for them by their proponents, though there was some truth, to a greater or lesser degree, in each of them". These theories relate to the sciatic nerve, the sacroiliac joint, psychoneurosis, the disc, muscle spasm and the facet joint (Mennel, 1960). Along the lines of the Disc Theory, Rowe (1971) claims that 70% of low back disability among men in industry is due to degeneration of the intervertebral disc, while Kraus (1965) maintains that more than 80% of LBP is due to muscular deficiency. It is reported in the literature that the majority of LBP cases seen in industrial settings have no known cause, and recover without any disease or mechanical cause being discovered (Glover, 1970). Rowe (1969) claims that "the kind of work done does not seem to be a significant factor in the production of low back disability, although it is reasonable to assume that a man with a backache would have more difficulty performing a heavy job that a light one". Rowe found that the incidence of LBP was only 12% greater in "heavy handlers" than in sedentary workers, the same difference found by Noro (1967) between light and heavy work in Sweden. Magora and Taustein (1969) found the greatest incidence of LBP in heavy industrial workers and nurses in Isreal (see Table I).

The extent of back pain, and ultimately absence from work, is related to the type of work undertaken and age of the workers. In an investigation into prevention of back disorders it was found that LBP was a major cause of industrial sickness and constituted the greatest amount of absenteeism when compared to other manual materials handling accidents (Stubbs and Nicholson, 1979: Davis and Sheppard, 1980; Dales *et al.*, 1987).

Rowe (1969) established that lost time at Eastman Kodak due to lower back problems amounted to 4 hours per man per week, and was second in medical reasons for absence only to upper respiratory infections which totalled 8 hours per man per week. Relating LBP to occupation, Ridd and Davis (1981) found from the British Telecommunications Industry that 30% of the personnel were sustaining 70% of the accidents; evidence that some tasks are more hazardous than others.

Table I: The incidence (%) of Low Back Pain (LBP) in workers among different occupations (from: Magora and Taustein, 1969)

Occupation	With LBP (%)	Without LBP (%)
Heavy Industry Workers	21.6	78.4
Nurses	16.8	83.2
Farmers	14.5	85.5
Light Industry Workers	14.1	85.9
Bus Drivers	11.9	88.1
Post Office Clerks	10.1	89.9
Bank Clerks	10.1	89.9
Policemen	6.4	93.6

THE APPLICATION OF MODELS

Models are representations that assist in the understanding of a given situation, even though such representations may require gross simplifications and problematic assumptions (Chaffin and Andersson, 1984). Comparisons between what actually happens, and what theoretically can happen, allows for greater insight into how components of a system function and are co-ordinated. This in turn assists in the achievement of a desired outcome. The use of models helps in the attempts made to enhance our understanding of human behaviour in a great variety of movement situations.

Mathematical models provide a means of predicting theoretically the outcome of a particular situation, be it energy cost, biomechanical stressors imposed on the body or even psycho-social factors related to human task performance. If the model is holistic and includes the biomechanical, physiological, psycho-social and conceptual areas of the Centre-M model proposed by Charteris *et al.* (1976) for human movement, and incorporates the basic factors influencing human task performance, then it can be assumed that it will provide a useful interpretation and/or explanation of the circumstances surrounding a particular activity.

Kroemer (1984) defines a model as:

> "an abstract (mathematical-physical) system obeying specific rules and conditions whose behaviour is used to understand the real system (worker - task - equipment - environment) to which it is analogous in certain respects (e.g.in physiological, biomechanical and psycho-physical traits)" (p56).

Feasible models, therefore, provide the underpinnings for methods and techniques in order to quantify human capabilities. However, as Taboun and Dutta (1984) illustrate, there are limitations to the use of such models, and reasons for this are as follows:

- The assumptions that form the basis of many models are not always complete or verified as was the case with Garg (1976) when developing an energy cost model for varied MMH activities. In some cases not all of the relevant aspects are considered, rendering the detailed analysis insufficient (e.g. Aberg *et al.*, 1968).

- They may only consider performance on one occasion, limiting the use for repetitive tasks. For example, Frederick (1959), when investigating the energy consumption of lifting various weights at different height ranges, and Kamon and Belding (1971) and Kamon *et al.* (1978), when looking at the effects of temperature on the physiological cost of carrying loads.

- Various functions incorporated within a model relate essentially to an industrial male or female population which is representative of the normative data used for the establishment of the model criteria. However, the same model may still be used as a guideline for another population, bearing in mind that over and/or underestimates may occur due to differing population morphologies. The outcome of such an analysis would nevertheless provide important information about potential risk areas for the industrial worker, and recommendations may be made to optimise working conditions and performance.

The needless loss of skilled manpower and working hours, as a result of injuries incurred in the MMH working environment, brings about significant financial costs for the related industries, insurance companies and governmental agencies (causing capital to become unavailable for economic growth (Mital, 1984a). The resulting injuries frequently lead to permanent partial or total disability of the worker. Kroemer (1984) states that the ergonomic approach for reducing or preventing overexertion injuries relies on the following basic premise: "The risk of an overexertion injury sustained in manual materials handling decreases as the handler's capability to perform such an activity increases". Therefore, one way in which to improve the individual's capability is to match it with the job requirements, a process that may be simplified by the use of models and guidelines.

Many models have been developed to describe central (pulmonary, circulatory and metabolic systems) and local (muscular strength, stress responses of joints) limitations to individual working capability. Kroemer (1984) has categorised these models into the major disciplines of Anatomy and Anthropometry, Physiology, Orthopedics, Biomechanics, Psychology and Statistics. Looking in particular at the biomechanical method, this essentially considers the mechanical functions and musculoskeletal activities of the body. For example, load-bearing capacities of the spine and muscular strength. It is necessary when assessing a situation to incorporate into these models such external factors as good couplings between the individual and the floor (friction to prevent slippage), secure hand holds, temperature, clothing, and workplace layout. It is important to allow for unrestricted lifting posture as much as possible during performance.

A biomechanical model provides some insight into working situations, and also the means to predict potentially hazardous loading conditions on certain musculoskeletal components. For example, the same load picked up with different postures and lifted to different heights yields different stresses on the body, which, on the one hand may be harmless and pose no threat, or on the other hand may be intolerable and exceed the recommended limits for such an activity (Chaffin and Andersson, 1984). Therefore, due to the complexity of any MMH situation, the conclusions drawn from the guideline used in assessing the performance must be deemed specific to the situation.

The NIOSH Model

Herrin *et al.* (1974) concluded from an extensive review, that, of all the MMH activities performed in industry, the research findings were most conclusive when looking at manually lifting loads that were symmetrically balanced in front of the body, but, it was also found that little was known about asymmetric (one-handed or side) lifts and pushing and pulling in industry (Chaffin and Andersson, 1984). Nevertheless, the National Institute of Occupational Safety and Health (NIOSH, 1981) established the development of the Work Practises Guide to Manual Lifting (for two-handed symmetrical lifts), based on epidemiological, biomechanical, psycho-physical, work physiological and ergonomical factors.

This 'NIOSH' model may be used to analyze the physical demands of lifting tasks, and provides for recommendations to be made regarding the control of hazardous situations that give rise to fatigue and strain for the working individual, when they are performing either repetitive and non-repetitive two-handed lifts of objects of definable size and weight (NIOSH, 1981; Celentano and Nottrodt, 1984). It must be born in mind that these recommendations are specific to the situation with respect to worksite, heights, frequencies and durations of lift, and object sizes and weights (Celentano and Nottrodt, 1984). In the case of an already established working site and routine, where redesign would not be cost-effective, the model may be used to indicate whether or not screening and training would be necessary for the workers, to aid in the prevention of unnecessary injuries. The model would also indicate where engineering controls are necessary in situations where the job demands are beyond the scope of the workers' capability due to particular task related factors.

The attractions of the NIOSH (1981) model, and the guidelines that it provides with respect the manual lifting, have been outlined by Nottrodt (1986b) as follows:

- These guidelines are a comprehensive attempt (Chaffin and Andersson, 1984) to provide manual handling guidelines or acceptable load limits considering the epidemiology of musculoskeletal injuries, biomechanical and physiological factors and actual psychophysically-determined lifting limits

- The approach of the model"......moves away from the idea of a single upper limit just for the weight itself, towards a system of determining the limits for a given task by actually measuring it..." (Troup, 1982) and,

- The individual components of the model, which focus "... on those task and container characteristics that best define a hazardous lifting act...." (Chaffin and Andersson, 1984), can be manipulated and the effects of any changes can be quantified , albeit theoretically (Konz, 1982).

Kroemer (1984) maintains that the results of an analysis are only as good (reliable and valid) as the underlying model, and that due to the fact that the NIOSH (1981) lifting guide relies predominantly on a static model, its recommendations apply strictly only to isometric exertions, which are continuously extended to "smooth" (and slow) motions. This fact is laid down within the criteria for the use of the guide - that lifting be smooth, with little sustained exertion (i.e.the emphasis is not on holding or carrying).

From an ergonomic review (Dul and Hildebrandt, 1987) approximately 40% of the concrete guidelines included no individual factors (i.e. age, strength, general fitness, history of injury, psychosocial factors and work experience). When they were considered, the factors were generally found not to correspond well with the individual risk factors from epidemiological studies. It may be due to the common ergonomic principle that work should be so designed that any individual can work without health risk (Dul and Hildebrandt, 1987). Consequently, guidelines may tend to be conservative by not being truly specific to the target workforce under investigation, but rather being broad in order to encompass a greater percentage of the workforce. In the absence of epidemiological data, a comparison of maximum acceptable weight and static strength in the sagittal plane with the NIOSH guidelines for action and maximum permissible limits indicated that the guidelines may be conservative (Garg and Badger, 1986).

As established in a survey of 83 plants employing safety officers in Singapore (Tang, 1987), the NIOSH lifting guidelines may not have been locally applicable for the evaluation of the risk of overexertion from manual lifting of the local sample population used, due to their generally smaller anthropometric features and body build than that of those used in the development of the model. In this case, the results may have underestimated the actual risks involved. Nevertheless, these mathematical models provide a useful tool for objectively evaluating the potential risk of a situation. If used in task design, model guidelines such as NIOSH (1981) would encompass a great number of people, and as such the basic criteria tend to be conservative.

Although no one particular model is applicable to all MMH situations, the NIOSH model has been well used for it's analysis capabilities (Drury *et al.*, 1982; Garg *et al.*, 1983; Liles *et al.*, 1983; Celentano and Nottrodt, 1984; Garg and Badger, 1986; Nottrodt, 1986a), and has been successfully combined with a static biomechanical model to provide a more detailed analysis of the lifting situation and the compressive forces on the lower spine, as compared to acceptable NIOSH norms (Nottrodt, 1986a).

TASK CHARACTERISTICS AFFECTING MANUAL MATERIALS HANDLING

Nicholson and Legg (1986) maintain that human capabilities themselves may be influenced by a number of actual task variables within MMH activities. Even though workers may be ideally suited in a physical sense to a particular activity, inappropriate task characteristics may predispose them to a greater risk of injury. Task factors are, however, only one group of factors that need to be considered in the prevention of musculoskeletal injuries. Herrin *et al*. (1974 - see Appendix B), as discussed by Chaffin and Andersson (1984, p264), grouped numerous factors which can affect MMH performance according to worker characteristics, material/container characteristics, task characteristics and work practises. Based on these categorisations, much research has been carried out with respect to the limits imposed by each factor on task performance. Preference will be given to those factors affecting the task performance observed for this particular research.

The most fatiguing task variable in a study conducted by Habes *et al*. (1985) with a simulated assembly line, was weight of load. Maximal acceptable weight of lift (MAW), as obtained during psychophysical measurements, is the weight that the individual is willing to repetitively lift over a prolonged period of time and is defined by Ayoub *et al*. (1983) and Liles (1986) as the maximum weight an individual feels he or she can lift repeatedly without undue stress or overtiring. This particualr psycho-physical criterion has formed the basis of many studies, having been identified as a well established measure of worker capacity (Snook and Ciriello, 1972) .

The MAW has been found to be significantly influenced by the frequency of lift, height of lift and box size (Mital and

Manivasagan, 1983; Mital, 1984b); to be significantly lower for asymmetrical lifting than for symmetrical lifting in the sagittal plane (Garg and Badger, 1986), and to be significantly lower for females, but proportionally similar to male worker values (Cirello and Snook, 1983). Snook *et al.* (1970) found no significant differences between MAW of either lifting or lowering tasks, and there is conflicting evidence with respect to the influence of age on MAW, probably related to the particular sample populations used for each particular study. Mital and Manivasagan (1983) state that age and body weight appear to be important predictors of MAW, consistent with the findings of Mital and Ayoub (1980), whereas MAW was not influenced by the age of the subjects in studies carried out by Mital (1984b); Mital *et al.* (1978) and Ayoub *et al.* (1978).

It is important to note that it is the interaction of the various MMH factors that influences performance on a particular task. In a comparison between student and industrial subject populations, Mital and Manivasagan (1983) found significant differences in the effects of frequency (2 - 6 lifts/minute) on the maximal acceptable weight of lift (18 - 22 Kg), which was on average 6 kg lower for the student population, although the trend for both populations was practically identical. A possible reason for the differences could be the greater experience and learned techniques for lifting in the industrial population.

A number of studies (Snook, 1978; Garg and Saxena, 1979; Ciriello and Snook, 1983; Mital and Manivasagan, 1983; Mital, 1984b) have shown that task variables such as rate of lift, height and weight of lift, lifting technique and sex significantly affect self-selected workloads for specific tasks. However, lifting load and frequency have been shown to affect workload when adjusted singly (Nicholson and Legg, 1986).

Ciriello and Snook (1983) investigated the effect of task frequency on lifting tasks (low lift = floor to knuckle height and centre lift = knuckle height to shoulder height). The vertical lift distance was 51 cm, with specific task frequencies varying from once every 5 seconds to once every 8 hours. The faster rates of lift elicited higher heart rates and lower MAW (Kg) for both males and females over both lift heights, than did the slower lift rates. Although maximal acceptable weights were significantly higher for males, their heart rates were not significantly different from those of females. Both sexs chose weights, through the psychophysical method, that produced similar cardiovascular strain, with the higher task frequencies eliciting oxygen consumption values that were greater than the accepted physiological criteria for an 8 hour-day (approximately 1000 ml/min for males and 700 ml/min for females - NIOSH, 1981). It can, therefore, be concluded from that study that the psychophysical method yields overestimates of MAW for high frequency tasks.

Mital (1984b) found that individuals were not able to continue lifting the same MAW over an 8 - 12 hour work period as was estimated during the usual psychophysical technique trial period of 20 - 45 minutes. Assuming the initial trial period estimate for 8 hours to be 100%, the rate of decrease would be approximately 3.4% per hour for males and 2% per hour for females. Therefore, failure to adjust data collected after the 20 - 45 minute trial period would result in overestimations of the weights that people are willing to lift for 8 hours, and therefore increase the fatigue and the risk of injury (Mital, 1984b).

The general trend is that, as frequency increases, so heart rate and oxygen consumption increase, while maximal weight of lift decreases (Ciriello and Snook, 1983; Mital, 1984b; Mital and Fard, 1986). In one study there was a decrement of 7% in the weight lifted when the lifting rate increased from 1 to 4 lifts/minute, with a subsequent decrement of approximately 8.5% when the frequency increased from 4 to 8 lifts/minute (Mital and Fard, 1986). At the higher frequencies the build up of fatigue is greater and in order to compensate the individuals select lighter loads to lift (Mital, 1984b). Changes in electromyographic (EMG) amplitudes are normally interpreted as muscular fatigue caused by a change in the concentration of the chemical substance of the muscle (Jorgensen *et al.*, 1985). In looking at the EMG amplitudes of the back muscles, Jorgensen *et al.* (1985) found that under the varying testing conditions, the changes were most pronounced when lifting at the higher lift rate. It was concluded that the EMG amplitude changes were to a greater extent more dependent on the lift frequency than on the weight of the objects lifted.

MAW decreases as the starting point of the lift increases in height according to Mital (1984b) who found that higher weights were accepted for lower lifts, in spite of the greater heart rates, truncal stress and oxygen consumption than at other heights, because individuals could rely more on their thigh and back muscles. The increase in heart rate is probably due to the increased muscle mass involvement. At the higher levels it is mainly the arm muscles that are involved, creating lower acceptable weights, as well as lowered heart rates and oxygen consumption.

Habes *et al.* (1985) established during a test of muscle fatigue associated with repetitive arm lifts that the task variable "reach" produced significant inceases in EMG amplitude of the deltoid muscles and in the frequency shift of the upper trapezius. This is partly due to the lever action of the arm and the fact that the anterior deltoid and upper trapezius provide support when the arms are extended to a vertical full reach position. The statistically significant ($p < 0.05$) Borg RPE results obtained indicate also that the maximum reach requirement is perceived to be physically stressful. The significant decrease in back extension strength for full reach indicates that lifting with the arms fully extended is fatiguing to the low-back muscles, due to the load-moment effect.

As height of lift increases, the activity of the deltoid muscle decreases because it is not capable of sustaining the weight by itself. The stronger biceps muscle is recruited to a greater degree in order to complete the lift. The long head of the biceps attaches at the shoulder and aids the deltoid in shoulder flexion which occurs during lifting. (Habes *et al.*, 1985). With every lift the individual also lifts part of his body which in some cases may be as much as 60% of the individual's body weight (Ayoub *et al.*, 1978), and is therefore an additional factor to be considered in the onset of fatigue. Indications are that the combination of excessive height and weight requirements in an arm lifting task can add to localised muscle fatigue of the upper body (Habes *et al.*, 1985). Weight was a significant variable causing fatigue to both shoulder and arm muscles, and the results indicate that an acceptable weight level should be no greater than 80% maximum voluntary contraction (MVC - obtained by isometric vertical pull-strength measured at shoulder level with arms fully extended) even under low height and reach requirements.

Recommendations for the design of tasks that require approximately 5 lifts/minute for periods up to 1 hour are as follows (Habes *et al.*, 1985):

- Avoid combining appreciable weight levels (> 80% MVC) with excessive reach requirements (approaching full reach) because of their effect on the arms, shoulder and lower back

- Avoid combining heavy loads with height levels above shoulder height because of the potential for fatigue of the elbow and shoulder flexor muscles

- Permit work tasks that have excessive reach and height requirements only if the weight to be lifted is lower that 40% maximum voluntary contraction for that specific task.

Ljungberg *et al.* (1982) established during a study of physiological and psychological responses to horizontal lifting that doubling the lifting rate had only a slight affect on the weight preferred. Consequently 74% more work was performed, with only a slight increase in energy cost. More movements were made, creating a more dynamic working situation which reduces the detrimental effect of static work. Therefore, in order to complete a given quantity of work, it would be more advantageous to carry out that work at a relatively fast rate, as opposed to using a heavier weight. Similar results have been obtained by Snook (1978) and Garg and Saxena (1979) with vertical lifting.

Results of the investigation of manual handling tasks carried out by Ciriello and Snook (1983) indicate that apart from height and frequency, the size of the container (in particular the width which was defined as the distance away from the body) is also a significant variable to consider when establishing guidelines for maximum acceptable lift. Bigger boxes, for the same load, produce a larger bending moment on the spinal column, therefore lighter loads for lifting are usually accepted for the larger containers (Mital, 1984b). In other words, MAW decreases with an increase in box size (Mital and Fard, 1986). MAW of lift for males decreased significantly ($p<0.05$) by 6%, as box size increased from 30.48 cm to 45.72 cm, with both males and females lifting significantly more weight in the smaller boxes used, even at a rate of 12 lifts/minute.

PERCEPTION OF EXERTION/EFFORT

Perception of effort or workload is a complex phenomenon and more information is needed with respect to the factors/variables contributing to the experience of subjective perceptions (Leplat, 1978; Carton and Rhodes, 1985). Nevertheless, due to their practical utility, subjective measures have been widely used as workload assessment techniques (Eggemeier, 1981). Essentially, perceived exertion/effort is a privately experienced event, a subjective reaction to physical work which can only be measured indirectly through the use of self-report techniques (Gamberale, 1985). These subjective self-reported estimates of effort expenditure may be quantified using ratings of perceived exertion scales (Carton and Rhodes, 1985). According to Gamberale (1985), the applicability of such subjective values as criteria in the assessment of MMH activities depends on:

- The type of subjective reaction observed
- The way in which the reaction is observed and recorded
- The extent to which the reaction varies systematically in different work operations

- How well the reaction correlates with work intensity and work performance
- How well the reaction correlates with the physiological and neurological events.

The RPE scale as developed by Borg in 1970 is the most frequently used measurement of subjective reactions during physical work performance (Gamberale, 1985). This scale, presented in quarto format, was developed on the basis of empirical data from work on the bicycle ergometer and includes 15 points (6 through to 20) as shown in Figure 5 (Kinsman and Weiser, 1976):

6	
7	Very, very light
8	
9	Very light
10	
11	Fairly light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Very, very hard
20	

Figure 5: The Rating Scale developed by Borg in 1970 for Perceived exertion (from: Gamberale, 1985).

This is an ordinal scale where numbers are assigned according to the order of magnitude for an attribute. There is no true zero point and intervals on the scale are not necessarily equidistant, but are made to appear so by careful selection of verbal descriptions at equal intervals (Kinsman and Weinser, 1976). The basic assumption of such rating scales is that the individual is able to accurately match his perceptions with the corresponding numbers, by indicating a number equivalent to the perceived workload in relation to the immediately preceeding load. Empirical studies have shown that individuals are able to perform this task (Gamberale, 1985).

Hogan *et al.* (1980) outline various studies that highlight the reliability of the Borg RPE scale and its validity with respect to its significant relationship with variables such as heart rate, oxygen consumption and work performance output. The RPE scale is currently constructed so that the heart rate of normal, healthy, young-to-middle-aged people (25 - 45 years) working at moderate to high intensity levels can be predicted in a linear manner as 10 times the RPE value (Kinsman and Weisner, 1976; Gamberale, 1985). However, there are specific circumstances wherein the relationship between heart rate and RPE can be altered. In a study by Pandolf *et al.* (1972), changes in temperature affected heart rate but not RPE, and Gamberale and Holmer (1977) found similar results in simulated work with high heat stress, whereby the heat load was described as having an impact on perceived exertion that was not comparable to the physiological strain it produced. Gamberale (1985) outlines various investigations that reveal that the relationship between RPE and heart rate is highly dependent on the type of physical work involved. Nevertheless, as Gamberale concludes (1985), the RPE scale is valid and versatile and under given circumstances and conditions provides a reliable means of quantifying subjective perception of the physical demands of given tasks.

Fleishman *et al.* (1984) conducted a series of studies in order to examine the reliability and validity of an index of perceived physical effort (based on Borg's RPE scale) in assessing energy expenditure (usually expressed as a respiratory, metabolic or cardiovascular variable) and ergonomic costs (due to work output variables of motions used, time elapsed, weight, distances, frequencies and amount of material handled) of task performance. The work of Hogan *et al.* (1980) and Fleishman *et al.* (1984) examined how accurately individuals could perceive information about the actual physical costs of performing work in relation to objective measures of the physiological costs of that same work.

In physically demanding work, the physical capabilities of the individuals, and their psychological perceptions of both their capabilities and the demands of the job, constantly interact. Essentially, the physical demands of a job influence the individual's motivation, fatigue and satisfaction, while the individual uses these psychological factors to regulate physiological work rate (Fleishman *et al.*, 1984). Two basic factors contribute to the perception of exertion during physical work, namely a local factor (i.e. proprioceptive feelings of strain in the working muscles and/or joints) and a central factor (i.e. sensations from the cardiorespiratory systems) (Pandolf, 1975; Borg, 1978). In most instances peripheral input predominates over central cues, although it has been shown that pronounced central cues may dominate the perception of exertion (Carton and Rhodes, 1985). Other contributory factors are motivation and actual task demands and characteristics. Borg (1978) states that when studying subjective aspects of physical load in natural industrial situations, emotional and experiential factors become more important. Sensory aspects of the work task are essential for the experience, but they have to be complemented by factors related to how the individual evaluates the work in it's total social and physical working environmental settings (Borg, 1978).

It has been intimated (Hogan *et al.*, 1980) that subjective reports or estimates with respect to psychological perceptions required for physical work may be used as a component of job-analysis methodology. They could be used as a means of describing work structures, and in order to match the capacities of individuals, as they perceive them to be, to job requirements. This is based on the work by Hogan *et al.* (1980) and Fleishman *et al.* (1984) who demonstrated that individuals could reliably rate the amount of physical effort required to perform familiar tasks, and that these ratings accurately reflected metabolic costs of task performance. This work was based on a 7-point perceived physical effort scale, derived from Borg's 15-point scale, which provides a reliable and valid assessment device for predicting work costs. The results indicate that task ratings of perceived physical effort were highly related to metabolic costs, ergonomic costs and rating of physical abilities in task performance (Hogan *et al.*, 1980). No differences in ratings were found to be attributable to age, sex or occupational experience.

Results of the investigations of Ulmer *et al.* (1975) confirm the linearity and reproducibility of the RPE scale (Habes *et al.*, 1985), as well as finding a close correlation between RPE scores and the parameters of strain (heart rate) and stress (work load). Costa and Gafurri (1975) studied the relationship between RPE and shift work and found that RPE values were higher at night than during the day and apparently not influenced by heart rate which is lower at night than during the day, whether at rest or working. During the same study it was found that high volumes of noise produced by a motor, which can cause harmful auditory and extra-auditory effects, did not seem to influence perceptions of the physical work performed (Costa and Gafurri, 1975).

Ratings of perceived exertion have frequently been used during investigation of lifting MMH tasks for the evaluation of certain aspects of each particular task. Nicholson and Legg (1986) conducted a study of the effects of load and frequency on a selection of workloads in repetitive lifting. When the subjects worked with selected workloads for 1 hour, the work intensity was subjectively assessed as 'Fairly Light' (10.5 - 11.6) using the Borg RPE scale. RPE is often interpreted as a 'summing up' of the influence from all structures under stress during exercise (Ljungberg *et al.*, 1982). Estimates of perceived exertion (RPE) made after 4 and 13 minutes of work respectively showed significant increases, even when the weight was the same and there were no substantial differences in physiological variables (Ljungberg *et al.*, 1982). They go on to report that the subject probably fails to attain a steady state, in a perceptual sense, while performing the selected horizontal lifting tasks used. Therefore time can be assumed to be a limiting factor to performance, whereby working with the same weight induces a sense of increasing exertion over time, with no actual changes in the initial task demands.

Mital (1983) investigated one-handed lifting tasks with three loads (2.27, 4.54 and 6.84 kg) and reported that localised fatigue was generated in the back, shoulders and arms which was reflected in the RPE values. The RPE ratings were found to increase significantly ($p < 0.01$) with both load and time.

Overall, the particular tasks performed were perceived as 'Somewhat Hard' (13) at the end of the work period of 2 hours, when shoulder and arm fatigue were considered. Here the RPE values ranged from 'Very Light' (8) to 'Somewhat Hard' (13), with the average heart rate not equivalent to 10 times the RPE value. Looking in particular at the RPE values pertaining to the back, shoulder and arms, the values increased significantly with load and time for both males and females (Figure 6).

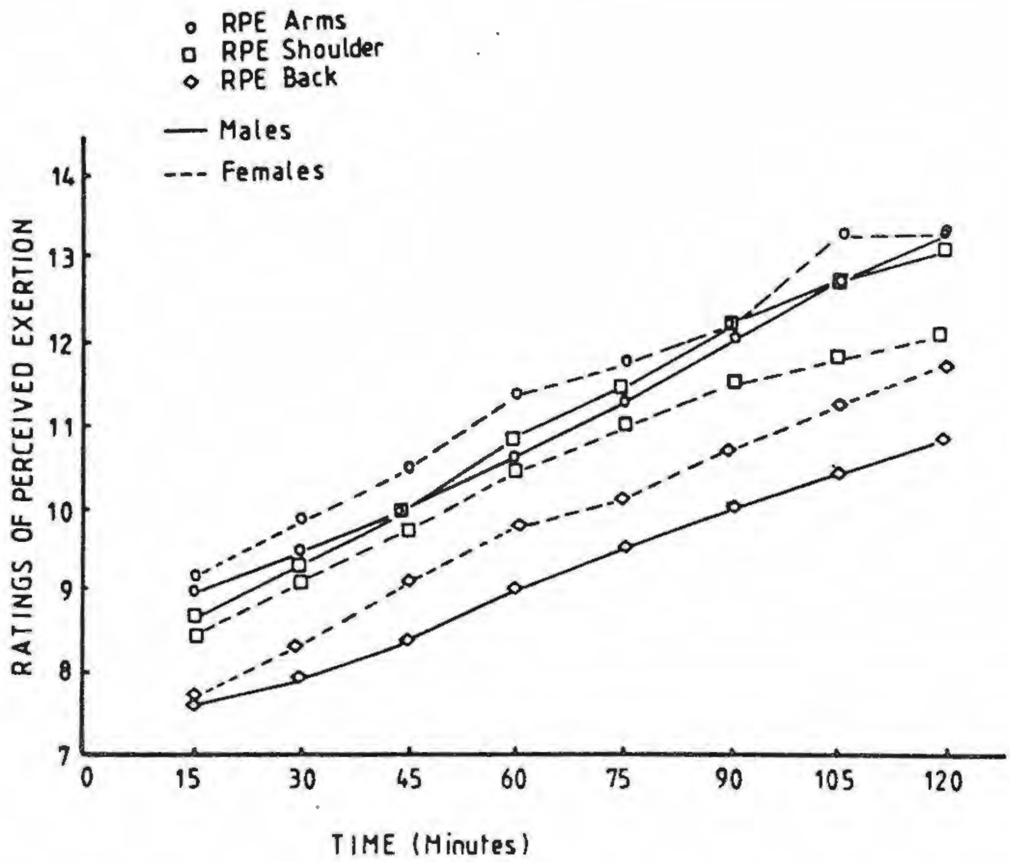


Figure 6: Variations of RPE for back, shoulder and arms with time for males and females during one-handed horizontal lifting (from: Mital, 1983b p. 570).

Comparing the male and female responses, the males indicated that the standing posture was more demanding on the back and arms, whereas the females perceived it to be more demanding on the shoulders. Females also considered reach distance to influence the exertion experienced in both back (significantly more strenuous, $p<0.01$) and shoulders (only slightly demanding,

$p<0.01$), and only load and time had a significant effect on their RPE values for arms ($p<0.01$). For both males and females the perceived exertion of the arm during one-handed horizontal lifting ranged from very light at the beginning of exercise to somewhat hard at the end of the activity.

In looking at the affect of task height and handle position on RPE in a holding task (containers' masses of 9 and 13 kg), Deeb *et al.* (1985) found that the positions 3/8 and 6/8 resulted in lower RPE values than all other positions (with waist height being optimal with respect to perceived effort) and floor level yielded the highest RPE values (see Figure 7). Correspondingly, body part discomfort among subjects was lowest in both frequency and severity at waist level. When citing severity of body discomfort during holding, the four worst sites were the lower-back (worst), mid-back, upper-back and shoulders. Buttocks, thighs and legs were only stressed at floor level due to the squatting posture required. It must be noted that the symmetrical positions (2/2 and 8/8) minimise hand forces and are optimal with heavy weights and during lifting (Deeb *et al.*, 1985).

Habes *et al.* (1985) found similar results to those of Mital (1983b) and Deeb *et al.* (1985). Subjects perceived most fatigue when required to lift an object to eye-level height (RPE of 16.4). The weight factor, even at 80% of maximal voluntary contraction, was not perceived to be as fatiguing as the height factor (RPE of 13.5). The perceived fatigue for the full reach variable fell between the values for the two weight condition(40% and 80% MVC), when the average RPE value was 12.3. Legg and Myles (1981) provide supportive data for the fact that, as load increases so the work intensity is perceived to be more difficult, with fairly constant RPE values over a relatively short work period (30 minutes).

GENERAL CONCLUSION

Due to the potential mismatch that may prevail between job requirements (task and container characteristics, workplace design and layout) and individual capabilities (worker characteristics such as age and sex, musculoskeletal strength, biomechanical, physiological and psychophysical tolerance to stress), numerous industrial MMH tasks could be hazardous, and ultimately injurious to the worker. Lower back pain has been implicated as one of the most frequent causes of temporary or permanent decrease in the working capacity of an individual (Andersson, 1981). This and other workplace-related overexertion injuries, occurs as a result of individuals continually handling loads (lifting, lowering, pushing, pulling, holding, carrying and walking) that result in sprains and muscular strains, the effects of which may be traumatic or cumulative (wear and tear on the intervertebral discs resulting in back pain).

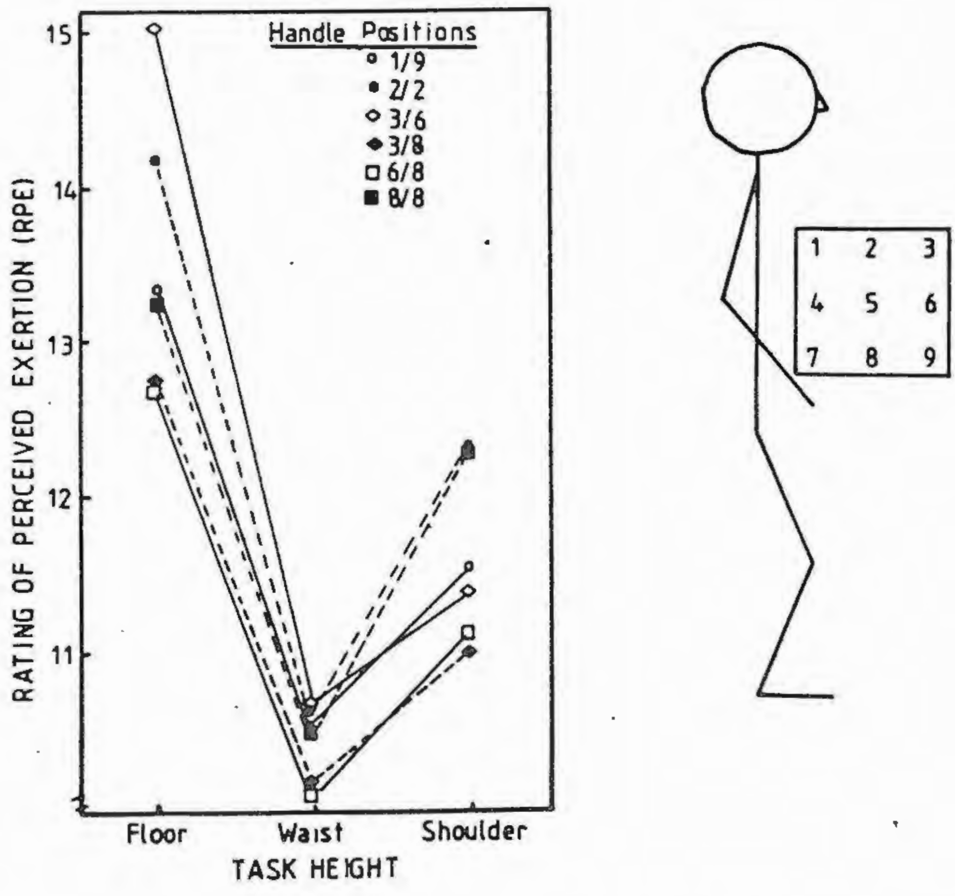


Figure 7: Effect of task height and handle position on RPE (Modified from: Deeb *et al.*, 1985 p.757).

There is a need to identify an approach for the reduction of the injuries that occur during MMH activities which constitute a major requirement in many third world occupations. A primary goal of management should be the health and welfare of the workers. In the past, work accidents have been considered as inevitable, but workers are a vital component in the economic and social development of the community and their health is therefore important (Nordin, 1987). This is particulary true for the developing, third world nations that are striving for economic growth and recognition world-wide. Where care is taken to ensure the safety of the workforce, employees would inevitably be more motivated, have greater job satisfaction, less absenteeism and achieve better productivity levels and standards.

A multi-disciplinary and cooperational approach between science and industry is required to increase individual worker and managerial awareness of the impact of workplace injuries. In this light it is necessary that the need is met for the exchange of prevention data and techniques between industry and scientists, and between developed and developing countries on a practical level (Nordin, 1987). Research in American and North European countries has led to the development of many models which provide a means of predicting theoretically the outcome of a particular situation and which help in the attempts to enhance our understanding of human behaviour and its limits. There is, however, no one set guideline that is wholly applicable to all situations, and it is important to be cognizant of the fact, when working with a model, that any interpretations made are specific to the situation at hand. Models generally enable the researcher to work with hypothetical values in order to achieve an optimal state of affairs. Nevertheless, what is optimal in one situation may not necessarily be so in another. If a model proves to be adaptable across cultures, then its value and importance is great in terms of transference of preventative data and techniques for reducing work-related injuries from one nation to another. There is still a great deal of work to be carried out in an ever-expanding field of research and this is merely the beginning.

CHAPTER III

EXPERIMENTAL METHODS AND PROCEDURES

INTRODUCTION

There is wide scope for research into the development of guidelines for safe lifting practices within the South African industrial setting. High priorities should be given to the special needs of vulnerable and high-risk groups, within the working population (Jardel, 1987). A multidisciplinary approach is required to increase the awareness of the impact of workplace injuries among individuals, communities, industries and governments, alike. This may be achieved by bringing together industry and scientific research groups and exploring the transfer of practical prevention means from developed to developing countries (Ferrara and Nordin, 1987). In other words, it is of vital importance that there be an exchange of prevention data and techniques between industry and scientists, and between developed and developing nations, on a practical level (Nordin, 1987).

A great deal of research has been carried out in the field of manual materials handling (MMH) in North American and European countries, whereby models have been developed to assess the physical demands of various tasks as imposed by the dimensions of the task such as frequency and duration of lift, height of lift, and mass and size of the container. The concept of fitting the task to the man, an ergonomical approach, is still relatively new in South Africa, and requires further investigation. As stated previously, it was the aim of this analysis to assess, *in situ* (within a SA industry), the extent of suitability of these task variables to the workers' capabilities. The NIOSH model ultimately interprets the suitability of task demands by recommending load mass to lift, based on the various task factors affecting performance. Assessment was therefore based on the recommended load mass of lift as established by the model for each given task situation, taking into account external factors where necessary, and comparing the recommended load mass to actual masses lifted.

WORKSITES

Two shopping centre Supermarkets for fast-moving groceries in an Eastern Cape City, labelled W1 and W2 for ease of reference and confidentiality, agreed to be testing sites for the purposes of this study. The on-site personnel in the relevant working area (the Bulkstore storage section) became the *in situ* industrial subjects whose performance was analysed. Prior to any data collection in the field, the manager was requested to complete and sign an informed consent form (Appendix C). This form was explained as waiving any legal recourse against the researcher or Rhodes University. Participation as a subject was entirely voluntary and the subjects had the liberty to withdraw from the study at any time and for any reason. It must, however, be pointed out that an observational methodology was selected for data collection, and therefore performance of the individuals in the field was disrupted as little as possible. Direct measurements were taken and when necessary, black and white photographic prints and slides were taken of the individuals performing their tasks.

Due to the size of the worksite area at W1 data regarding specific task characteristics such as container dimensions, shelf heights and worksite layout could be collected as rapidly and as unobtrusively as possible. Such data could be collected without interfering with the Bulkstore assistants who were working in other sections of the bulkstore. A comprehensive data collection sheet was developed for this purpose which is presented in Appendix F with all of the data collected.

Verification of similarity of worksites W1 and W2

The two worksites (W1 and W2) were visited on separate occasions, and from direct observation it appeared that the working situations were similar. In order to justify this observation, shelf layout was recorded and containers were selected at random from W1 and W2 and measurements of their mass (Kg) and dimensions (cm) recorded. Table II outlines the eleven corresponding containers (same brand and content) from the two supermarkets, detailing all dimensions and shelf site.

Table II: Random Sampling of Containers from Supermarkets W1 and W2.

ITEM	PACK-ING	STORE	SHELF	CONTAINER DIMENSIONS LENGTH (cm)	WIDTH (cm)	HEIGHT (cm)	VOLUME (cm3)	MASS (Kg)
Ricoffy	OP	W1	2	54	40	20	43200	13
		W2	1&2	53	38	18	36252	13
Comfort	C	W1	1	46	32	32	47104	20
		W2	1	46	31	33	47058	20
G/C/F	C	W1	2	57	34	30	58140	21
		W2	1	57	36	30	61560	21
Omo	C	W1	1&2	57	34	29	56202	22
		W2	1	57	33	30	56430	22
Punch	C	W1	3	59	36	30	63720	22
		W2	1	57	33	30	56430	22
Vim	OP	W1	1	51	31	20	31620	23
		W2	1	51	32	20	32640	23
Domestos	OP	W1	1	47	40	27	50760	23
		W2	1	47	40	27	50760	23
Frisco	OP	W1	1	54	40	20	43200	13
		W2	2&3	54	40	20	43200	13
Kellogs	C	W1	2&4	62	57	44	155496	16
		W2	1	61	55	44	147620	16
Oros	C	W1	1	35	24	26	21840	15
		W2	1&3	35	25	26	22750	15
Sardines	C	W1	1	31	23	23	16399	13
		W2	1	30	23	23	15870	13

Where: OP = Open Packaging (Cardboard base, plastic covering)
C = Cardboard Carton/Box

Subsequently, analysis by Student's t-test was conducted using the volume (cm^3) of the containers, and it was esablished that there were no significant differences ($p < 0.05$) in the size of the containers from the two supermarkets. As can be seen from Table III, there were no differences in mass (kg) for each respective container from W1 and W2.

As the shelving units indicated the height to which the containers were lifted, the shelf heights were measured and were 22, 121 and 220 cm from W1 and 24, 118 and 192 cm from W2 respectively. A t-test calculation revealed no significant differences ($p < 0.05$) between these shelf heights.

In general W1 had a larger, more organised working and storage area. W2, on the other hand, was substantially smaller in overall size (although shelving layout and containers handled were similar) and had the added assistance of a roller-belt along which the containers were pulled/pushed from the truck-end to an off-loading area within the storage section of the department. It was therefore concluded that due to the similarity of the two working areas, with respect to cartons handled, heights lifted, and storage layout, and due to the relative inaccessability of W2 for in-depth data collection, W1 would be evaluated further by analysing selected MMH activities that were performed in the storage section of W1.

WORKING CONDITIONS

Manual labour still has a significant role to play in industry, particularly in developing countries, and in situations where storerooms operate on a vastly smaller scale than warehouses where mechanical assistance is more easily accessible. Factors that may affect performance fall into the two basic categories of physical and psychosocial factors, both of which were considered in the present study in order to obtain an overall perspective of the situation.

Physical factors

The ambient temperature on the days of data collection averaged minimum 8°C and maximum 25°C. There were no extreme and varying temperatures which could influence the performance of the workers in one way or another. The relatively constant, cool environment within which the manual labour was performed was deemed suitable, and in no way uncomfortable.

Lighting and ventilation were good, when considering that the Bulkstoremen were working indoors for the majority of the day, in a storeroom that had no windows and consequently little natural light.

As is usually the case for smaller operations, the storage space at W1 was maximised by narrow aisles and shelving units built up to the ceiling. The particular layout for the major worksite (W1) studied is detailed in Figure 8. The trolleys could only be pushed/pulled along the main corridor (labelled A) as the aisles between shelves were too narrow for laden trolleys.

The only mechanical aids evident in W1 were the jack lifts on wheels (to aid in the transportation of the pallets loaded with containers from the Receivings section to the check-in in area of the Bulkstores), and the trolleys to transfer the containers from the pallets to the shelves. Ladders were also used to enable the Bulkstoremen to climb to the higher shelves.

Human assistance and `teamwork' was generally prevalent in situations where mechanical aids were not available or where there was insufficient space within which to use them, and at times where consignments were deemed too large for one individual to handle. In such instances, 'human chains' were formed and containers passed rapidly from one individual to another until the entire consignment was placed in storage. Rest periods were taken when needed.

<u>Psychosocial factors</u>

Job satisfaction is an important motivational factor in any working situation, and inherent in job satisfaction is how the individuals perceive the demands placed upon them. If they feel that they are being worked beyond their capacities, or simply 'too hard', then job satisfaction could be affected, and ultimately task performance. Consequently, it was deemed necessary to record the subjective perceptions of the demands placed upon them by the tasks performed (as outlined in detail under Ratings of Perceived Exertion). They were also requested to rate the extent of fatigue or pain felt in self-selected parts of their bodies after a days' manual work in the Bulkstores.

An observation was also made of the general working ambience of the Bulkstoremen, competition among peers, and communications with managerial staff.

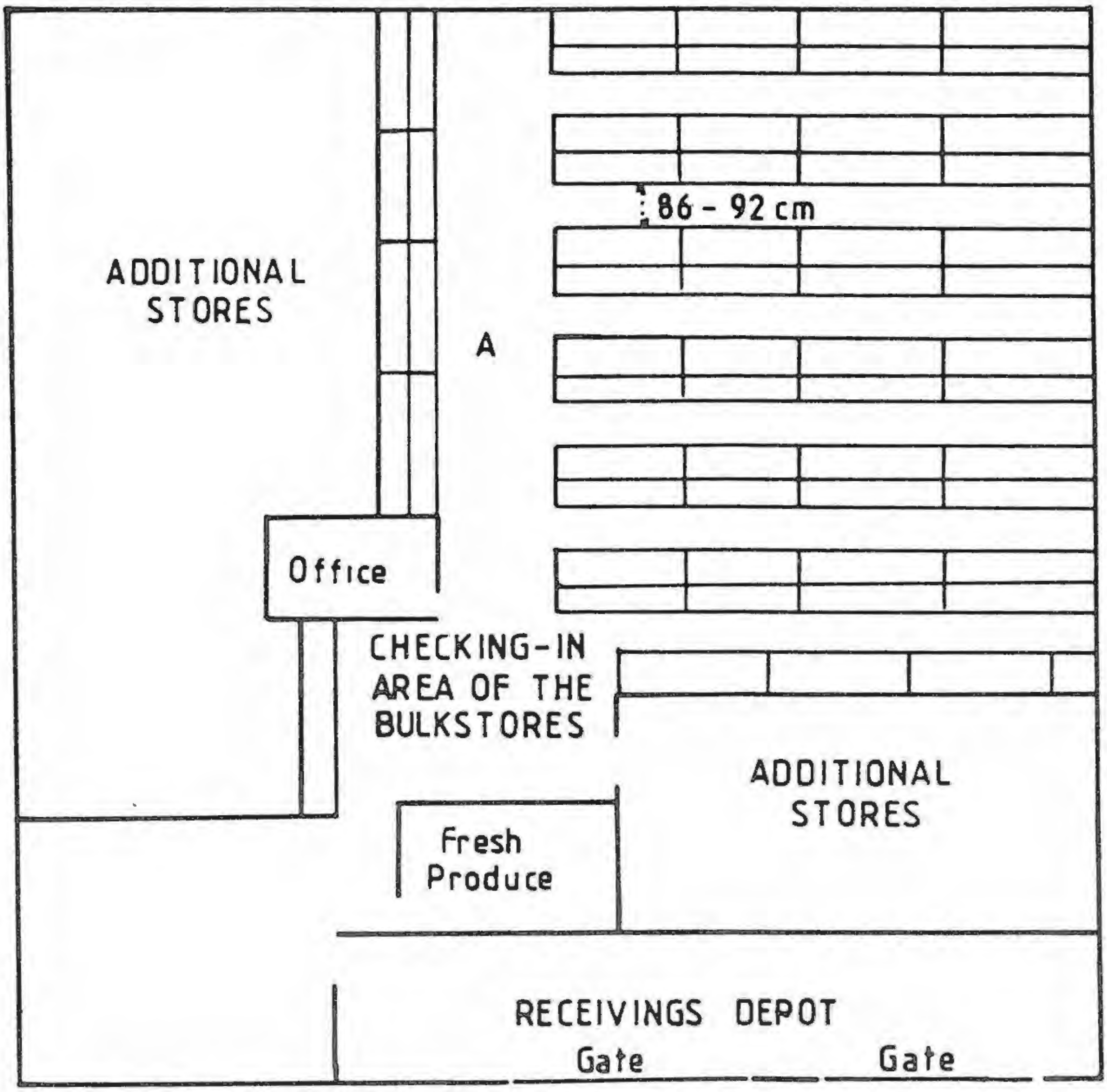


Figure 8: Schematic of Storage and layout facilities at W1 Shelves (in rows of 4 x 2 Standard Shelving Units)

TASK ANALYSIS

Task analysis refers to a detailed break-down of the components of a task or job into workable units or sub-tasks, for evaluation and determination of their relationships. There are many frames of reference that may be adhered to, depending on the nature and requirements of the assessment, such as a particular characteristic, or a string of events, forces involved, type of postures assumed. In other words, task analysis is defined by the requirements of the evaluation, and is specific to the particular area of study.

Analysis of the tasks performed at W1 took the form of being:

QUALITATIVE: by identifying all the tasks performed by the relevant individuals

QUANTITATIVE: whereby the time spent on each respective task was quantified, with respect to the qualified personnel (Bulkstoremen) working at their 'normal pace' using a definite and prescribed method. In such a case, the task was quantified in terms of absolute duration in minutes and/or hours, and as a percentage of the total working hours for the day/shift.

The first step undertaken in this particular task evaluation was to identify the most important aspects of the task. Due to the fact that there were so many tasks within the Supermarket, a form of task analysis methodology similar to that described by Celentano and Nottrodt (1984) was used. These investigators revealed that tasks could be categorised according to the common task elements of lifting, lowering, carrying, pushing, pulling and others, within a single trade. As a result, the manual material handling task elements of lifting containers was chosen for investigation. The appropriate NIOSH mathematical model was used for the analysis and assessment of the extent and suitability of the physical demands that the lifting task elements (frequency, duration, mass of load, height of lift) imposed on the workers.

Subsequent to communication with the Subject Matter Expert (SME), identified as the managerial member of staff in charge, and following direct observation of the workers/industrial subjects activities, it was established that the daily representative task for the Bulkstoremen was off-loading goods, by lifting or lowering, from the pallets and trolleys onto the shelves. In order for adequate data to be collected, for ease of analysis, and due to the specific requirements of the NIOSH model, respective sub-tasks of the lifting MMH lifting task were identified for analysis.

One of the criteria of the NIOSH model states that lifting be smooth with little sustained exertion. Therefore, the lifting task was broken down into it's constituent sub-tasks as follows:

> Where an object was lifted from the pallet/trolley to waist height or shoulder height (lifting sub-task 1), held in that position momentarily and/or carried a short distance (holding and carrying sub-task) then lifted onto a shelf (lifting sub-task 2). One MMH task of transferring a carton from A to B involved two lifting sub-tasks, and one holding and carrying sub-task.

The overall process adopted for this particular research is outlined in Figure 9, which indicates that the first step in the assessment process was to identify the representative occupational lifting/lowering MMH tasks relative to the occupation of the target workforce. The criteria determining whether or not a task was representative, for the purposes of this research included:

- that the task was performed frequently, as justified through the Activity and Time analysis

- that the workload requirements of a single person could be easily determined

- that the tasks required minimal use of the mechanical aids present in the Bulkstore area

- that the task was representative of the average physical demand of a Commercial Warehouse workforce

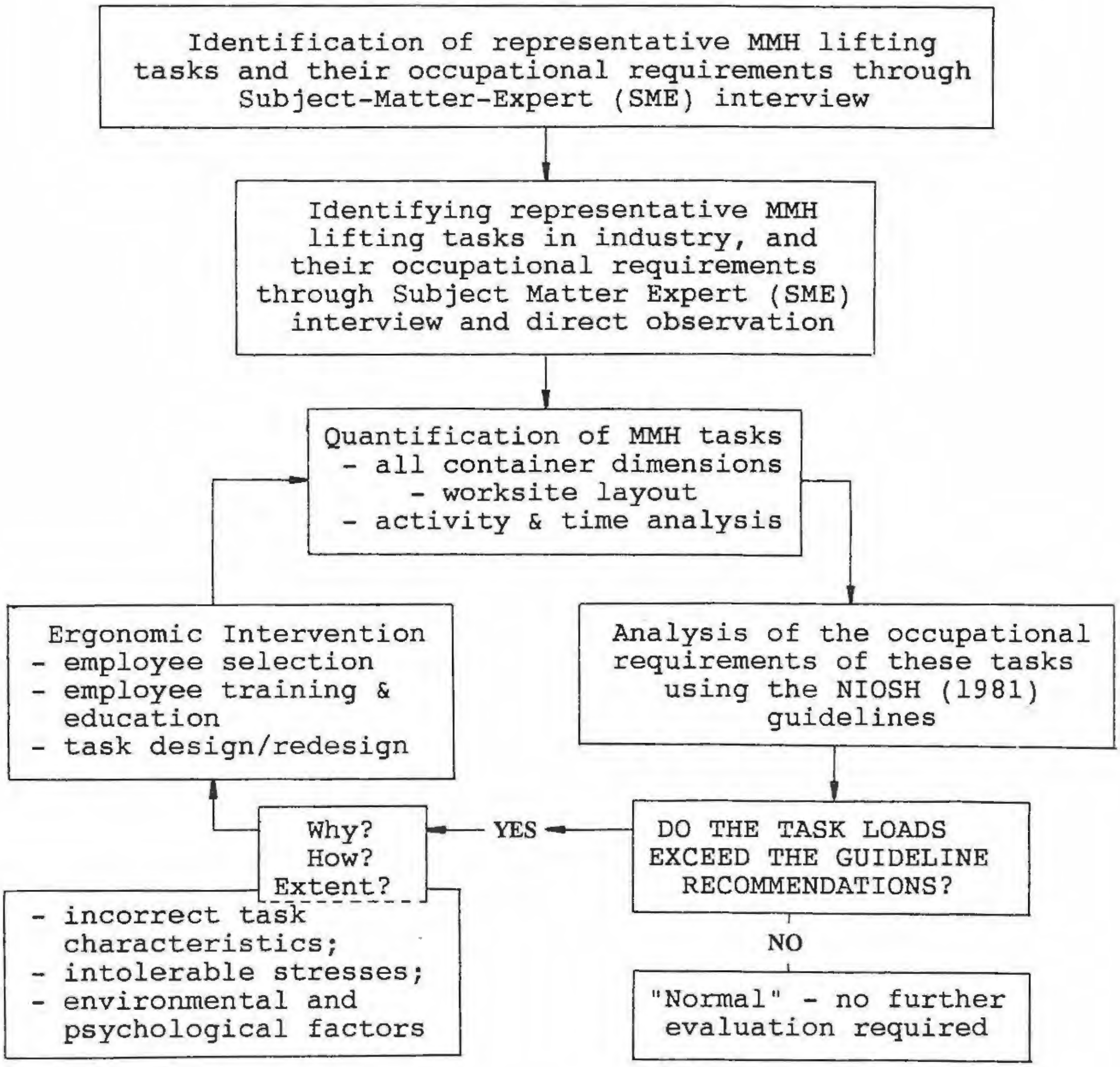


Figure 9: Stages in the objective identification and assessment of the physical demands of lifting Manual Materials Handling (MMH) tasks in Industry.

- that the task involved a high percentage of personnel within the worksite area. There were three men assigned as Bulkstore Assistants, whose job it was to check-in and transfer the goods from the incoming pallets to the shelves for storage. Others within the worksite area, were designated as 'shelf-fillers', who retrieved goods from the shelves and transported them to the sales are for restocking of those shelves.

The information pertaining to the tasks performed was obtained from personnel at the worksite, and managerial staff during a Subject-Matter-Expert (SME) interview. The purpose of such an interview was three-fold. Firstly, there was a need to subjectively identify and quantify the representative MMH tasks for the particular trade, as outlined above. Secondly, a general task description was required, to ensure that the task characteristics were such that they could be considered as appropriate job requirements in similar occupations throughout South Africa. Thirdly, the work-site area had to be evaluated in terms of accessibility for data collection.

Once the representative tasks had been identified, lifting sub-tasks were selected that, for the most part, satisfied the following guideline criteria (NIOSH, 1981):

- that the object was of known mass and size, with a moderate width of 75cm
- that lifting was smooth, with little sustained exertion
- that the lift was two-handed and symmetrical in the sagittal plane
- that lifting posture was unrestricted
- that there were good couplings ie: handles, shoes and floor surfaces
- that the lift or lower was unaided ie: no mechanical aids.

It was further assumed that the workforce was in reasonably good physical condition, and that when not lifting the individuals were at rest, or performing some other less physically demanding task (for example stock-taking, sweeping).

THE LIFE-CYCLE OF A CONTAINER AT W1

All container consignments arrived at the Receivings Depot of W1, and were off-loaded manually from the incoming trucks onto the pallets. These pallets of goods remained in the Receivings area until all ordered goods were accounted for. Subsequently, the pallets were pushed/pulled with the aid of hydraulic jacks on wheels to the Bulkstore storage area, where all containers were checked for a second time and price marked (mainly by Subject 2, with occasional assistance from Subjects 1 and 3). The containers were subsequently transferred manually from pallet to trolley (by all three subjects) for access to the shelving units. The aisles were too narrow for pallet access.

Once a trolley was loaded, the Bulkstoremen (mainly Subjects 1 and 3) pushed/pulled it to the designated shelving unit, and lifted/lowered the goods from the trolley to the shelf. The shelf in the Bulkstores was regarded as the final destination of the containers for the purposes of this research. Ultimately, workers designated as 'Shelf-Fillers' retrieved containers from the shelves by lowering them onto the trolley, opened them and price-marked each individual commodity stored within. Opened containers for restocking the shelves were then transported on the trolleys via lift, or carried up the stairs, to the sales area whereupon the 'Shelf-fillers' refilled or restocked the relevant shelves. This constituted the final breakdown of the complete container into it's component parts.

CHOICE OF SUBJECTS AND PERSONAL INFORMATION

The subjects in the present study were those individuals who were involved in the representative tasks identified during the SME interview, namely the Bulkstore Assistants at W1. Overall, data were collected on three male Bulkstoremen, who accounted for the required high percentage of personnel within the selected worksite area, as they were the individuals primarily involved in tasks within the bulkstores. As can be seen from Table III, the subjects (S1, S2 and S3) had an average age of 34 ± 8.5 years, mass of 73.6 ± 5.5 Kg and stature of 176 ± 2.2

cm. Further worker physical attributes obtained were reach height (an average of 205 ± 3.3 cm to the palm of the hand as when holding a carton at full reach); shoulder height (average of 146 ± 1.6 cm); waist height (average of 100 ± 7.1 cm); and knuckle height (average of 77.7 ± 1.7 cm). It must be noted that these were the only experienced employees who routinely performed their work according to the job description, working at a normal pace, and who were selected for measurement during job evaluation. This ensured that the job description was accurate.

Table III: Age and Morphological Characteristics of the Subjects

	Subjects					
Variable	S1	S2	S3	Ave	sd	Range
Age (yrs)	27.0	29.0	46.0	34.0	8.5	20.0
Mass (kg)	73.5	67.0	80.5	73.6	5.5	14.5
Stature (cm)	174.0	175.0	179.0	176.0	2.2	6.0
Reach Ht (cm)	200.0	207.0	207.0	205.0	3.3	8.0
Shoulder Ht (cm)	146.0	144.0	148.0	146.0	1.6	5.0
Waist Ht (cm)	95.0	95.0	110.0	100.0	7.1	16.0
Knuckle Ht (cm)	77.0	76.0	80.0	77.7	1.7	5.0

(Subjects S1 and S3 performed the majority of tasks analysed)

The terms subject, industrial subject, worker and bulkstoremen are interchanged freely throughout this text, as they all describe the same individuals who performed the tasks analysed. Each subject was assigned a code number for ease of data recording, reduction, and most importantly, for confidentiality. The subjects' morphological characteristics were recorded *in situ* together with age and sex. The subjects were also asked whether they suffered any type of disability or pain at the end of a routine working day, that may have had the cumulative effect of interfering with the efficiency of their daily work. Here the subjects demarcated sites on a diagram of a man (see Appendix E for a Sample data sheet), and rated the severity of the fatigue or pain felt in each designated area using the RPE scale. Subjects were observed during task performance *in situ* and the relevant information recorded.

RATINGS OF PERCEIVED EXERTION (RPE)

"It has become apparent that an individual's perception and subsequent verbalization of work cost represents an excellent means of assessing the demands of vigorous physical activity" (Morgan, 1975). This is, however, dependent on the subjects understanding of the concept of perceived exertion and assigning a value to what they are feeling.

Subjective estimates of the general effort expenditure during a given MMH task task were quantified *in situ* using the standard 15-grade RPE scale (Figure 5) as developed by Borg (1970). The standard instructions were modified in order that the workers understood the concept of rating, on a scale, a 'perception' of the demands that were imposed by the particular tasks they performed. It was necessary to explain that a rating of 6 applied to simply standing doing nothing physically active, and 20 related to the inability to perform more work or lifting tasks at that particular time due to physical exhaustion or pain. It is also essential to point out that great value was placed by the workers on the verbalisations of the rating scale (i.e.'very, very light' to 'very, very hard').

When requested to rate a particular task, each worker responded by pointing to the rating of his choice. This value was recorded after verbal confirmation by the investigator to prevent inaccuracy in data recording. Previous experience revealed that during exercise a hasty indication on the scale could be easily misinterpreted.

Ratings were taken at random throughout the data collection period so as not to interfere with task performance by requesting a rating after every task performed (i.e. when each trolley was off-loaded). This was essentially due to the fact that RPE did not form the basis of this research, but was used to enhance the interpretations and analysis of task performance of the Bulkstoremen in Worksite 1.

COMPUTER SOFTWARE PACKAGES

The primary computer software package to be used for data reduction was that developed by the Lotus Development Corporation. The Lotus 1-2-3 package may be described as a vast electronic worksheet, with database handling facilities, as well as state-of-the-art graphics. It is one of several packages allowing for systematic data manipulation and analysis, enabling presentable data layout and storage.

The NIOSH lifting model, developed into a computer software package for quick and easy data manipulation and analysis based on the formulae presented by NIOSH (1981), was used to evaluate the physical demands of certain lifting/lowering MMH tasks in relation to norms established for other industrial populations. This model has been scientifically established, and although no one particular guideline is applicable to all MMH situations the "Work Practices Guide to Manual Lifting" (NIOSH, 1981) has been used in the analysis of many different lifting and lowering tasks (Drury *et al.*, 1982; Garg *et al.*, 1983; Liles *et al.*, 1983; Celentano and Nottrodt, 1984; Garg and Badger, 1986).

NIOSH LIFTING MODEL

In the development of the NIOSH lifting model, four major domains were considered (epidemiological, biomechanical, physiological and psycho-physical), constituting the data which is used to define the two lifting limits known as the Action Limit (AL - reflecting the lifting capabilities of 75% of females and 99% of males), and the Maximal Permissible Limit (MPL - fewer than 1% of females and 25% of males). These values inherantly apply to the North American and European sample populations used during establishment of the model norms. However, the limits determine the potential hazards associated with a particular situation when compared to the actual load requirement of a particular task (Celentano and

Nottrodt, 1984; Nottrodt, 1986a), and provide guidelines for safe lifting practices for both occasional and frequent lifts.

The model used to calculate the recommended load limits is given by the following equation:

$$AL = 40 (15/h)(1 - 0.004 [V - 75])(0.7 + 7.5/D)(1 - F/F max),$$

Where: 1. AL is in kilograms;

2. V = the vertical location of the hands at the origin of lift (in cm). Assumed to be between 0 cm and 175 cm and representing the range of vertical reach for most people;
3. H = the horizontal location of the hands forward of the mid-point between the ankles at the origin of lift (in cm). Assumed to be between 15 cm (closer would result in interference with the body), and 80 cm (beyond which objects cannot be reached by most people);
4. D = the vertical travel distance from the origin to destination of lift (in cm). Assumed between 25 cm and (200 - V) cm. D is set at 25 cm for all distances less than 25cm;
5. F = the frequency of lifting in lifts per minute, assumed between .2 (one lift every 5 minutes) and F_{max} (F is set at 0 for lifting less frequently than once per 5 minutes); and,
6. F_{max} is the maximum frequency that may be sustained over the specified duration of task performance.

The Maximal Permissible Limit (MPL) is three times the AL.

According to the guidelines, if the actual load is:

- below the AL, then the lift is considered to represent nominal risk, and represents an acceptable demand for the majority of industrial workers

- between the AL and MPL, then the lift should be viewed as being unacceptable without administrative (employee screening, selection, education and training) or engineering (mechanical aids or task redesign) controls

- above the MPL, then the lift should be considered to be unacceptable, and only engineering controls can be used to reduce the risk of injury to acceptable levels.

Due to the large individual variability in risk of injury and lifting performance capability, controls need to be of both an engineering and administrative nature (NIOSH, 1981). According to NIOSH (1981), the Maximum Permissible Limit (MPL) is based on the following principles:

> Musculoskeletal injury rates and severity rates have been shown to increase significantly in populations when work is performed above the MPL.
>
> Biomechanical compression forces on the L5/S1 disc are not tolerable over 650 kg (1430 lb) in most workers. This would result from conditions above the MPL.
>
> Metabolic rates would exceed 5.0 Kcal/minute for most individuals working above the MPL.
>
> Only about 25% of men and less than 1% of women workers have the muscular strength to be capable of performing work above the MPL.

However, based on the subjects used in the present study, who were relatively young, physically fit and healthy, and for whom manual labour constituted a major proportion of their daily occupation ensuring continual 'in-house' training (considering that South Africa is held to be a developing country), the guidelines were modified. If the actual load mass per task fell between the AL and MPL, then the lift was viewed as being acceptable and thus did not require administrative or engineering controls (Figure 10). The MPL was, for the purposes of this research, used as the cut-off limit for acceptable load mass. Any task or sub-task load masses falling above this calculated value were consequently regarded as unacceptable, and engineering and administrative controls were deemed necessary. In other words, the task required modification.

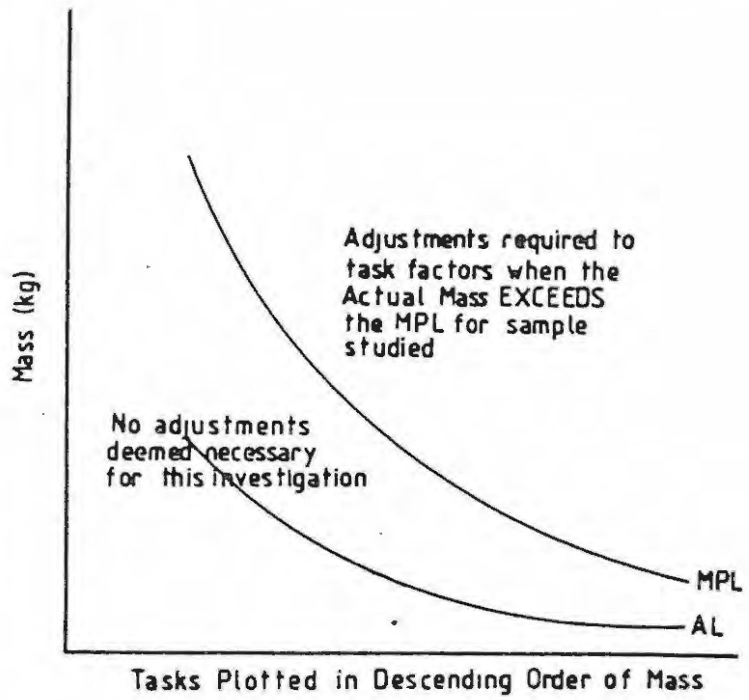


Figure 10: Schematic diagram of the MPL as the cut-off limit for the purposes of this study, based on the specific sample used.

For those tasks where the actual load mass of the container handled was above the recommended MPL for that particular task, the computer software package was designed to enable one to re-input data, and make the necessary hypothetical adjustments to the task performed. The data could be manipulated in such a way as to increase the MPL and bring the actual load mass to an 'acceptable' level. Such data manipulation was based on the four basic factors of the model (V, D, H and F). In other words, where the actual load mass was found to be unacceptable according to the guidelines, the four components of the model (H, V, D and F) were analyzed seperately where relevant, to identify appropriate solutions (NIOSH, 1981). As the NIOSH model computer programme calculated the recommended AL and MPL, it also established the suitability of the V, D, H and F components of task performance in terms of their numerical value distance from the value of 1; that factor furthest from 1 being the biggest discounting factor to performance. This relates to the immediate problem area requiring first consideration for modification, in order to hypothetically render the situation more suitable to the worker's capabilities (See Appendix E for two samples illustrating the discounting factors, task A3.1 with frequency and task D20.4 with the H-factor).

Initially the load limits of each of the vital stages of all tasks (identified by the sub-tasks) were calculated using the NIOSH software package. Subsequently, those cases in which lift frequency was greater than the Fmax value recommended by the model were modified by reducing the task frequency to the recommended Fmax value. In order to analyse the tasks further, a "worst-case" scenario was adopted. This was based on the fact that when the "worst-case/subtask" was modified to an acceptable situation (governed by the structure of the model) then all other sub-tasks for that particular task must also be acceptable.

In all there were 191 tasks of lifting cartons from the trolley to the shelf, which amounted to 1020 sub-tasks. The tasks were broken down into component sub-tasks based on the following assumptions:

- that the sequence undertaken when lifting containers to shelves 1 and 2 was that the cartons were lifted from trolley to waist height, whereupon the lift was halted as the cartons were held and carried (for a limited carrying element of no greater than eight natural walking strides) to the relevant shelving area for storage. Here the cartons were lifted from waist height onto the shelves.

- that when lifting cartons onto shelves 3 and 4 the cartons were lifted from trolley to shoulder height, carried and then lifted from shoulder height to full-reach whereupon a second worker (either on a ladder or standing astride the aisle on the higher shelves) retrieved the container and placed it on the shelf.

The relevant information for each of the 1020 sub-tasks was applied to the NIOSH computer model, and, in general, the "worst-case" was identified as lifting the cartons from the base of the trolley (at a height of 21 cm) to either waist or shoulder height (100cm and 146 cm respectively). Overall, 191 sub-tasks were identified, and those that had actual load mass above the MPL were hypothetically manipulated.

OBJECT DATA

In any "fast-moving" grocery store, the goods handled come in many assorted forms of packaging. Thus there was a need for some form of classification for ease of data collection and handling in the present study, and the items were classified into three major types:

- cartons (box-type containers made of cardboard) of which 185 were measured, accounting for 76.8% of containers handled within the Bulkstores of W1

- open packaging (containers with cardboard bottoms and plastic coverings) of which 40 were measured (16.6% of containers handled), and

- packets (plastic and paper, some of which could be termed cartons due to the firmness of their contents giving them a carton-like quality). 16 packets were measured (6.6% containers handled) of which 6 contained firm contents and were included in the analysis of containers handled

Due to the nature of this research, only cartons and carton-like containers were used, as specified in the NIOSH model guidelines. Based on the afore-mentioned method of classification, and the requirements of the NIOSH model, and prior to any other data being collected, all carton dimensions were measured and recorded in a standardised manner as follows:

- height (distance in centimeters from the top to the bottom of each container)

- width (distance in centimeters from side to side of each container)

- length, the distance from the front of the object which was generally labelled with the brand name and contents, to the back, measured in centimeters)

- content (solid or liquid), and

- mass (measured in kilograms): all containers were weighed for consistency in data collection, as the majority of goods had no gross mass printed on the outside of the carton, and those that did were reweighed on a standard portable scale and it was evident that the margins of error were different from one variety of goods to another.

A standard laboratory quality tape measure was used to measure the relevant distances on the containers, and an average was taken of three measurements for each dimension. This was due to the fact that some cartons were slightly distorted during transit and the average of three values lead to greater accuracy in measurements. A portable spring-scale was used to measure the masses of the containers. This could be taken up to the higher shelves in order to weigh cartons located there. This proved to be an easier method of data collection (i.e. taking the scale to the cartons rather than the cartons down to the scale), due to the lack of mechanical assistance to retrieve the cartons from the higher shelves and it avoided interfering with the work of the Bulkstoremen. This was a relatively time-consuming task, but accuracy was essential. All cartons had to be accounted for so that actual data collection during task performance could rely on an accurate data base of cartons and their dimensions. This in turn allowed for greater attention to be paid to the actual task performance of the workers during the activity and time analysis.

As the containers were generally assigned to the same shelf for storage (this being the final lift height of the object, when the carton dimensions were measured) it was recorded which shelf the containers were on. It was also noted whether there were handles on the containers and whether or not these were used by the workers when they manually handled the goods.

TASK DATA

As has been stated previously, the type of task analysed was delimited to two-handed lifting in the sagittal plane, based on Celentano and Nottrodt's (1974) task analysis, and the requirements of NIOSH. Consequently, the task data collected was basically defined by the measurements required for the NIOSH model. In each lift performed, the following measurements were required:

- The initial grasp and pick-up height of the object, measured from floor level to the hands, which was designated V for the purposes of NIOSH.

- The final 'put-down' height indicated the vertical travel distance of the object (D) from the origin to the destination of the lift.

- A third distance that was taken into account was the reach distance, or horizontal location (H) of the hands at the origin of lift, measured from the centre of gravity of the object to the centre of the mid-line between the ankles.

  The 'Rule-of-thumb' method for this particular measurement ($H = 15 + W/2$) (see Table VIII) provides an effective means of unobtrusively establishing the reach distance due to the fact that all container dimensions were known, and a note was made of how the subjects picked up each container. The constant 15 relates to the closest that the carton may, as a rule, be held to the mid-line of the body (Chaffin and Andersson, 1984). W is the width of the carton (cm).

- Task frequency (F) was estimated as the average number of lifts per minute, and

- Duration or length of the shift was recorded in hours and minutes to give an indication of the amount of time spent on each particular task.

General layout of the storage area was studied, with special note taken of the height, width and depth of the shelving units for storage of the containers. Gross body posture (stoop or stand) and number of people involved in transportation of each container was also recorded.

DATA COLLECTION

Once the characteristic task of lifting containers from the trolley to the shelves had been identified during the SME interview, both Supermarkets (W1 and W2) were visited on numerous occasions for general observation and data collection. Initially the height, depth and width of the shelving units in the bulkstores were measured and each shelf was labelled (1 to 4 from the base to the top). The space between the shelves was also recorded. Figure 11 illustrates the standard shelving unit dimensions, and Figure 8 the worksite layout.

The second step in the data collection process was to obtain dimensions of all the containers within the fast-moving groceries section of the bulkstore. These data were initially itemised as cartons per shelf, which enabled identification of respective lift heights for each task of off-loading goods from the trolleys to the shelves. The cartons were subsequently categorised into four groups (A, B, C and D) according to their size (volume; cm^3). The reason for this was that when the Bulkstoremen worked to task for off-loading the trolleys, without undue interference and stoppages, the frequency of lifting the containers per minute and the duration of each particular task was governed by both the size of the trolley and containers. The dimensions of the trolley were; height 21cm, base length 121cm, width 65cm, and the handles were 93cm from the floor. Thus the standard trolley could only hold a certain number of cartons depending on their size (i.e. with the larger cartons, there were generally fewer cartons to lift per trolley than with the smaller cartons, more of which fitted onto the trolley). Hence, size factors dictated how many cartons could be handled at one time.

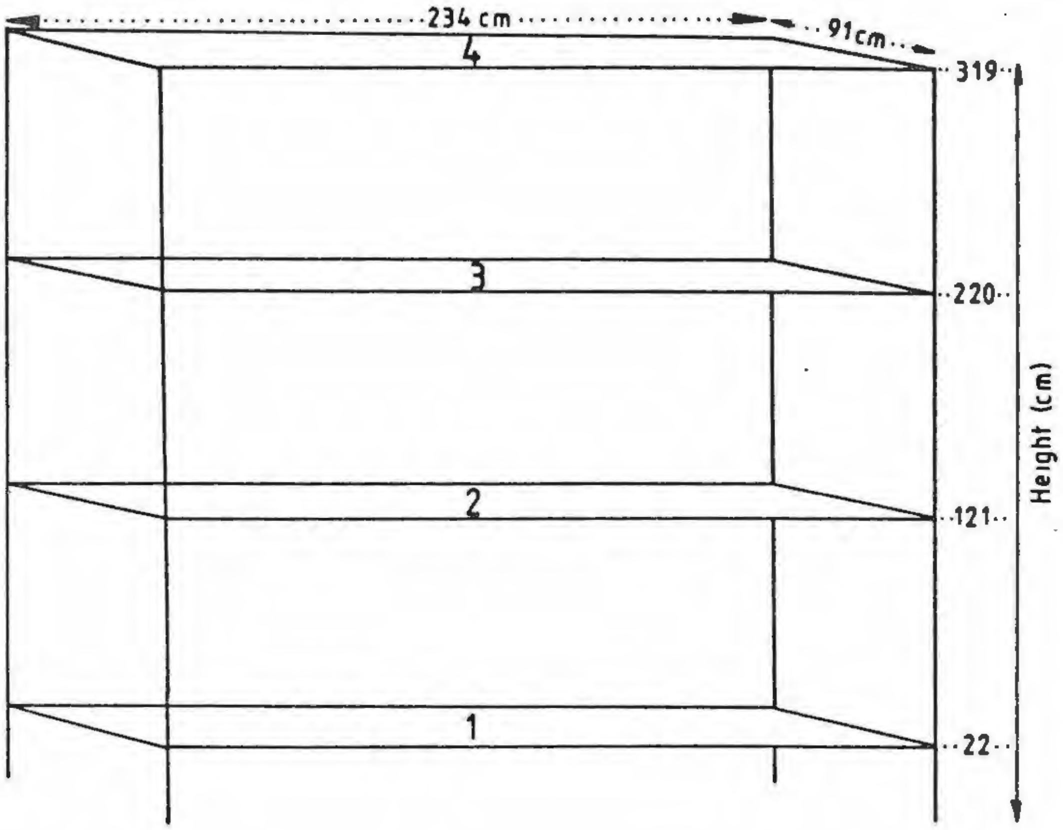


Figure 11: The standard shelving unit dimensions from the Bulkstores Storage Depot at W1

CATEGORISATION OF CONTAINERS

There was a need to categorise the tasks, and due to the multi-factoral nature of the tasks performed and data collected, it was decided to group the containers by volume (cm^3), as it was the size of the containers which had a bearing on the frequency and duration of each task of off-loading the trolley, as described previously. Such a categorisation allowed for easier data manipulation and presentation, and average values could be obtained for frequency and duration per group. It would have proved inordinately time-consuming, given the constraints of this research, to have observed every goods container as it arrived, in order to obtain a frequency, or rate of lift per minute, during task performance.

The containers were basically categorised according to the distribution of their volumes about the average value ($\bar{x}$), using one standard deviation on either side of the average value as the division values to formulate the groups. That is, (1 SD < $\bar{x}$ > 1 SD) whereby Group A = 0 - 1 SD < $\bar{x}$ (cm^3)

Group B = 1 SD < $\bar{x}$ - $\bar{x}$ (cm^3)

Group C = $\bar{x}$ - 1 SD > $\bar{x}$ (cm^3)

Group D = 1 SD > $\bar{x}$ (cm^3) +

Consequently, the resultant groups were as follows:

Group A volume range = 0.0 - 11703.7 cm^3 (13 cartons)

Group B volume range = 11703.8 - 36496.5 cm^3 (102 cartons)

Group C volume range = 36496.6 - 61289.3 cm^3 (56 cartons)

Group D volume range = 61289.4 + cm^3 (20 cartons)

Note: the average volume for all the containers measured was 36496.5 cm^3, with a standard deviation of 24792.8 cm^3.

ACTIVITY AND TIME ANALYSIS

In order to establish the working routine of the individuals under observation, and the particular tasks they performed and time spent on each one, the workers were observed for three entire shifts. During this period, the time spent on each activity in general was recorded (in hours and minutes). The main activities performed by the Bulkstoremen, of which seven types were accounted for, were:

1. Lifting cartons to shelves from the trolley

2. Adjusting the containers on the shelves to make more space for other cartons

3. Checking-in goods as each consignment arrived, by counting and price-labelling each carton

4. Transferring goods from the incoming pallets to trolleys to transport the containers to the shelving units. The aisles were too narrow for the pallets.

5. Stock-taking of goods on the shelves

6. Cleaning up (sweeping, clearing away empty cartons)

7. If the subjects were involved in any other other type of activity, such as talking, resting, running errands, to name a few, then these were accounted for under the category of 'other' activities

Figures 12 to 14 illustrate some of the activities of the Bulkstoremen, with particular focus on their lifting techniques when transferring containers from the trollesy or pallets onto the shelves.

During the same period, a stopwatch was used to record the frequency (lift/minute) for each task observed during off-loading of the containers from the trolleys onto the shelves. This enabled an average value to be obtained for each group of cartons. This process of data collection is termed an activity and time analysis.

A factor which aided in the data collection was that the researcher developed a pleasant rapport with the workers concerned. It was felt that they were not intimidated by her presence, or compelled to adapt their working routine, as an observational methodology was used for data collection and their work was interfered with as little as possible. No expensive equipment was required, with the tapemeasure, scale, stopwatch and data sheets constituting most of what was required for on-site data collection. It is important to point out that the establishment of a sound database of container dimensions and mass, and height of lift prior to further data collection allowed for greater ease in data recording during the activity and time analysis.

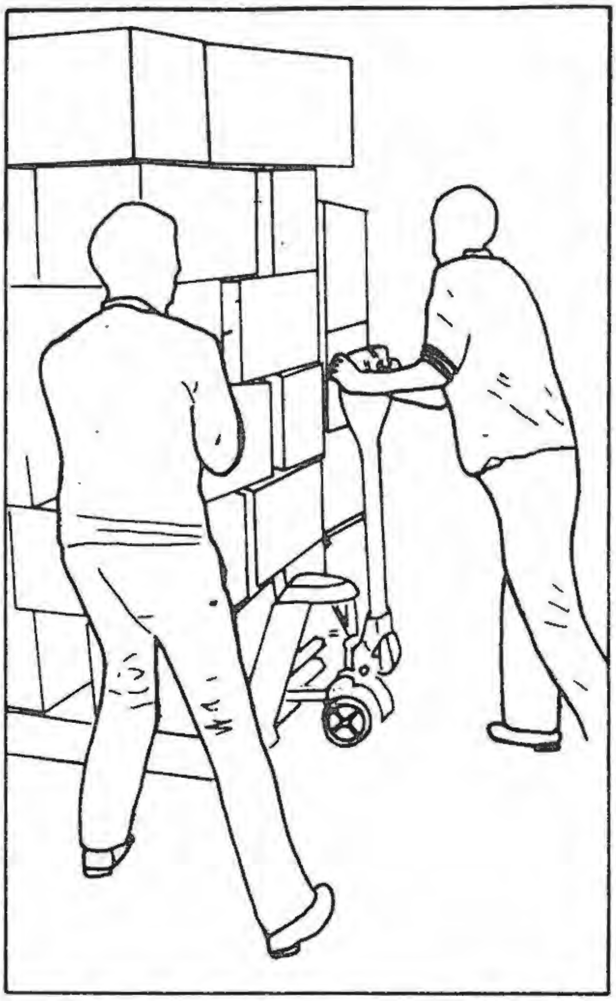


Figure 12:

Workers collecting a pallet of containers from the Receivings Depot, and pushing or pulling it to the checking-in area of the Bulkstores.

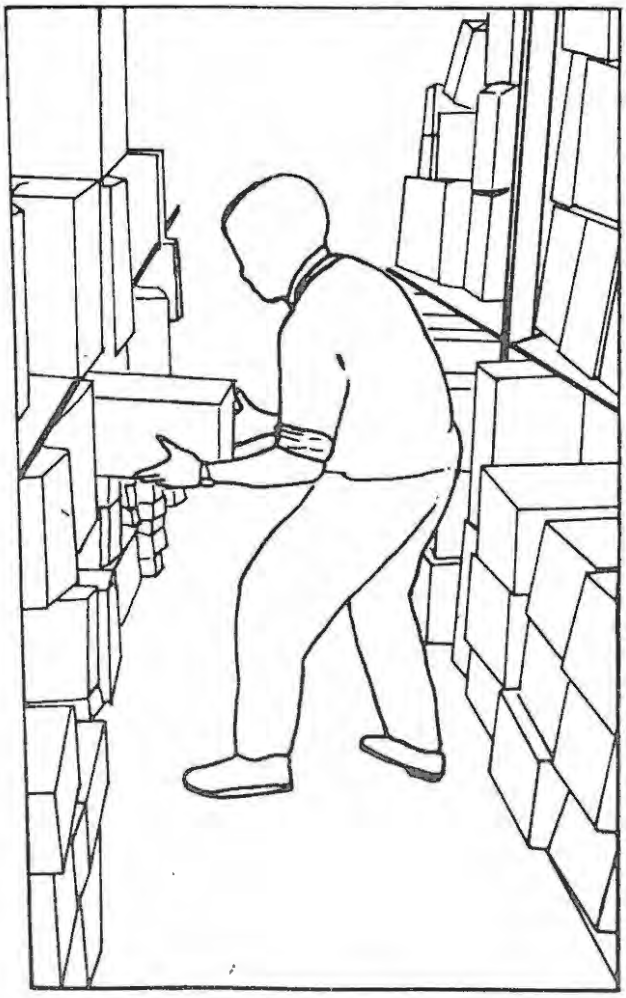
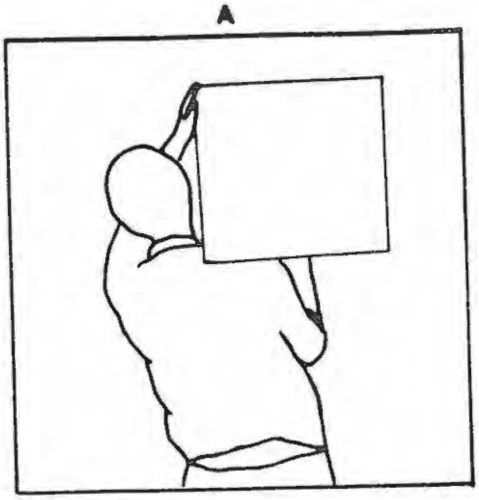


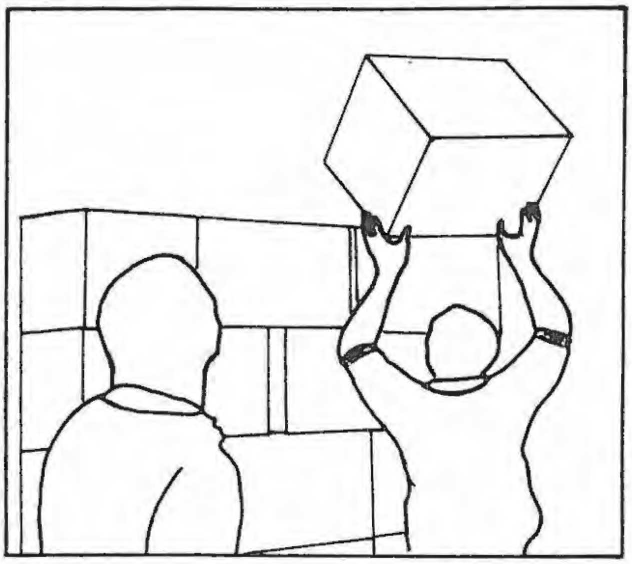
Figure 13:

A worker lifting a container onto Shelf 1.

A



B



C

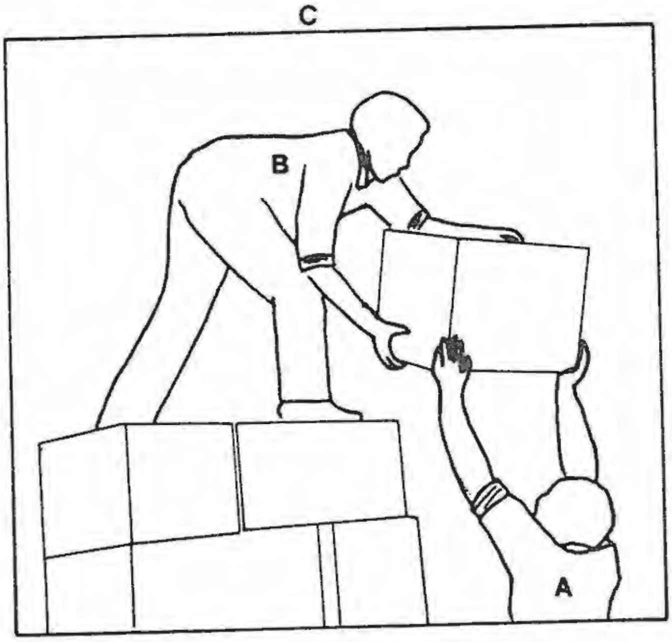


Figure 14:

Alternative means of lifting containers onto the shelves:

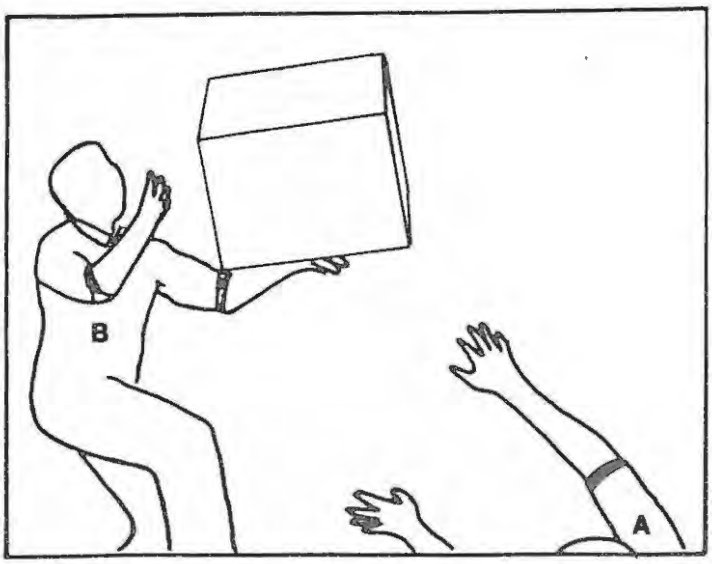
a) Worker carries container on shoulder (or at waist level) to the designated shelf.

b) Worker lifts container onto other containers already on the shelf.

c) Worker 'A' lifts the container at full-reach to 'B'.

d) Worker 'A' throws the container up to 'B'.

D



STATISTICAL ANALYSES

The hypothesis was that no significant difference exists between the actual load mass lifted and those recommended by the NIOSH lifting guidelines (specifically the Maximal Permissible Limit or MPL) for the basic tasks performed, and for the hypothetically optimised tasks.

In order to identify whether there was an overall significant difference between the Actual Load Mass (ACT), the Action Limit (AL) and the Maximal Permissible Limit (MPL), for all 191 tasks analysed, a two-way Analysis of Variance (ANOVA) (Ferguson, 1981) was performed ($p < 0.05$). This analysis investigated the significance of any overall differences between the three variables (ACT, AL and MPL) for the basic task performance as observed within the Bulkstores. Secondly, an ANOVA was performed on the hypothetically adjusted data in order to identify whether or not the alterations made resulted in a significant change to the data (i.e. if there was a significant difference between the variables, then the alterations themselves were significant and not due to chance). A *post hoc* Scheffé test was conducted in order to identify where the differences occurred.

"Student" t-test calculations were used where necessary to assess the significance of any differences which occurred between two sets of related variables.

CHAPTER IV

RESULTS AND DISCUSSION

Manual materials handling tasks are inherent in many different jobs in industry, and performance of such tasks exposes the worker to a variety of biomechanical hazards, such as musculoskeletal strains and sprains and low back pain (Garg *et al.*, 1980). In industry today, approximately 30 % of all jobs involve some degree of manual lifting (NIOSH, 1981). The majority of tasks within this broad category of manual lifting consist of two-handed lifting of boxes, or other types of containers and objects, to and from various heights. A great number of work-related injuries arise from the manual handling and/or mishandling of materials in what Ayoub *et al.* (1980) define as "unaided human acts of lifting, lowering, pushing, pulling or holding and releasing an object".

Assembly-line work generally requires frequent lifting of relatively light loads, with the rate of work governed by the rate at which goods are placed on the conveyor belt. The lift usually originates at waist or table height and the object handled is placed on a conveyor belt or pallet that is located at the same height and some distance from the body. In other words, this is a relatively standardised set-up, and such lifting motions do not usually impose high biomechanical and metabolic demands characteristic of back lifting, but rather impose a localised load on muscles of the upper extremity (Habes *et al.*, 1985). This is in great contrast to the work performed within the storage section or warehouse of 'fast-moving' grocery Supermarkets. Herein there were numerous variables to consider due to the fact that the containers did not have a standardised weight, size or content, (although the majority of goods were packed in cartons), and there were differing shelf heights upon which the containers were placed. It must be pointed out that the goods were termed 'fast-moving' as their storage time on the shelves was dependent on the demands of the consumers and shelf-filling within the supermarket. As new stock arrived, goods were lifted and lowered to and from the shelves in the Bulkstores with relative frequency.

The aim of this research was to assess the demands that a representative lifting task imposed on the workers within the fast-moving grocery storage section of a Supermarket. If a worker's capabilities (e.g. strength and endurance) are not sufficient to meet the demands of the task, then exertion related injuries are more likely to occur. It is believed that many of these injuries occur because man exceeds, or is asked to exceed, his physical capabilities (Snook *et al.*, 1970). In order to reduce the incidence and severity of such work-related injuries, there is a need to establish a means of improving working efficiency and maintaining a suitable working environment. Matching the capabilities of the worker with the requirements of a particular MMH task, or designing/redesigning such jobs on the basis of the capabilities of the workforce, reduces the risk and severity of injury in the lifting MMH environment (Chaffin *et al.*, 1978; Garg and Saxena, 1980; Dul and Hildebrandt, 1987; Van Wely, 1987).

Analysing the MMH activity of lifting *in situ* within a warehouse was relatively complex as there was little standardisation in task performance. Containers were not only lifted to a particular shelf with a specific height, but also to the shelf height plus the height of a carton or cartons already placed on the shelf. The containers themselves were also of varying sizes and masses consequently exposing the workers to constantly differing stressors. When all the containers were grouped together as a whole, the mass ranged from 2 to 28 kg (2.7% to 38% average body mass of the workers), with an average value of 13.4 kg (18.2 % average body mass), and a median of 13 Kg (17.7% average body mass of the workers). The most common mass was 8 kg (10.9% average body mass). Volume (cm^3) ranged from 3672.0 to 155496.0 cm^3, with an average value of 36496.0 cm^3, the median was equivalent to 30504 cm^3 and the mode was within the range 22000 - 22999 cm^3.

There are many factors affecting MMH task performance which fall into the basic categories of worker, container, and actual task characteristics (Herrin *et al.*, 1974; Ayoub *et al.*, 1980). There is, however, a great deal of inter-relationship between these factors which ultimately influence the outcome of the task performance. Container characteristics include mass, overall size and dimensions, and distribution and stability of the load. These factors inter-relate with the capabilities of the worker (based on biomechanical, physiological, epidemiological and psychological criteria (NIOSH, 1981), as well as training, experience and health status (Herrin *et al.*, 1974)), to govern the nature of the task to be performed. Accordingly, the actual task factors themselves namely height, frequency and duration of lift, correspondingly combine with the container and individual characteristics.

The question may arise as to whether the contributory factors of the container and worker actually govern the nature of the tasks performed. These factors are physically present and presumed unchangeable over a short period of time (i.e. the container characteristics are deemed to be fixed, as are the capabilities of the workers). Alternatively, the nature of the task (lifting objects to a particular or differing heights at a given rate) could govern which containers may be manually handled by whom. The answer is that all factors need to be considered based on their inter-relationships and not in isolation, and thereby worker capabilities matched with the demands imposed by the container and task factors.

Table IV and the corresponding Figure 15 provide a general overview of the procedures involved in data collection and analysis for the present study.

CONTAINER MEASUREMENT AND MANAGEMENT

As has been described in the methodology, 191 containers in total were comprehensively measured within the carton or carton-like classification. These were subsequently categorised into four groups (A, B, C and D) according to their Volume (cm^3). An example of the relevant information obtained for the manually handled containers that were measured and recorded is provided in Table V.

TABLE IV: SUMMARY OF DATA COLLECTION AND ANALYSIS PROCEDURES

1. **Container measurement and management (pages 92 - 106)**

1.1 191 containers' dimensions and mass measured

1.2 Containers categorised according to shelf and size

1.3 Torques calculated for smallest, largest and average container per shelf.

2. **Activity and Time analysis (pages 106 - 115)**

2.1 Identification of all tasks performed by the workers and time spent on each activity

2.2 Morning, afternoon and full-day activity comparison.

2.3 Measurement of frequency and duration of each lifting task averaged for each size group of containers.

3. **NIOSH analysis (pages 115 - 134)**

3.1 Identification of sub-tasks = 1020 subtasks overall.

3.2 Initial NIOSH analysis to identify 191 worst-cases.

3.3 Detailed NIOSH analysis on these 191 'worst-cases' with particular focus on the 103 tasks with ACT greater than MPL. Task factors adjusted in order that ACT is less than MPL. Location of ACT about the AL and MPL load limits plotted on pie-graph.

3.4 ACT, AL and MPL plotted against task for all 191 tasks analysed before and after adjustments were made.

3.5 ANOVA and Scheffé on these 191 tasks to see if there was a significant difference between the overall average ACT, AL and MPL before and after adjustments were made.

3.6 ANOVA and Scheffé on 103 tasks requiring adjustment to see if there was a significant difference between ACT, AL and MPL before and after adjustments were made.

3.7 Task-factors adjusted (F-factor and H-factor) plotted on pie-graph indicating what percentage of the overall number of tasks required the factor adjustment, illustrating which factors were adjusted.

3.8 Students t-test calculations to test if frequency reductions and raising the initial lift height produced a significant difference in the MPL.

4. **RPE (pages 134 - 139)**

4.1 Discussion on the random RPE ratings with respect to lifting task performance and localised fatigue and/or pain experienced at end of working day

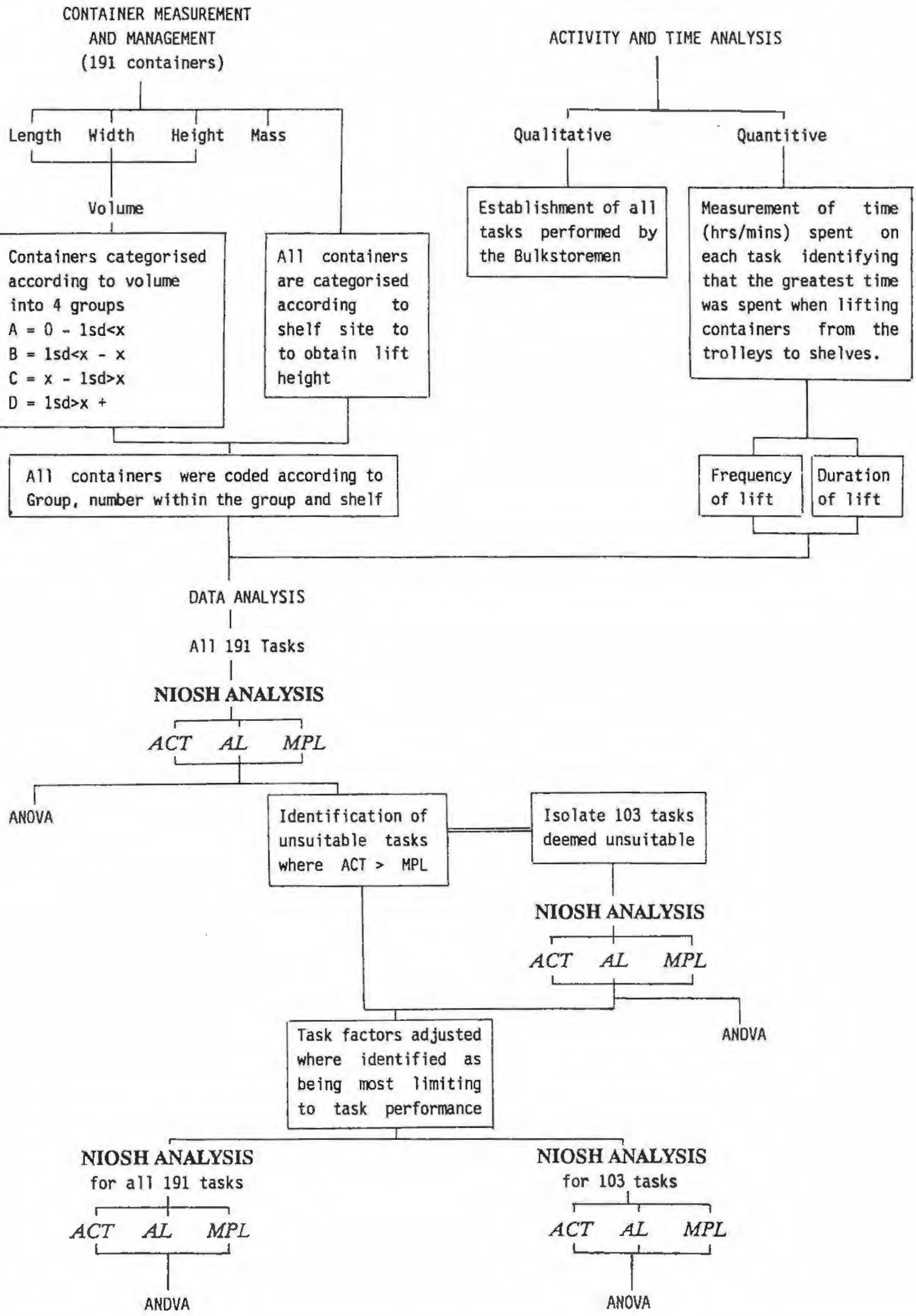


Figure 15: Flow diagram of the processes undertaken during data collection and analysis

The data for all 191 containers are detailed in Appendix F, and were used during the specific task analysis of the activities of the Bulkstoremen. All containers were assigned a code for ease of task identification, data handling and manipulation. The codes indicated in which group (A, B, C or D) the containers were classified, the specific number allocated to each container within the group, followed by which shelf the containers were lifted to (indicating height of lift). For example, the first container, given the code A1.1 indicates that this was the first carton in Group A, stored on shelf 1. A10.4 was the tenth container in Group A, stored on shelf 4, and so on.

TABLE V: Relevant information pertaining to a sample of the containers according to the group classification by volume (cm^3)

CODE	LENGTH [cm]	WIDTH [cm]	HEIGHT [cm]	MASS [kg]	VOL [cm3]	DESCRIPTION
A1.1	17.0	18.0	12.0	2.0	3672.0	CLIFTON
A2.2	22.0	18.0	13.0	5.0	5148.0	SPICES
A3.1	26.0	20.0	12.0	4.0	6240.0	INSTANT POSTUM
A4.3	31.0	25.0	9.0	4.0	6975.0	PULVEX DOG POWDER
A5.1	35.0	23.0	10.0	7.0	8050.0	PURITY BABY APPLES
A6.2	27.0	20.0	15.0	7.0	8100.0	BAKED BEANS
A7.4	31.0	17.0	16.0	4.0	8432.0	SELF SHINE
A8.3	27.0	19.0	17.0	6.0	8721.0	COOPER DOG SHAMPOO
A9.4	22.0	17.0	25.0	6.0	9350.0	GLAD BAGS
A10.4	26.0	19.0	20.0	5.0	9880.0	GLAD BAGS
B11.2	45.0	37.0	10.0	21.0	16650.0	POG RICE *
C16.4	54.0	40.0	20.0	13.0	43200.0	RICOFFY **

Table V (with data detailed in Appendix F) also provides all container dimensions (length, width and height in centimetres), mass (kg) and volume (cm^3). The description of the containers allowed for quick identification during the activity and time analysis. The five containers with an asterix beside the description were packets with carton-like qualities (in that their contents were solid and the packet maintained a carton-like shape). The double asterix pertained to one container with a cardboard base and plastic covering. These containers formed part of the analysis due to their carton-like qualities.

The data in Table V, and Appendix F are presented in ascending order of volume (cm^3) by which the containers were grouped. In other words, the containers in Group A were smaller by volume (an average of 8249.2 cm^3) than those in Group D (averaging 89256.5cm^3). The volume range for each group is detailed in Chapter 3 and a summary of the container characteristics per group is presented in Appendix G).

The containers were initially anlaysed per shelf in order to establish a set of standard heights to which the containers were lifted (the D-factor of the NIOSH model), as well as the storage layout of the containers within the Bulkstores of W1. Switzer (1962) identified that the amount of weight lifted decreases with an increase in the height of lift. Ayoub *et al.* (1978) also found that lifting capacity decreases with an increase in the height of lift, and with an increase in the height of the origin of the lift. Snook *et al.* (1970) established that individuals had a higher lifting and lowering workload for the knuckle to shoulder height than for the floor to knuckle height level, or shoulder to reach height level. Combinations of excessive height and weight requirements in an arm lifting task can add to localised muscle fatigue of the upper body (Habes *et al.*, 1985). One recommendation put forward by Habes and associates was that work tasks with excessive reach and height requirements should only be permitted if the weight to be lifted is lower than 40% maximum voluntary contraction for that specific task.

Based on the specific shelf heights, the containers were being lifted to between 22cm and 121 cm for Shelf 1, and between 121 and 220 cm for Shelf 2. Shelves 3 (220 cm) and 4 (319 cm) were beyond the average reach range of the workers (205cm), with the reach range built into the NIOSH model at 175cm. As observed, the workers assisted one another in lifting containers up to the top two shelves. One worker would stand astride the shelves or on a ladder while the other passed or threw the container up from full reach or shoulder height respectively (Figures 16 and 17). Nevertheless, the containers were still being passed up to full-reach from shoulder height constituting a fatiguing act (Snook *et al.*, 1970; Habes *et al.*, 1985).

When a trolley was loaded with containers, there were varying lift heights from the trolley to the waist or shoulder level of the workers, and then from waist/shoulder height to varying levels on the shelves. The act of lifting a container from the trolley to Shelves 1 and 2 followed the same sequence of lifting from the trolley to waist height (a vertical lift distance of 79 cm - waist height of 100 cm from trolley height of 21 cm), followed by lifting from waist height to the shelf. For Shelf 1 the lift distance ranged from waist height (100 cm) down to the actual shelf level (22 cm), to a horizontal lift from waist to shelf onto containers already on the shelf at a height of 100 cm resulting in no actual vertical lift distance. For Shelf 2 the lift distance ranged from waist height (100 cm) to shelf height (121 cm), a distance of 21 cm, to 75 cm (waist height of 100 cm onto the top of containers already on the shelf at a height of approximately 175 cm. The vertical lift heights onto the shelves depended on the actual size and height of each container as it was placed on the shelf.

Lifting to shelves 3 and 4, beyond the normal reach range of the workers (Figure 16) followed the sequence of lifting from trolley to shoulder height (a vertical lift distance of 125 cm), and then shoulder height to full-reach (lift of 59 cm) where it was passed or thrown up to a co-worker (Figure 17). It must be pointed out that the trolley height was taken at the base level of 21cm from the floor. This task of lifting a container from the base of the trolley was found to be the most demanding for the worker based on the NIOSH analysis to be described in detail under the NIOSH analysis section. The lifting technique utilised during manual lifting of containers is important (Grandjean, 1980; Nachemson and Elfstrom, 1980)

Figure 16:

A carton being placed on Shelf 3 (220 cm from the floor), beyond the average full-reach of the workers (205 cm).

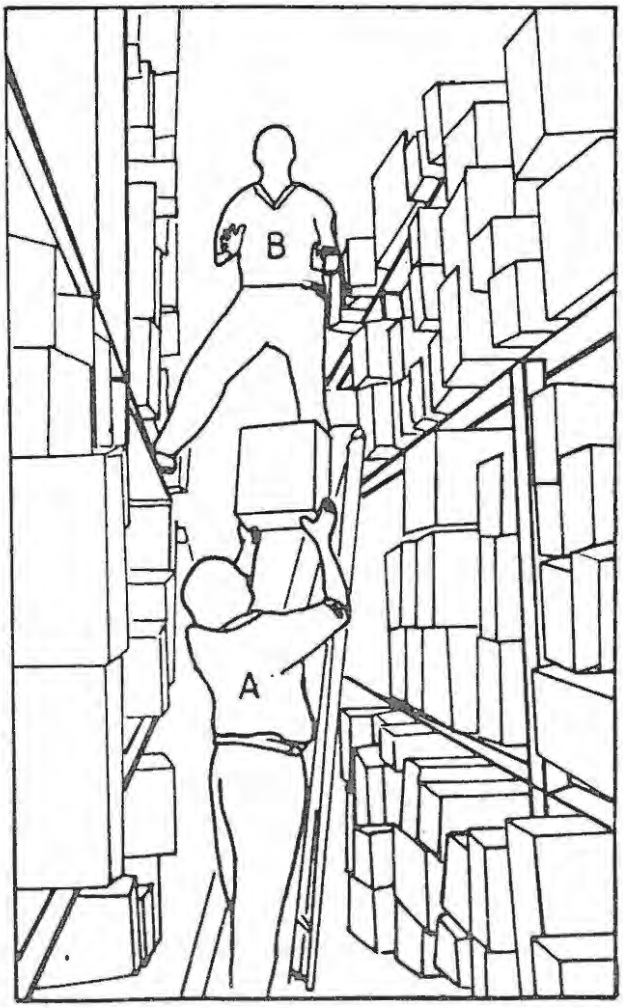


Figure 17:

The alternative means of placing a carton on Shelves 3 and 4. Worker 'A' either passes or throws the container up from full-reach to 'B'.

particularly when grasping containers at or close to floor level.

When lifting the cartons from the base of the trolley to waist or shoulder height, the workers would combine flexing the knees and leaning forward over the trolley in order to get a good grasp of the container. Knee flexion reduces the horizontal reach factor/moment arm by reducing the distance between the centre of mass of the worker and that of the container. Consequently lower torques should be experienced in the lower back at the L_5S_1 disc. However, in order to get a good grasp on the container, the workers would lean forward with a rounded back. This curvature of the lumbar spine causes subsequent heavy, asymmetrical loads being placed on the intervertebvral discs in the frontal plane (Grandjean, 1980). Ideally, the workers should flex their knees and keep their backs as straight as possible in order to reduce the stress on the intervertebral discs (Grandjean, 1980).

Figure 18 illustrates the distribution of containers for fast-moving groceries by length, width and height (all in cm) and mass (kg) per shelf. As can be seen from the Figure and corresponding Table VI, on average the heaviest (15.7 kg) and second to largest by volume (39711.9 cm^3) were stored on shelf 3 (220 cm from the floor). Table VII illustrates that the larger mass and H-factor, when compared to the other shelves, imposed the greatest resultant forward bending moments (of 72.6 Nm) based on the average dimension values for all containers located on Shelf 3. As a value of 175cm was the average reach height built into the NIOSH model it was assumed to be so for the subjects partaking in this research. Care should be taken in lifting such heavy, large containers to extreme height levels (Habes *et al.*, 1985). A possible reason for the placement of these containers at such a height could be that the consignments are always larger by quantity, resulting in the smaller variety of containers found on Shelf 3 (17 different container sizes and brands). The products located on Shelf 3 were generally cleaning fluids and powders and it may have initially been an attempt to keep such products away from other consumable goods. The motivation and teamwork of two individuals working together would have assisted in the lifting of the heavier, larger containers to the higher levels.

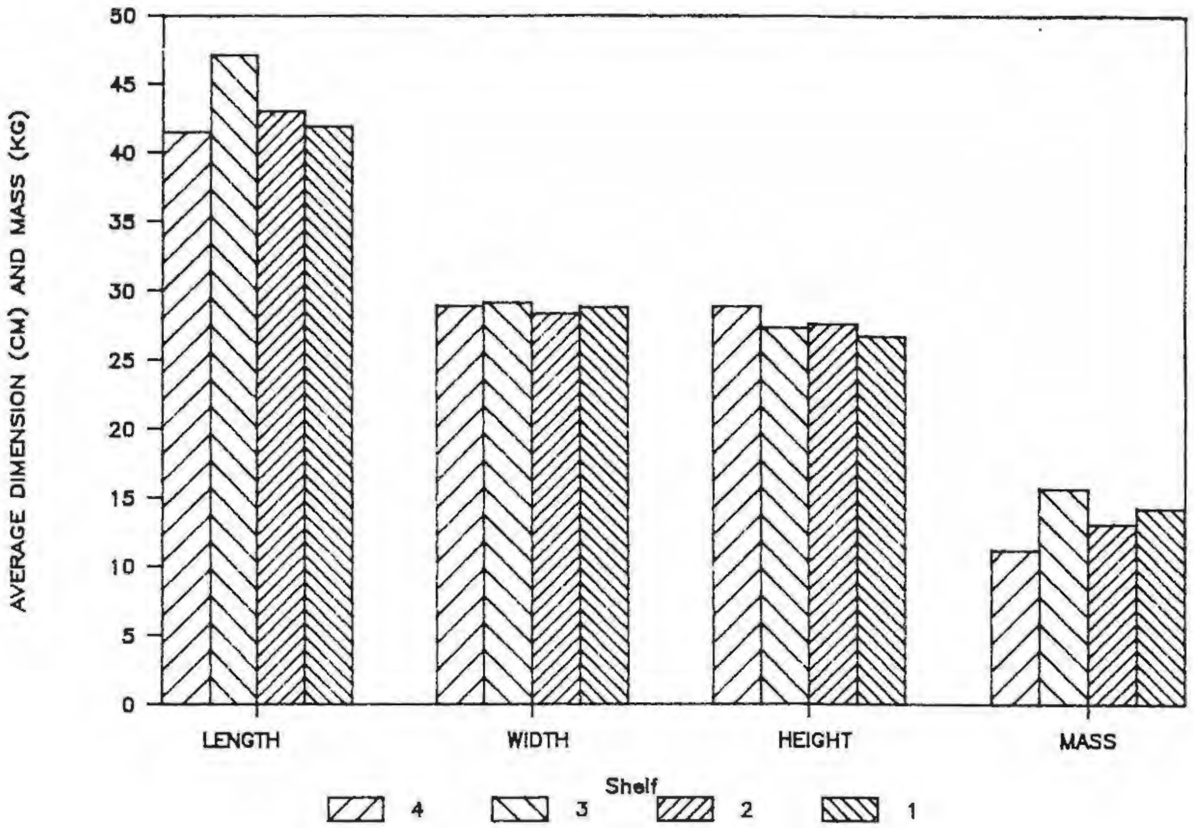


FIGURE 18: Distribution of Containers per Shelf, indicating the average values for all container dimensions and mass

Table VI: Average Values of Container Dimensions, as distributed per shelf, or against the wall within the Bulkstores storage section of W1

SHELF	LENGTH [cm]	WIDTH [cm]	HEIGHT [cm]	MASS [kg]	VOL [cm3]	Qty
4	41.5	28.9	28.9	11.2	41342.7	46
3	47.1	29.2	27.4	15.7	39711.9	17
2	43.0	28.4	27.6	13.2	35512.7	59
1	41.9	28.9	26.8	14.3	33797.1	66
WALL	52.3	33.3	13.0	22.0	22704.0	3

Based on the findings of Snook and Irvine (1968) maximum work loads acceptable to male industrial workers were highest for the knuckle to shoulder height, for weights of 15.85 and 22.65 kg. In the present study this height range would encompass lifting from the trolley to Shelf 2, given that lifting from the trolley to Shelf 2 is broken down into the two stages of trolley to waist, and waist to shelf. It could therefore be concluded that lifting the heavier goods onto Shelf 2 would be more optimal for the workforce, although lifting from the floor to knuckle height elicited the lowest acceptable workloads for the same weights (Snook and Irvine, 1968). Shoulder to reach height elicited acceptable workloads between those found acceptable for the other lifting ranges. The findings of Snook *et al.* (1970) were very similar to those reported earlier by Snook and Irvine (1969).

On average the lightest (11.2 kg) but largest containers (volume of 41313.7 cm^3) were located on shelf 4 (319 cm from the floor). This could be due to the fact that they were easier to throw up to the second worker due to their lighter mass. The results of a study by Ayoub and co-workers (1978) where they determined and modelled the lifting capacity of male and female industrial workers, indicated that the lifting capacity of the workers decreased almost linearly with the increase in the box size and frequency. Ciriello and Snook (1983) found similar results which indicated that bigger boxes, for the same load, produced a larger bending moment on the spinal column, therefore lighter loads for lifting are usually accepted for the larger containers (Mital, 1984b). In other words, maximal acceptable weight (MAW) decreases with a increase in box size (Mital and Fard, 1986). Essentially, the larger the container, the larger the forward bending moment acting on the L_5S_1 disc (Frankel and Nordin, 1980). However, mass effects the torque as may be seen in Table VII when establishing the forward bending moment (torque) acting on the L_5S_1 disc for various container sizes and masses.

The torque at any one joint is dependent on the amount of force tending to rotate the segments, multiplied by the perpendicular (normal) lever-arm distance (Chaffin and Park, 1973). Consequently, there is a positive curvi-linear relationship between the load in the hands and the predicted compression load on the L_5S_1 disc (Chaffin and Park, 1973). As the load in the hands increases, so the predicted compression on the lower lumbar disc increases. Habes *et al.* (1985) established from a study with a simulated assemblyline that the most fatiguing task variable was the weight of the load lifted. Maximal accepted weight (MAW) of lift is a psychophysical criterion defined by Ayoub *et al.* (1983) and Liles (1986) as being the maximum weight an individual feels he or she can lift repeatedly without undue stress over a period of time. In several studies, the MAW has been found to be significantly influenced by freqeuncy of lift, height of lift and box size (Mital and Manivasagan, 1983; Mital, 1984b).

An important point to mention is that the masses lifted in the Bulkstores of W1 could not be selected or adjusted by the workers manually handling them. The configuration of the containers (dimensions and mass) may be deemed to be uncontrollable, considering that the containers were supplied pre-packed and sealed by the distributers, and changing the configuration of the containers to ensure a lighter load might not prove to be cost-effective for the suppliers. Ultimately, the height to which the containers were lifted, and the frequency with which they were handled would influence the forces acting on the lower lumbar disc, as well as all the musculature involved in lifting. These factors may need to be considered further in situations whereby the mass may not be changed, therefore task factors must be adjusted to reduce the physical demand imposed on the worker.

The lever-arm distance involved in the torques measured was the horizontal distance between the centre of mass of the worker (acting through the L_5S_1 disc) and that of the container. As it is generally accepted that the distance from the centre of mass of the body to the front of the abdomen is 15 cm (NIOSH, 1981),the simplified 'rule-of-thumb' distance or H value was used (H = 15 + 1/2 container width). The force in the hands was assessed, for convenience, in newtons by multiplying the object mass by 10 (the resulting error of 1.9%, being constant and negligible, was discounted). The resultant forward bending moments were calculated for the smallest, largest and average containers per shelf (Table VII). An example of the torque calculation is given below the table.

TABLE VII: Torque forces/forward bending moments (Nm) of the smallest, largest and average sized containers per shelf

(masses, kg; H-factors, m; Torques, Nm)

Shelf	Container Size Groups								
	Smallest			Largest			Average		
	Mass	H	Torque	Mass	H	Torque	Mass	H	Torque
4	4	0.235	9.40	16	0.435	69.60	11.2	0.295	33.04
3	4	0.275	11.00	22	0.330	72.60	15.7	0.296	46.47
2	5	0.24	12.0	8	0.310	24.80	13.2	0.292	38.54
1	2	0.24	4.0	7	0.320	22.40	14.3	0.295	42.19

Shelf 4 (Smallest): Torque = (15 + 17/2) x 40 = 9.40 Nm

Table VII illustrates that even though a carton may be large, if it has a corresponding small mass (kg), then the resultant forward bending moments on the lower lumbar disc may be less than those imposed by a smaller, heavier box. For example, looking at the distribution of containers located on Shelf 1, the largest had a torque of 22.40 Nm (the container mass was 7kg, with a width of 34 cm equivalent to an H-factor value of 32.0). However, the average container to be found on Shelf 1 with a mass of 14.3 kg, and width of 28.9 cm (H-factor of 29.5) had a resultant moment force of 42.19 Nm, 19.79 Nm greater than the larger container.

The same effect was found on Shelf 2 with the average container (smaller H-factor) having a resultant torque 13.74 Nm greater than the largest container. The greatest torque (72.60 Nm) was found with the largest container located on Shelf 3. This container did not have the largest H-factor overall, but the combination of a relatively large H-factor and mass contributed to the sizable torque. The container imposing the least force on the lower lumbar disc of the worker could be found on Shelf 1.

Looking at the torque values based on the average container dimensions and masses per shelf, the containers on Shelf 3 imposed the greatest stress with a torque of 46.47 Nm (greatest average mass and H-factor), followed by the containers of Shelf 1 (42.19 Nm, second largest average mass). Shelf 2 had an average torque value of 38.54 Nm, with Shelf 4 having the lowest average torque value of 33.04 Nm (together with the lowest average mass and H-factor). In all 46 different containers (by 'brand' and/or size) were located on Shelf 4, 319 cm from the floor. These containers were the largest by average, with the lowest mass, and due to their bulky size they may have been placed at such a height in order to allow for more containers to be placed on the lower, more accessible shelves. Presumably the larger the container, the larger its component items, or the greater the quantity of smaller items. Given the same demand for items, and that the larger containers accomodated more items than the smaller containers, the smaller containers would be opened more frequently. This may have been a reason why the smaller containers were located on Shelf 1 and the larger on Shelf 4.

On the whole, the smallest (33797.1 cm^3) and second to heaviest (14.3 kg) containers were placed on shelf 1 (22 cm from the floor). Mital (1984b) found that heavier weights were accepted for lower lifts in spite of the greater heart rates, truncal stress and oxygen consumption incurred as compared to when lifting to higher heights. This would probably be due to the fact that the individuals could rely more on their thigh and back muscles. Increased heart rate is possibly due to the increased muscle mass involvement. At the higher height levels of lift it is mainly the arm muscles that are involved, creating lower acceptable weights of lift as well as lowered heart rate and oxygen consumption (Mital, 1984b). The 'average' torque force, based on the average dimension values for all containers located on Shelf 1 was 42.19 NM. This is evidence that even when a container is small and may be held relatively close to the body, reducing the H-factor, if it has a large mass then the resultant forward bending moments will be great. The greatest variety of containers (66 different 'brands' and/or sizes) was found on the lowest Shelf. This may have been due to the fact that on average the smallest containers were located on Shelf 1, and presumably there would be more space available for a greater variety of containers, given that the quantities per container were not too great. Alternatively, the accessibility to the shelf for container placement and retrieval could result in the greater variety of containers on the low shelf.

Shelf 2 (121 cm from the floor, 21 cm higher than the average waist height of the workers studied) was the site for containers of an average mass of 13.2 kg and volume 35512.7cm^3. The resultant torque forces based on the average container dimensions was 38.54 Nm. There were 59 different containers situated on this shelf, which, based on the findings of Snook *et al*. (1970) and Snook and Irvine (1969) has been found to probably be the most optimal shelf height to which objects should be lifted. Again the possible reason for the great variety would be the accessibility for carton placement and retrieval. Three different sizes of containers were stacked against the wall on a pallet at either 14 or 21 cm from the floor. This particular consumable product was sugar, which could probably be deemed a perceived necessity of daily living, would be in continual demand. Hence, the intake and output of sugar would be regular and it was stored in a readily accessible place.

The width (cm) of each container was the dimension used to calculate the NIOSH 'H' value (horizontal distance between the centre of mass of the body to the centre of mass of the container). This was due to the fact that the industrial subjects generally picked up the containers from the trolley with the longest side (measured as the length in cm) between their hands. The 'H' value ranged from 22.5 cm to 43.5 cm, with an overall difference of 21 cm. The overall average 'H' value was 28.1 cm, corresponding to a container with a width of 26 cm. This was obtained from the table of 'Rule-of-Thumb' 'H'-values indicated below (Table VIII). The most commonly occuring 'H' value was 30 cm, with an overall median value of 29cm.

TABLE VIII: "RULE OF THUMB" H-FACTOR VALUES

(where H = 15 + 0.5*W, and W = Width of object)

W	H	W	H	W	H	W	H	W	H
10	20.0	20	25.0	30	30.0	40	35.0	50	40.0
11	20.5	21	25.5	31	30.5	41	35.5	51	40.5
12	21.0	22	26.0	32	31.0	42	36.0	52	41.0
13	21.5	23	26.5	33	31.5	43	36.5	53	41.5
14	22.0	24	27.0	34	32.0	44	37.0	54	42.0
15	22.5	25	27.5	35	32.5	45	37.5	55	42.5
16	23.0	26	28.0	36	33.0	46	38.0	56	43.0
17	23.5	27	28.5	37	33.5	47	38.5	57	43.5
18	24.0	28	29.0	38	34.0	48	39.0	58	44.0
19	24.5	29	29.5	39	34.5	49	39.5	59	44.5

(Based on the concept that an object may not, generally, be held closer than 15 cm to the centre of mass of the human body (NIOSH, 1981))

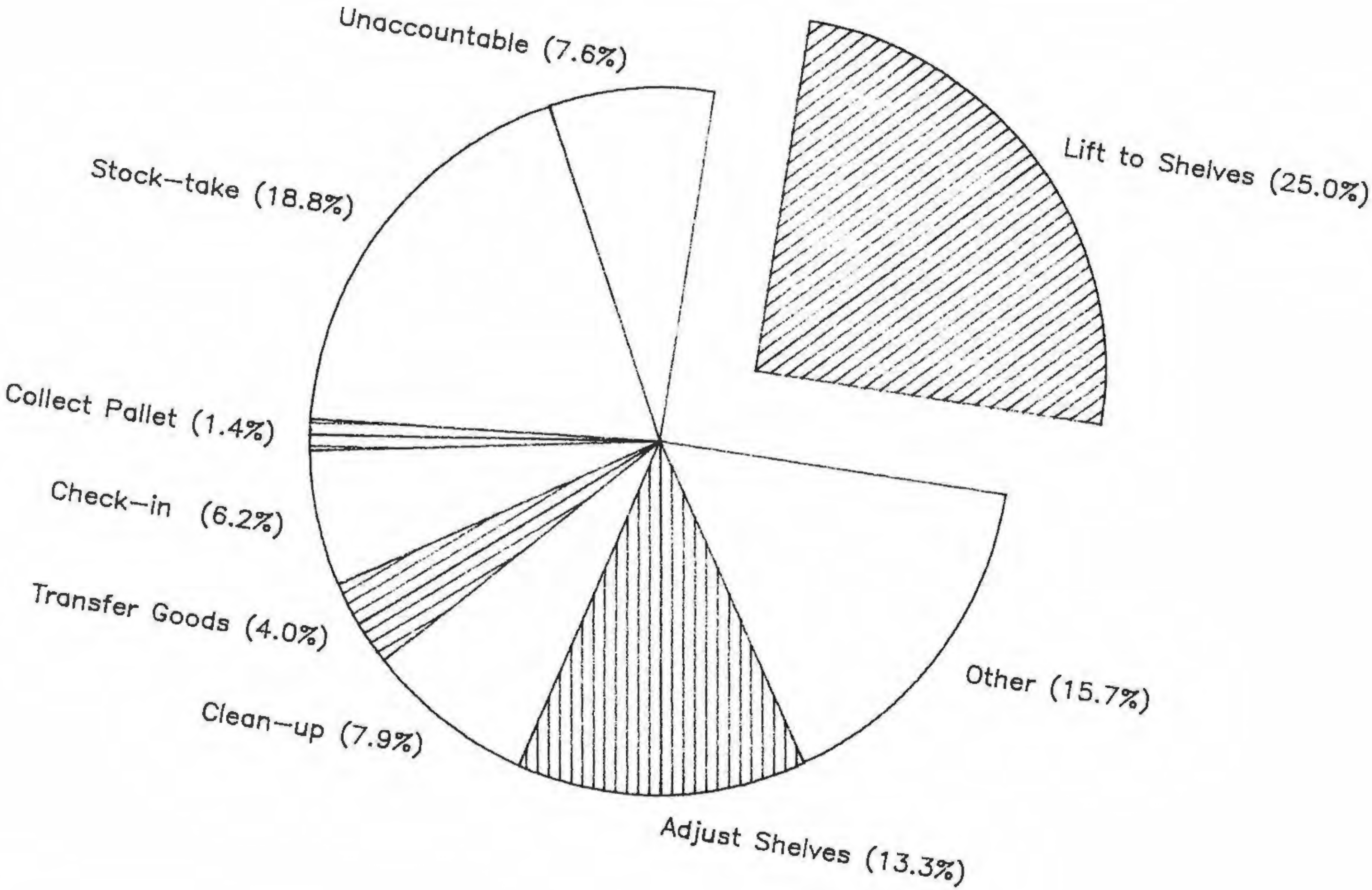
ACTIVITY AND TIME ANALYSIS

Task diversification is important when considering the demands placed on the workers. If the worker performs a variety of tasks per day it allows for a change of focus of attention, and varies the nature of the demands imposed on the body. Diversification in the tasks performed also relieves the boredom and possible carelessness associated with the monotony and repetitiveness of continually performing the same activity. In situations where work is monotonous and repetitive or physically demanding, regular rest periods have proven to be effective (Heinrich, 1959). It has been concluded (Heinrich, 1959) that a worker with a fatigued mental, nervous or muscular system is a 'bad risk' for himself and his employer. Periods of dynamic work, interrupted by brief periods of rest provide the ideal way to perform physical activity (Astrand and Rodahl, 1977). Rest periods may be passive or active, and an active rest period from one activity may be involvement in another which is less physically demanding. Fatigue is generally specific to the task, for example the muscle fatigue associated with repetitive arm lifts (Habes *et al.*, 1985). Due to the cumulative effects of fatigue, changing the activity allows the fatigued muscles time to recuperate, provided that the rest period is of sufficient duration. Fatigue and discomfort are common complaints during activities that require some form of static effort, and recovery may take as long as twelve times the original period of activity (Grandjean, 1980).

In order to ascertain the amount of time spent on each identifiable task carried out by the Bulkstormen in W1, they were observed for several working days, from which three days were used for actual data collection. In general, the morning and afternoon working periods lasted 210 minutes each, giving a total working time of 420 minutes. This amounted to 7 working hours per working day, with one hour per day for tea and lunch breaks, giving a total working shift of 8 hours.

Seven common activities were identified for the three individuals assigned to work in the bulkstores. The time spent on each of these tasks for two of the Bulkstoremen (S1 and S3) over the three days of observation, is presented in Figure 19 (detailed in Appendix H). Time was recorded in hours and/or minutes and as a percentage of the total working time (420 minutes) per day, for morning and afternoon sessions, and totalled for the full-day. The third Bulkstoreman (labelled S2) was in charge of checking-in the containers as they arrived and stamping and labelling them. Consequently he spent less time doing the other tasks, and was not considered when the

FIGURE 19: ACTIVITY AND TIME ANALYSIS
OF TWO BULKSTORMEN FOR 2 DAYS



other two Bulkstoremen manually lifted the cartons from the trolleys to the shelves.

Figure 19 illustrates the average time spent on each task by the two industrial subjects under observation. Overall, only 7.6 % (31 minutes) of their working time was unaccountable. From the activity analysis and break-down of the tasks performed, the Bulkstoremen spent more time lifting containers from the trollies to the shelves (25.1% or a total of 1 hr 45 minutes) than any of the other activities performed. It is, however, important to note that when undertaking the act of lifting containers to the shelves, there was not a continuous 1 hr 45 minutes work. Rather, it took on average no longer than 10 minutes duration per trolley. That is, it took the bulkstormen 10 minutes to off-load goods from one trolley to the shelves, once the trolley had been loaded up and transported to the relevant storage area. The extent of the lifting task was generally based on the frequency and quantity of the influx of new stock. They were not governed by a constant demand for goods on the shelves, as assembly-line workers are governed by the speed of the conveyor belt.

On completion of off-loading one trolley, the individuals rested or collected more containers from the check-in point. From general observation, the Bulkstoremen worked in their own time and rested when they considered it necessary. This was an ideal means of reducing the cumulative effect of fatigue. The lifting tasks were so varying, based on differing container sizes and shelf heights, and some of the tasks would have been more demanding than others. Consequently, the Bulkstoremen did not take regular rest breaks on the hour, but rested when they subjectively perceived the need to rest. The important fact to remember is that the individuals were involved in one task or another throughtout their working shift and did not slacken by resting more than working. The task diversification ensured that the workers were involved for the majority of the working day. Charteris *et al*. (1987) established that if workers work to task, being told that they may leave once a certain amount of work has been completed, this quota is likely to be carried out as quickly as possible to allow the worker free time to pursue other interests. This type of work option could give rise to a greater amount of cumulative fatigue than would ordinarily be experienced if the work quota was allocated and distributed over the entire 8-hour working shift. Rest periods should be regular (Heinrich, 1959), but not necessarily enforced by management. Rather, the individual actually involved in the manual tasks should be able to select when he needs a rest, within certain limits.

The next most dominant manual activity that the Bulkstoremen performed was the adjusting of containers already on the shelves in order to make space for more incoming goods. This was achieved by moving the containers and stacking them in a more orderly manner, or transferring the respective containers from one shelf to another. This activity amounted to, on average, 55.86 minutes or 13.3% of their total working time per day observed. In order to manually adjust the layout of the containers, by lifting, pushing and pulling, the Bulkstoremen actually climbed onto the shelves, which permitted them to systematically restack the cartons where necessary. This activity was performed under extreme conditions of spatial constraints, given that the vertical height between the shelves was only 88cm, and the average upright stature of the workers was 176 cm. Such a stooped posture while manually handling loads could predispose the workers to back pain due to the heavy, asymmetrical loads being placed on the intervertebral discs in the frontal plane (Grandjean, 1980).

Intermittently the Bulkstoremen would assist in the collection of pallets of goods from the Receivings Section (an average of 5.88 minutes or 1.4% of their observed working time). The pallets were generally brought through from Receivings to the Bulkstores by the workers who off-loaded the trucks at the Receivings section. Nevertheless, at times the Bulkstoremen assisted when they had no containers to stack on the shelves. When available, the two Bulkstoremen (S1 and S3) assisted the third (Bulkstoremen S2) with the checking-in process of the containers. This did not appear to be a heavy manual task, taking up on average 6.2% or 26.04 minutes per day for Bulkstoremen S1 and S3, when they stamped, labelled and counted the containers.

Once the containers had been checked in, they were transferred from the pallets onto trolleys, with Bulkstoremen S1 and S3 assisting when required for an average of 16.38 minutes or 3.9% of their working time. This particular activity of transferring the goods onto the trolleys was very variable, with a great deal of twisting and horizontal lifting, but did not form a major constituent of the daily activities of Bulkstoremen S1 and S2. While it was beyond the scope of the present study, it could be recommended that this particular activity itself be observed and analysed for the demands it imposed on the worker. It was not as controlled as the lifting of goods from the trolleys to the shelves for which the NIOSH model analysis was applicable. Other guidelines would need to be utilised, possibly in conjunction with the NIOSH model, which can deal with the twisting effects during lifting.

An important duty in any storeroom is the cleaning up and clearing away of any unused material, throwing away the broken and empty containers, sweeping and clearing the aisles. These maintenance activities generally amounted to 7.9% or 33.18 minutes per day on average for Bulkstoremen S1 and S2. It is essential for the prevention of injury that there be little, if any, obstruction in the path of the worker during the lifting and carrying of containers. Obstructions which may trip the worker or cause him to fall because they are in his movement pathway are avoidable, provided that the worksite is maintained in an orderly manner.

An equally important activity for the smooth running of any storage facility is Stock-taking, which is essential for the re-ordering of goods when stocks are depleted. For 18.8% (1hr 18.96 minutes) of their allotted 8 hour working shift, the Bulkstormen were involved in locating the goods on the shelves, counting how many were in stock and finally recording the quantity of goods on the shelves. In order to ensure that the number of containers were counted accurately the workers again climbed onto the shelves where space permitted. This, however, could not impose the same demands on the worker as when adjusting the containers as the workers either sat on the shelf or stooped with no manual activity being involved.

Finally, for 15.7% (1hr 5.94 minutes) of the time, S1 and S3 performed tasks such as running errands for management or communicating with their supervisor who appeared to be approachable. This interaction implies that management recognised the work performed by their employees and were in relatively constant close contact. Otherwise the workers talked amongst themselves or merely rested after they had executed what they perceived to be a particularly demanding task.

When comparing the morning to afternoon working periods (refer to Table IX) the Bulkstoremen S1 and S2, on average, performed more lifting in the morning. Lifting during Day 1 of observation comprised an average of 89 minutes (42% of the working period of 210 minutes) during the morning as opposed to 31 minutes (15%) during the afternoon. Although the workers were given the afternoon off on the second day of observation, they lifted for an average of 97 minutes (46%) of the morning shift. On Day 3 an average of 71 minutes (34% shift) lifting during the morning was recorded with 20 minutes (10% shift) in the afternoon.

Taking average values for the two complete days of observation during which data were collected (Table IX), the industrial subjects lifted for 80 minutes in the morning (38% shift) compared to 26 minutes (12% shift) in the afternoon. The main activity which appeared to take precedence for Bulkstoremen S1 and S2 during the afternoon working periods was stock-taking. This task averaged 5 minutes (3% shift) during the morning while an average of 74 minutes (35% shift) was recorded for the afternoon working period. Assisting with the checking-in of goods amounted to 7 minutes (4% shift) in the morning compared to 19 minutes (9% shift) during the afternoon. More cleaning-up was carried out during the afternoon (23 minutes or 11% shift) as opposed to 10 minutes (5% shift) in the morning. It appears that the majority of the relatively manual activities were performed during the morning, which may have a physiological basis in the diurnal rhythms of the workers. The cumulative effects of fatigue (Heinrich, 1959; Habes *et al.*, 1985) from the mornings activities could also induce feelings by the workers of physical inability to cope with the manual handling of many containers during the afternoon.

TABLE IX: Duration of Morning and Afternoon activities for Bulkstoremen S1 and S2 as presented in minutes and as a percentage of the total working period (210 minutes for both sessions)

	Morning		Afternoon		Full-day	
TASK	min	%	min	%	min	%
Lift to Shelves	80.0	38.1	26.0	12.4	105.0	25.0
Other	36.0	17.1	30.0	14.3	66.0	15.7
Adjust Shelves	42.0	20.0	14.0	6.7	56.0	13.3
Clean-up	10.0	4.8	23.0	11.0	33.0	7.9
Transfer Goods	9.0	4.3	7.0	3.3	17.0	4.0
Check-in	7.0	3.3	19.0	9.1	26.0	6.2
Collect Pallet	6.0	3.0	-	-	6.0	1.4
Stock-take	5.0	2.4	74.0	35.2	79.0	18.8
Unaccountable	15.0	7.0	17.0	8.1	32.0	7.6
TOTALS	210.0	100.0	210.0	100.0	420.0	100.0

Morning and Afternoon working periods last 210 minutes each, giving a total working time of 420 minutes (7 hours from an 8 hour working day as tea and lunch breaks have been subtracted).

During the days of observation prior to data collection, and the three days of activity and time analysis, the researcher was *in situ* for entire working shifts, and became *au fait* with the workers themselves, as did the workers with the researcher. The data collection procedure thus became less formidable for the workers who accepted the presence of the researcher and continued working 'normally'. There was consequently no reason to expect a Hawthorne effect in which the workers performed in such a way that they may have differed from their natural routine. All that was required of them was that they continue working their normal daily routine. The general working ambience within the bulkstores was friendly and amicable, with the Bulkstoremen working to task when new consignments of goods arrived. Once a consignment was transferred to the shelves, the workers involved themselves with other tasks, as described previously, until another consignment arrived and was checked in. It was thus evident that there was task diversification throughout the working day of the Bulkstoremen, together with a relatively positive working attitude.

Due to the relatively constant contact between management and employees, the Supervisor was able to recognise the effort afforded by the Bulkstoremen and consequently provide a reward. On one particular day of observation (day 2), he permitted the Bulkstoremen the afternoon off as they had worked particularly 'hard' in the morning, and no large consignments were arriving that afternoon. Due to there being a special offer in the Supermarket, a great quantity of stock had been received during the morning and the Bulkstoremen were required to work more rapidly than usual. The manual activity of lifting containers from the pallets to the shelving units averaged 46% of the morning (1 hr 37 minutes) as opposed to an average of lifting for 41% and 33% of the time for the other two mornings of observation.

It must be pointed out that whenever a relatively large consignment arrived, other workers assisted the Bulkstoremen. In several cases 'human chains' were formed and containers passed from one worker to another at waist level. This consequently reduced each individual's contact time with the containers as no prolonged carrying or holding was required and containers were shelved at a much quicker rate than when one individual performed the task. This process enhanced the spirit of teamwork and cooperation that prevailed with the Bulkstores of W1.

The actual temperature within the working area was kept relatively constant because of the refrigeration plant for fresh produce at the one end of the Bulkstores. The environment was thus cool and well ventilated with good lighting. The floor surface was rough which assisted in the alleviation of slippage problems when manually handling containers such as pushing/pulling pallets or trolleys. Hence there was good surface contact between the worker's shoes which had firm soles and the floor. The Bulkstoremen themselves wore overalls which did not appear to restrict their movement.

NIOSH ANALYSIS

Mathematical models obey specific rules and conditions, and as such are used in our attempts to understand human task performance and the worker-task-environment system (Kroemer, 1984). They provide a means of predicting theoretically the outcome of a particular situation, and may be assumed to provide a useful tool of interpretation and/or explanation of the circumstances surrounding the particular activity. The biomechanics of a model provide a means of predicting potentially hazardous loading conditions on certain musculoskeletal components. The same loads picked up with different postures and lifted to different heights yield different stresses on the body. These resultant stresses may either be harmless and pose no threat, or be intolerable and exceed the recommended limits for such an activity (Chaffin and Andersson, 1984). The NIOSH model was developed for the purposes of analysing the physical demands of lifting tasks. Based on the model, recommendations may be made regarding the control of hazardous situations that give rise to fatigue and strain for the working individual when performing either repetitive and non-repetitive two-handed lifts of objects of definable size and weight (NIOSH, 1981; Celentano and Nottrodt, 1984). It is important to point out that any recommendations based on a model are specific to the situation with respect to the worksite, heights, frequencies and durations of lift, object sizes and weights (NIOSH, 1981; Celentano and Nottrodt, 1984).

As has been stated previously, a computer programme was developed for quick data entry and subsequent analysis of lifting tasks, governed by the criteria of the NIOSH guideline and formulae. Of the 1020 sub-tasks analysed using the programme, one 'worst-case' sub-task was identified per task. The 'worst-case' implied that for each particular task, one sub-task had an actual mass (kg) closest to or greater than the MPL. These 'worst-cases' amounted to 191 sub-tasks, the details of which are tabulated in Appendix I with particular emphasis on the variables pertinent to the NIOSH model.

Table X is an example of the format in which the data are presented in the appendix, in the order with which the data had to be entered into the computer programme. The data were presented in this format in order to make entry into the computer system relatively quick, reading from left to right. The task code is as described previously, with Vi representing the height at the origin of the lift, and Vf the final lift height (Vf - Vi constituting the vertical lift distance). Hi and Hf correspond to the H-factors at the origin of the lift and at the completion of the lift respectively. The H-factor being the horizontal distance between the centre of mass of the container and that of the body.

The frequency of lifting is presented in lifts per minute, for which an average value was obtained for the four groups into which the containers were sub-divided according to volume. Group A had an average frequency of 14, Group B of 11, Group C of 8 and Group D of 7 lifts per minute. Duration was another factor averaged per group and is presented in hours per day. Containers in Groups A and B were lifted for the same duration per trolley which averaged 10 minutes (0.17 hours per day). The duration of handling containers in Group C was 4 minutes (0.07 hours per day) and Group D 5 minutes (0.08 hours per day). The shorter duration in Groups C and D was as a result of larger containers being handled, fewer of which fitted onto the standard-sized trolley when compared to the smaller containers in Groups A and B.

TABLE X: Tasks characteristics pertaining to the NIOSH model for ten 'worst-case' sub-tasks per task

SUB-TASK	No.of People	MASS kg	Vi cm	Vf cm	Hi cm	Hf cm	lift/ minute	Duration hrs/day
A1.1	1	2	21	100	24.0	24.0	14	0.17
B95.2	1	2	21	100	29.0	29.0	11	0.17
B6.1	1	3	21	100	25.5	25.5	11	0.17
B4.4	1	3	21	146	25.0	25.0	11	0.17
B20.2	1	4	21	100	29.5	29.5	11	0.17
A7.4	1	4	21	146	23.5	23.5	14	0.17
B5.2	1	4	21	100	26.5	26.5	11	0.17
A4.3	1	4	21	146	27.5	27.5	14	0.17
A3.1	1	4	21	100	25.0	25.0	14	0.17
B32.4	1	5	21	146	26.0	26.0	11	0.17

As a general rule, the 'worst-case' sub-task in the lifting of containers from the trolleys to the shelves, was that sub-task requiring the worker to lift the container from the base of the trolley (21cm from the floor) to either waist or shoulder level (100 and 146 cm from the floor respectively). Each 'worst-case' sub-task was analysed further for each of the 191 cases, in order to find a means of optimising the situation so as to place less strain, both physical and mental, on the worker. It was assumed that once the 'worst-case' had been optimised, all other sub-tasks per task would place even less strain on the worker. Grandjean (1973) maintains that the maximum power for lifting a container is obtained between 40 and 50 cm from the floor. In the present study lifting from 21 cm above the floor resulted in a stooped posture, thus generating greater stressors within the lower back, and other related musculature for lifting activities (Grandjean, 1980). Due to the relatively small size of the trolleys, which were generally off-loaded within 10 minutes, the workers stooped frequently in order to retrieve the containers from the base of the trolleys.

While 10 minutes may not be excessively demanding in itself, it must be realised that this procedure is followed for what amounted to one and three quarter hours of lifting per day (approximately ten times a day). The majority of musculoskeletal injuries occuring in the workplace are as a result of manual materials handling with particular attention now being focused on overexertion injuries, 60% of which over the last five years in the United States were as a result of manual lifting (Tang, 1987). MMH is the principal source of compensable work injuries in the United States amounting to 23% of all injuries, 79% of which are injuries to the lower back (Snook, 1978). Lower back injuries are not usually serious, with four out of five injured workers returning to work within three weeks (White, 1966). However, back pain predisposes the worker to further injury which could be of a more serious nature and back injuries occur frequently, affecting more than half of the working population at some stage during their working career (Rowe, 1971; Grandjean, 1973). It is generally the cumulative effects of wear and tear on the intervertebral discs in the lumbar region due to continual loading and stressing that causes the inevitable recurring discomfort preventing the individual from working satisfactorily. Initially no pain or discomfort may be felt, but as the situation continues, so the mechanisms of the lumbar system are gradually worn down until a severe condition arises which generally needs no traumatic event to occur. Chaffin and Park (1973) have found that those who lift heavy objects have eight times the number of lower back injuries compared to those who do not lift heavy objects.

Initial task factor analysis

The Pie-chart (Figure 20) and corresponding Table XI illustrate the location of the actual task masses (ACT) about the load limits (AL and MPL) of the NIOSH model for the 191 lifting tasks analysed. Of the 191 tasks, 103 were located above or equal to the MPL (53.9%), a situation whereby adjustment was deemed necessary in order to reduce the demand imposed on the worker. 83 tasks (43.5%) were between the AL and MPL and only 5 tasks (2.6%) were below the AL.

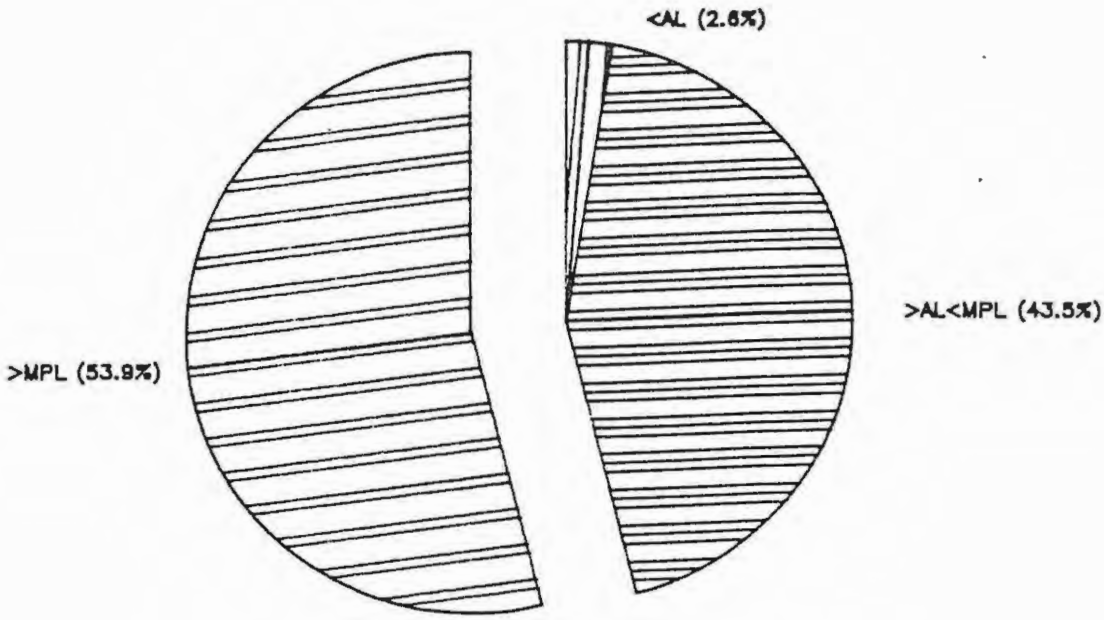


Figure 20: Location of Actual Mass (kg)
about the load limits (AL and MPL)

TABLE XI: Location of tasks according to the NIOSH Load Limits (Action Limit (AL) and Maximal Permissible Limit (MPL)). MPL was the cut-off level for the purposes of this research, and tasks with an actual mass > MPL were adjusted and optimised.

	NUMBER OF TASKS		
	<AL	>AL<MPL	>MPL
ACTUAL TASKS	5	83	103
PERFORMED	2.6%	43.5%	53.9%
OPTIMISED	5	186	0
TASKS	2.6%	97.4%	0%

% of total number of 191 tasks analysed

Figures 21, 22 and 23 provide a more dramatic illustration of the situation. The tasks, all of which were different yet identifiable by their codes, were plotted along the X-axis. The task codes for every 20th task are presented for ease of reference. Overprinting would occur if all the task codes were to be printed. For identification of one particular task, the corresponding data, in the order of tasks from left to right on the graph, is presented in Appendix J. The tasks differed in that each one had its own lift height and frequency and specific container size for a given mass. As the NIOSH model establishes recommended load limits to be lifted, the mass (kg) of each container was plotted together with the recommended load limits (MPL and AL in kg) for each of the tasks.

Due to the complexity of the nature of the tasks performed, these graph have been used merely as a presentation of the results of the NIOSH application. They provide a means of illustrating the fact that there were manual lifting tasks performed which were deemed unacceptable according to the recommended load limits (MPL and AL) where the actual mass of the task was greater than its recommended MPL. Figure 21 presents the overall picture, which is broken up into Figure 22 (the first half of the tasks with mass ranging from 28 to 13 kg) and Figure 23 (those tasks with masses ranging from 12 to 2 kg). In the two latter graphs, the task codes are presented at 10 unit intervals, with the data being more distinguishable for each task. They present a much clearer picture as to which tasks with the lower masses are greater or less than the MPL when compared to Figure 21 incorporating all the tasks on one graph.

The tasks were plotted in descending order of mass (kg) in order to reveal the effect of increasing mass on the demands imposed on the individual, based on the NIOSH mathematical model. There is great variation in the the parameters plotted (particularly the MPL and AL) and this is due to a number of factors. No one particular task factor was controlled, as it was performance *per se* that was being analysed *in situ* within a normal working environment and without any investigative

FIGURE 21: ACTUAL MASS AND LOAD LIMITS

FOR ALL TASKS ANALYSED AT W1

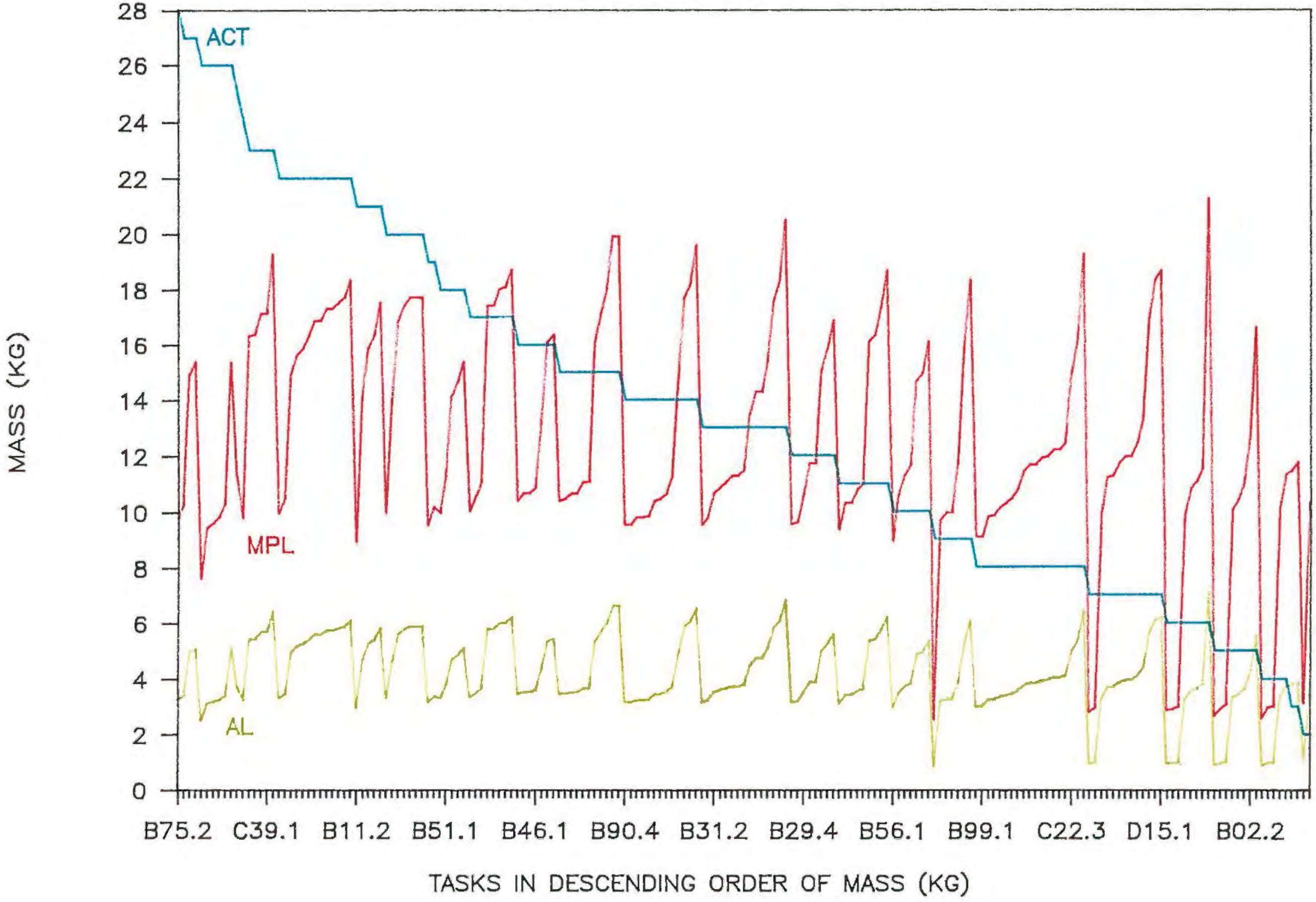


FIGURE 22: ACTUAL MASS AND LOAD LIMITS

FOR TASKS (MASS 28–13KG) ANALYSED AT W1

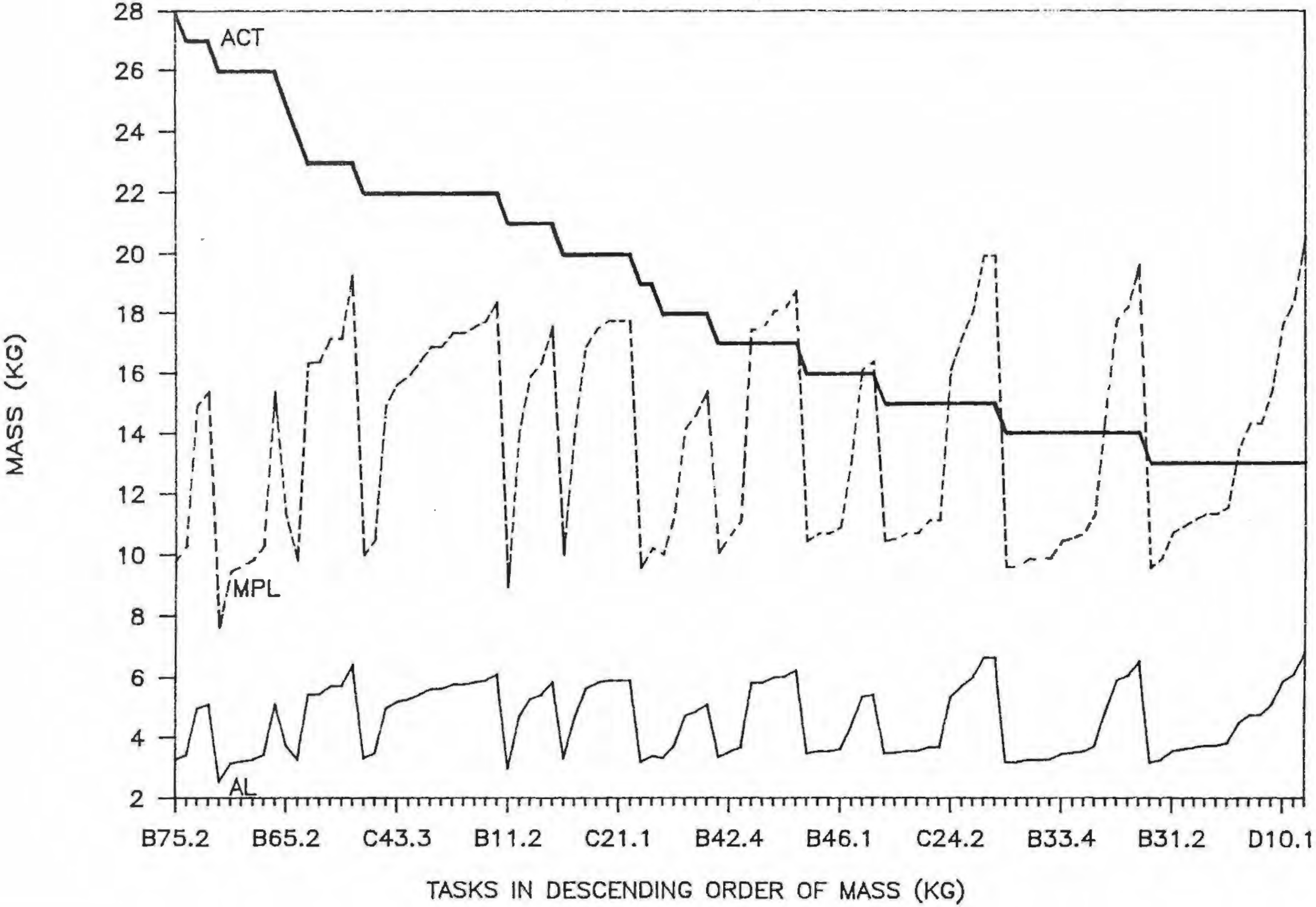
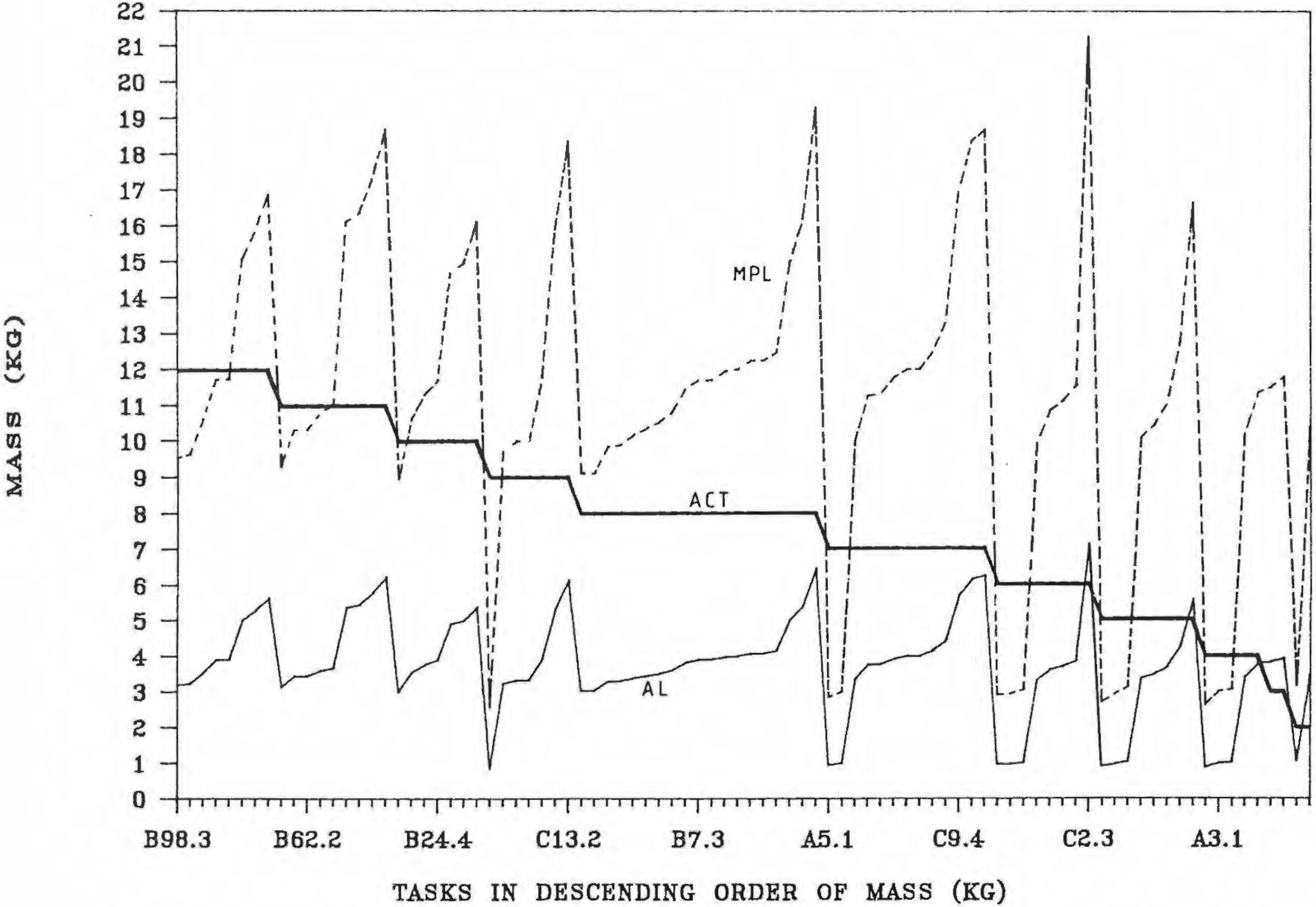


FIGURE 23: ACTUAL MASS AND LOAD LIMITS

FOR TASKS (12 – 2 KG) ANALYSED AT W1



controls being enforced upon the workers. The cartons handled were of all different sizes which consequently affected the H-factor (horizontal distance between the centre of mass of the container and that of the worker). The workers worked at their own paces (i.e. there was no set frequency or duration for task performance, and average values had to be obtained), and the containers were lifted to varying heights. These were the established heights of the four shelves, however often the containers could not be placed on the actual shelf itself, but on containers already on the shelves.

It is, however, evident that as the mass of the container increased so the demands imposed on the workers increased, which supports the findings of Chaffin and Park (1973) who established that as the load in the hands increases, so the predicted compression load on the L_5S_1 disc increases. The maximum acceptable weights that individuals are willing to lift without undue stress have been found to be significantly influenced by frequency of lift, height of lift and box size (Mital and Manivasag, 1983; Mital, 1984b). Within the bulkstores of W1, those containers with a mass above 18kg were deemed unacceptable based on the capabilities of the workforce as established by the NIOSH model. These container masses were all located above the MPL of the guideline. However, it was not necessarily the mass alone which produced the unacceptable situation. The other contributory task factors also need to be considered in the role that they played in producing the unacceptable task situation, particularly the frequency of lift and the H-factor. There were other tasks of lighter mass which fell above the MPL due to inappropriate frequencies of lift, or carton size, which emphasises the importance of looking at each task in its entirety, combining the effects of container, task and individual characteristics.

In order to establish whether there was an overall significant difference between the Actual Mass which had an average value of 13.4 kg, the Action Limit (average of 4.19 kg) and the Maximal Permissible Limit with an average value of 12.56 kg for all 191 tasks analysed, prior to any adjustments being made, an analysis of variance with 2-way classification was performed

($p<0.05$). The *post hoc* Scheffé test based on the ANOVA revealed that there was no significant difference ($p<0.05$) between actual mass and MPL. This is not to imply that the tasks were suitable if no significant differences were found; it was deemed necessary to adjust those tasks whose actual mass was greater than the MPL, the effects of which may have been hidden when considering an overall average. The action limit average was, however, significantly different ($p<0.05$) from both the actual mass and the MPL.

Task-factor adjustment

In general, the factors rendering the tasks unsuitable (actual mass greater than MPL) were the frequency and H-factors. The results of a study carried out by Ayoub *et al*. (1978) indicated that the lifting capacity of the subjects decreased almost linearly with the increase in box size and frequency of lift. Figure 24 and Table XII illustrate what percentage of the 65 tasks required adjustment of these factors, and what percentage was unaltered as the tasks were deemed suitable.

Of the 103 tasks which required appropriate adjustment due to their actual masses being greater than the recommended MPL for that particular task, 63% (65 tasks) required a reduction in frequency of lift. It has been established by Genaidy and associates (1984) that, for maximum physiological efficiency in repetitive lifting tasks of half an hour's duration, the frequency of lift should be between 5 and 11 lifts per minute, with the optimal frequency reported at 9 lifts per minute. These findings have been supported by Garg and Saxena (1979). Das (1951) found an optimum frequency of 5 lifts per minute for lifting a weight of 13 kg from floor to table height. Mital and Manivasagan (1983) have found significant differences in the effects of frequency (2 - 6 lifts per minute) on the maximal acceptable weight of lift (18 - 22 kg). Supportive research indicates that rate of lift significantly affects self-selected workloads for specific tasks (Snook, 1978; Garg and Saxena, 1979; Ciriello and Snook, 1983; Mital, 1984b). The general trend is that as frequency increases so heart rate and oxygen consumption increase while maximal weight of lift

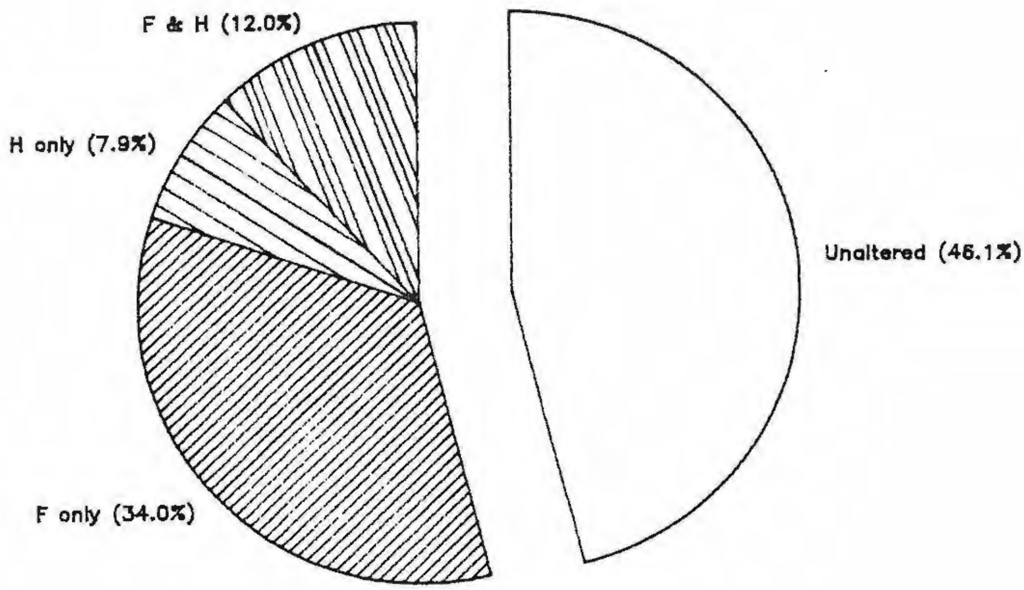


Figure 24: Task Factors adjusted
to hypothetically optimise performance

TABLE XII: Adjustment of task factors for those tasks with an actual mass > MPL. The necessary factors were adjusted as shown in order that the actual mass < MPL.

		Task factors adjusted		
	Unaltered	f only	h only	H
No. Tasks	88	65	15	23
% Total	46.1%	34.0%	7.9%	12.0%

f = frequency factor (lifts/minute)
h = horizontal distance (cm) of centre of mass of container from centre of mass of worker
H = f and h factors altered

decreases (Ciriello and Snook, 1983; Mital, 1984b; Mital and Fard, 1986).

Figure 25 illustrates the actual and adjusted frequencies (lifts per minute) plotted against mass (kg) for the 65 tasks of the present study which required a change in the frequency factor based on the NIOSH analysis. From an average frequency value of 14 lifts per minute, those tasks within Group A which required adjustment were lowered to an average value of 13 lifts per minute. Group B adjustments went from 11 to 9 lifts per minute and Group C 8 to 7 lifts per minute. Once the frequency factor had been adjusted where necessary, average frequency values were obtained per kilogram. As can be seen from the Figure 25, the adjusted 'optimal' frequencies fell into the range recommended by Genaidy and associates (1984) and Garg and Saxena (1979) with the exception of the lighter containers with a mass of 4 to 7 kg. This implied that the Bulkstoremen would be able to work at a faster rate for the lighter masses according to NIOSH (1981) than recommended by Genaidy and co-workers (1984) with respect to physiological efficiency. A Student's t-test indicated that the reductions in the frequency factor were significant ($p<0.05$).

It may be seen from the figure that the actual frequencies followed the general trend reported by Ciriello and Snook (1983) and Mital (1984b) with the exception of those containers with a mass greater than 21 kg where an increase in frequency was shown. This may not be a true representation as it could be the result of obtaining average frequency factors for each group of containers. The adjusted frequencies for the given masses based on the NIOSH model illustrate the general trend more effectively. At the higher frequencies the build up of fatigue is greater, and in order to compensate, individuals select lighter loads to lift (Mital, 1984b). In a situation where the mass is unchangeable and workers are unable to select lighter loads to lift, the frequency needs to be adjusted to compensate for the fixed mass.

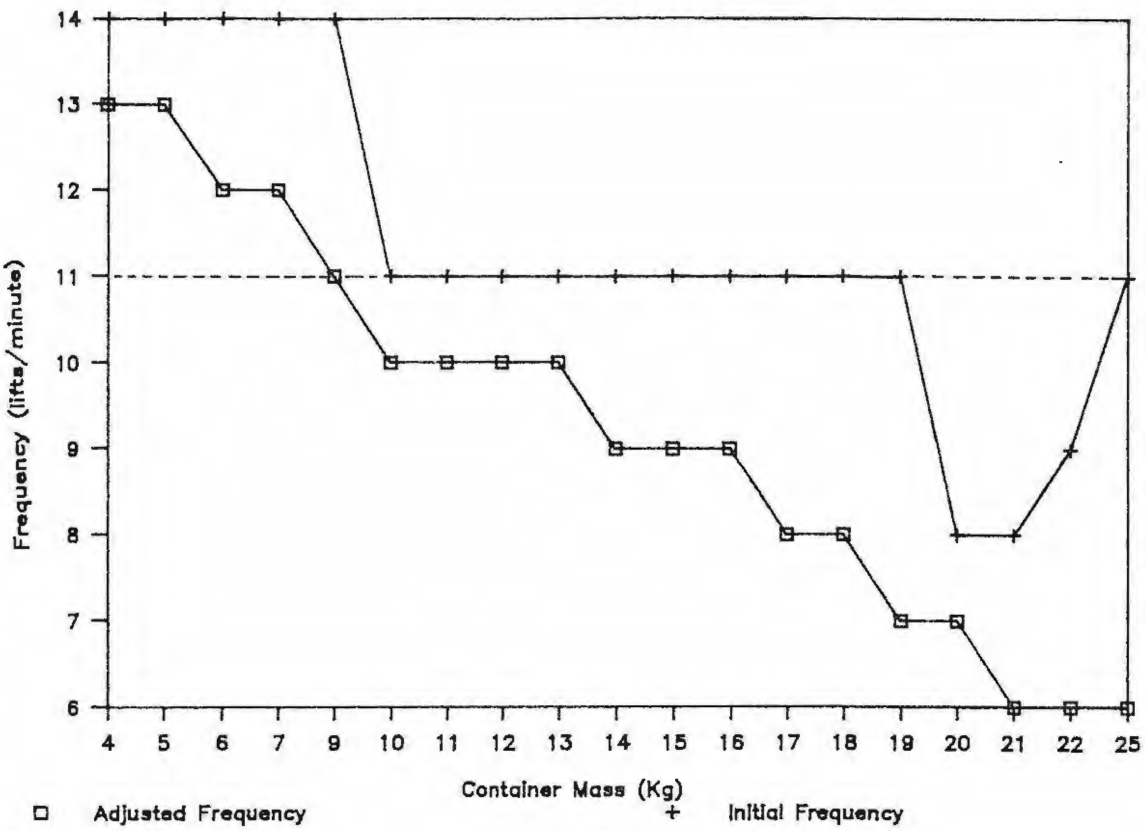


Figure 25: Frequency of lift pre- and post-adjustment where ----- is the maximum frequency level recommended by Genaidy and associates (1984) for physiological efficiency

Frankel and Nordin (1980) and Ciriello and Snook (1983) have reported that the larger the container the larger the forward bending moment acting on the L_5S_1 disc. This is essentially due to the rotational stresses imposed on the lower lumber spine. In light of this it was deemed essential to consider the size factor of the containers because, for 7.9% (15) of the tasks the NIOSH model identified the H-factor as being the most limiting factor. This was as a result of the relatively large horizontal distances between the centre of mass of the worker and of the specific containers lifted. Lifting capacity decreases with an increase in box size (Ayoub *et al.*, 1978; Mital and Fard, 1986). However, it is often not possible to reduce the size of the containers. Hence, adjustment to the H-factors was done by hypothetically adding in a second person to the lifting task. The mass handled per person was accordingly halved, and the H-factor reduced per person as a container is not usually held by both people at the centre, but closer to the edges. A standard H-factor value of 25 cm was assumed allowing for suitable handling of the containers by both people, assuming they grasped the containers at the ends.

It has been stated previously that lifting performance becomes inefficient when the frequency is reduced below 5 lifts per minute (Genaidy *et al.*, 1984) and according to the NIOSH analysis 12.0% (23 tasks) required an initial adjustment to the frequency factor as it was furthest from optimal, followed by an adjustment in the H-factor. This was due to the fact that at some stage the frequency factor was no longer the worst area where the H-factor then became the most limiting factor to performance.

Due to the fact that the initial lift height (Vi) of 21 cm created the 'worst-case' situation, the 38 tasks requiring adjustment to the H-factor were re-analysed with a Vi of 40 cm, as Grandjean (1973) indicates that maximum power for lifting a load is obtained when the object is gripped 40 - 50 cm above ground level. Subsequent t-test analysis revealed that lifting from an initial height of 40 cm produced MPL values which were significantly lower ($p<0.05$) for those tasks where the Vi was 21 cm (as in the Bulkstores of W1). It must be pointed out that this analysis was only carried out on those tasks requiring the introduction of a second person, in order to reduce the limiting H-Factor. This was necessary because the nature of the layout of the Bulkstore area was such that the narrow aisles between shelving units would restrict the working space if two individuals had to lift one container onto a shelf. Therefore, for these particular tasks the origin of lift height (Vi) was increased from 21 to 40cm, and the tasks further analysed with respect to reduction in frequency in an attempt to produce an optimal situation where ACT was less than MPL without introducing the second person.

For the total of 38 tasks re-analysed with Vi=40 cm, even though the H-factor was limiting at the outset, 6 (15.8%) of the tasks could be optimised by reducing the frequency factor to not less than 6 lifts per minute. For 8 (21.1%) tasks, the H-factor remained the limiting factor and a second person had to be introduced in order to optimise the situation. Where frequency was the limiting factor, 18 tasks (47.4%) could be optimised by reducing the frequency. For 12 of these 18 tasks where the frequency was reduced to 6 lifts per minute, the H-factor became limiting at 7 lifts per minute. 6 (15.8%) tasks which initially had a limiting frequency factor required a second individual to be introduced as frequency alone would have to be reduced below 6 lifts per minute. Therefore, although raising the intial lift height from 21 to 40 cm resulted in significant changes ($p<0.05$) in the MPL, there were still 14 tasks which required the addition of a second person in order for the task to be performed without unacceptable demand being placed on the workers.

Figures 26, 27 and 28 illustrate that the actual masses (ACT) for all the lifting tasks analysed were below the MPL after the necessary factors were adjusted with actual data presented in Appendix K. These graphs are presented in the same format as Figures 21 to 23. Figure 26 illustrates the actual masses and adjusted load limits for all 191 tasks, broken down in Figure 27 (those tasks with masses ranging from 25 to 11.5 kg) and Figure 28 (tasks with masses ranging from 11 to 2 kg). Tasks were again plotted in descending order of mass (Kg) and it can be assumed that the lighter the mass, the more acceptable the tasks become, with there being reduced differences between AL, ACT and MPL. This is, however, dependent also on the other factors that influenced task performance (size of container, height of lift and so on).

Once the tasks which were deemed unsuitable for performance had been theoretically optimised, by adjusting the relevent task factors, the overall actual mass (ACT) average for all 191 tasks was found to be significantly below the average MPL and significantly above the average AL ($p<0.05$). Due to the fact that average values tend to mask the extreme values a second analysis of variance and Scheffé test were performed on the 103 tasks requiring adjustment.

FIGURE 26: ACTUAL MASS AND LOAD LIMITS

POST--ADJUSTMENT OF VARIOUS TASK FACTORS

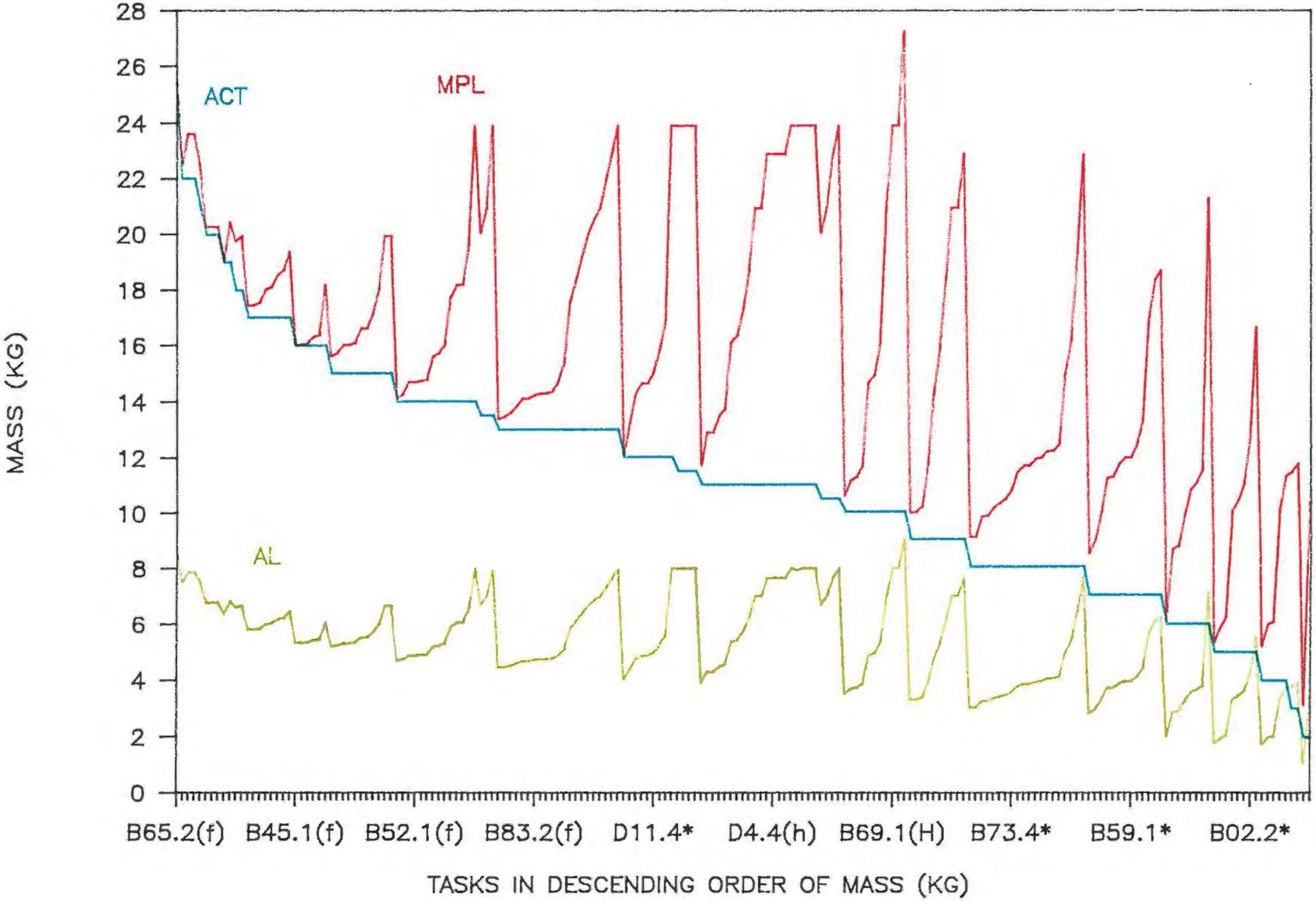


FIGURE 27: ACTUAL MASS AND LOAD LIMITS

FOR TASKS (25 – 11.5KG) POST-ADJUSTMENT

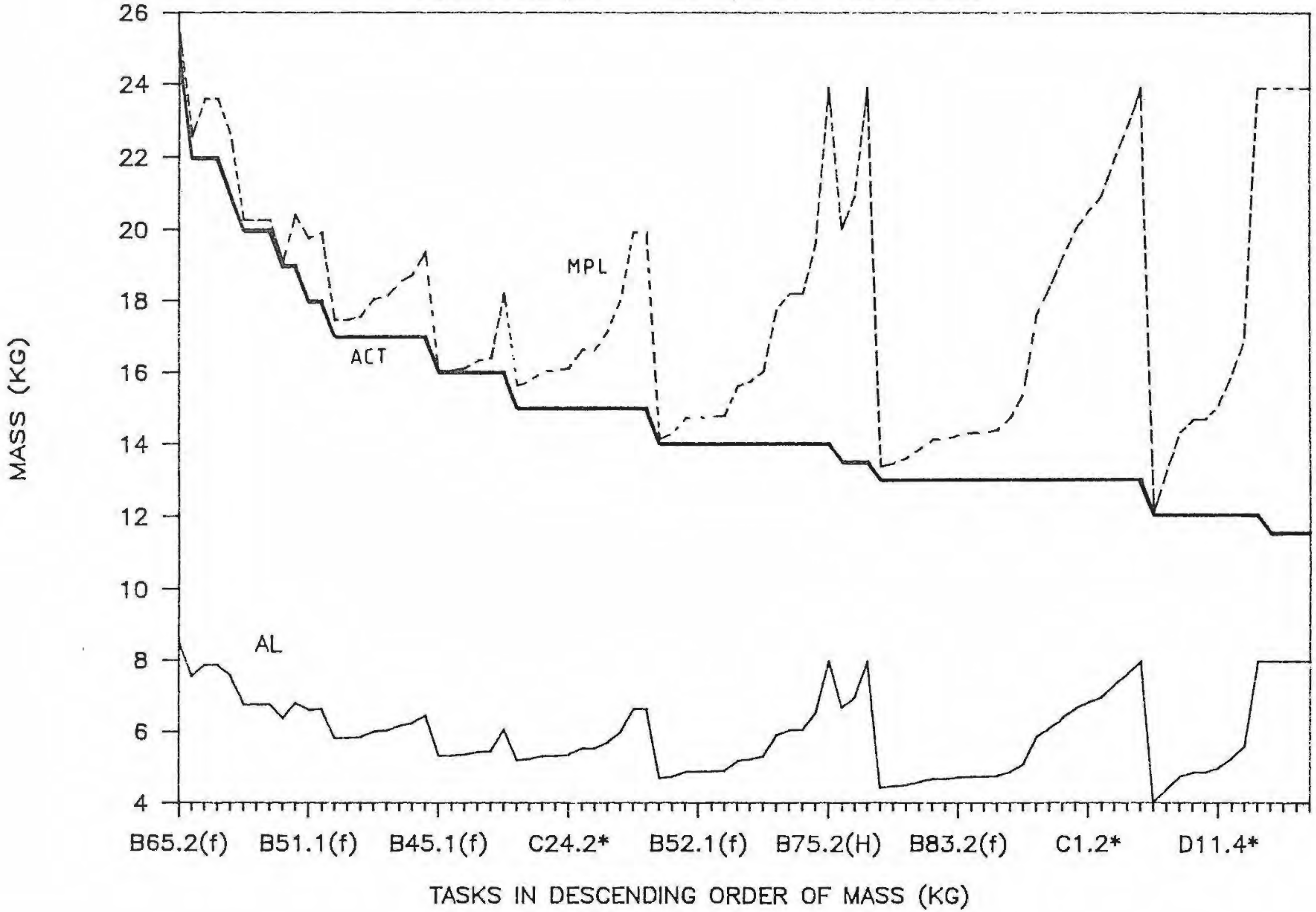
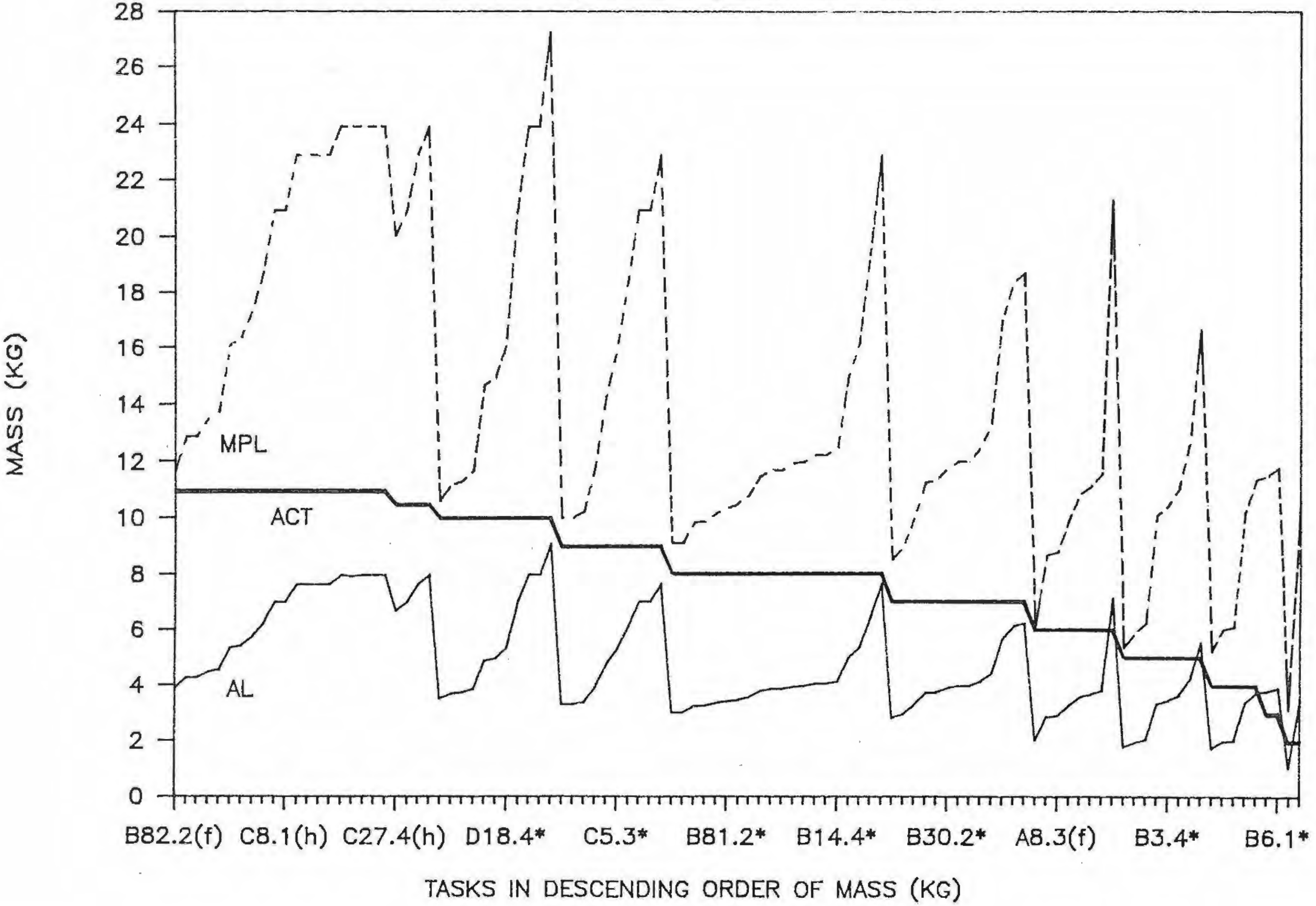


FIGURE 28: ACTUAL MASS AND LOAD LIMITS

FOR TASKS (11 – 2 KG) POST-ADJUSTMENT



For these 103 tasks deemed unsuitable, a significant difference ($p<0.05$) was found between the ACT (average of 16.8 kg) and MPL (average of 11.4kg), with the ACT and MPL both being significantly different ($p<0.05$) from the AL (3.8kg) prior to any adjustments being made. This implied that any differences between the two variables did not occur by chance, hence justifying the need for modification to task factors in order to bring the ACT below the MPL. Post-adjustment analysis revealed that the actual mass (12.7 kg) was significantly below the MPL (17.6 kg), and the AL (5.9 kg) was significantly below ACT.

The literature states that there are many factors which affect MMH task performance (Herrin *et al.*, 1974) and a multi-faceted approach was needed when analysing lifting tasks *in situ*. The NIOSH model provides for theoretical testing of possible solutions to MMH problems through the manipulation of the various task factor components built into the mathematical model. The practical application of this model in the analysis of manually lifting containers has proved to be a useful tool in the assessment of the demands imposed on the workers by the masses that they were lifting for given frequencies and heights as influenced by the container sizes and dimensions.

BODY FATIGUE AND RATINGS OF PERCEIVED EXERTION

Any part of the body which is subjected to repeated mechanical loads is liable to develop an injury, and the liklihood of such injury, caused by wear and tear or fatigue, depends not only on the size of the load but also on the frequency and duration of lifting (Peterson and Remstrom, 1986). Adaptation of the body to repeated physiological over-loading can cause sore muscles, pains in the legs and other similar conplaints as a result of an inflammatory response (Peterson and Remstrom, 1986). While mathematical models are useful tools in identifying the stresses imposed on the body they provide an objective means of analysis without consideration of the actual individual response to such demands. Perception of effort or workload is a complex phenomenon (Leplat, 1978; Carton and Rhodes, 1985) which essentially refers to a privately experienced event, a subjective reaction to physical work which can only be measured indirectly through the use of self-report techniques (Gamberale, 1985). In other words, perceived exertion can be seen as a psychological evaluation of the physical demands made on the body during physical activity (Scott, 1986). However, consistency in the individuals' interpretations of the concept of 'rating' perceived exertion when using a standardised scale such as that of Borg (1970) is a factor in RPE reliability.

Scott (1986) outlines the advancements made in recent years with respect to the usage of perceived exertion scales. One in particular has been the replacement of the verbal adjective equivalents for a particular rating such as 'very, very light' with appropriate 'behaviourial task' anchors such as 'like fishing from a small boat', with the loaded adjective of 'very, very hard' being replaced with 'like operating a jack hammer'. Hogan *et al.* (1980) utilised this revised technique and determined inter-rater reliability correlations as high as 0.98 against physiological and biomechanical parameters, even when the raters were unaware of the actual metabolic cost of the behavioural tasks. The revised perceived exertion scale has been validated against actual task performance under laboratory conditions using both physiological and biomechanical paramters (Scott, 1986). However, she maintains that for various culturally-based reasons within the South African context of a multi-ethnic society we have not yet achieved what Borg (1982) desired as a measure of perceived exertion which would be "... equally applicable to most people regardless of gender, age, circumstances and national origin". Research is ongoing (Scott, 1986) in an attempt to anchor the scale with behavioural tasks as schematic presentations which could be equally applicable to non-literate as well as literate workers, which would most importantly be reliable and valid in the sense of physiological and biomechanical correlates of task performance.

Two basic factors contribute to the perception of exertion during physical work (Pandolf, 1975; Borg, 1978), the first being the local factor of proprioceptive feelings of strain in the working muscles and/or joints. The second factor refers to sensations from the cardiorespiratory systems. In most instances peripheral input predominates over central cues, although it has been shown that pronounced central cues may dominate the perception of exertion (Carton and Rhodes, 1985). Borg (1978) states that when studying subjective aspects of physical load in natural industrial situations, emotional and experiential factors become more important. Sensory aspects of the work task need to be complimented by factors related to how the individual evaluates the work in it's total social and physical working environmental settings (Borg, 1978).

In physically demanding work, the the individuals' physical capability and psychological perceptions of both these capabilities and the demands of the job, are constantly interacting. Ultimately, the physical demands of the task influence the workers' motivation, fatigue and satisfaction, while the individual uses these psychological factors to regulate physiological work rate (Fleishman *et al.*, 1984). This was evidenced in the fact that the Bulkstoremen rested when they felt it necessary to do so, both during and between the manual lifting tasks which they performed for 25% of their working day.

The tasks performed *in situ* at W1 were not controllable in that frequencies and heights of lift, as well as the sizes and masses of the containers handled, varied. This resulted in varying demands being imposed on the workers throughout the working period due to the inconsistency of tasks performed and it was only possible to obtain an overall average perception of exertion. Ratings of perceived exertion were consequently recorded at random as it was also deemed necessary not to interfere with the performance of the workers too often.

The basic task requirement of the Bulkstoremen was to pack the containers as they came in onto the shelves, and as observed, the majority of containers appeared to have an assigned shelf upon which they were stored. A certain quantity of containers came in from the Receivings section which had to be placed on the shelves. Sometimes this quantity was large, which may have influenced the workers' perceptions of the task even before they performed it. Ratings of perceived exertion that were

recorded during the lifting of containers from trolleys or pallets onto the shelves ranged from 15 ('hard') to 20 (which represents exhaustion as a rating of 19 is 'very, very hard'). When investigating the effects of load and frequency on a selection of workloads in repetitive lifting, Nicholson and Legg (1986) found that when subjects worked with selected workloads for one hour, the work intensity was subjectively assessed as 'Fairly light' (10.5 - 11.6) using the Borg RPE scale. These high ratings in the present study may be attributed to the fact that the individuals were not able to adjust and select certain task factors such as container mass when lifting the containers. Ljungberg *et al.* (1982) established that RPE values increased with an increase in work duration although the weight remained the same and there were no substantial differences in physiological variables. It was somewhat unexpected to record such high ratings in the present study where each actual lifting task was of no greater than 10 continuous minutes duration, although they could have been the result of accumulative fatiguing effects of lifting and a perceptual response to the quantities of containers to be lifted.

The maintenance activity of cleaning-up was given the average rating of 6 (where 7 is termed 'very, very light'), as were the tasks of checking-in and price marking the containers. Pushing and/or pulling a loaded pallet of containers was rated as being between 'hard' and 'very hard' with a value of 16. When the workers assisted in the off-loading of the trucks as they arrived with a consignment of goods, the tasks was rated as being 19 ('very, very hard'). The workers termed 'Shelf-fillers' rated the restocking of shelves at 11 ('fairly light'). When the lift from the Bulkstores was out of order and the Shelf-fillers had to carry the containers upstairs to the selling area, the task was rated at 19 ('very, very hard'), as was the task of lowering the containers from the shelves within the bulkstores for price-marking of all the goods within.

Localised muscle fatigue

During lifting, localised fatigue is usually generated in the musculature involved. Mital (1983) found that RPE values pertaining to the back, shoulders and arms increased significantly with load and time for males and females. Standing posture was indicated by males to be more demanding on the back and arms, whereas females perceived it to be more demanding on the shoulders (Mital, 1983). Investigation of particular body parts which were identified as being fatigued or painful after a full day of work, the neck and shoulders were rated at 16 for the Bulkstoremen and 19 for the Shelf-fillers. A possible reason could be that the Shelf-fillers dealt more with extended reach onto the shelves sorting out the piles of cans and boxes at above head height. The sorting and arranging of produce on the shelves would require more static effort than when the Bulkstoremen lift a container onto a shelf in the storage warehouse. The end product for the Shelf-filler has to be a neat and tidy presentation for the consumer. Arms, particularly in the biceps region, were rated as being 15 and 8 for the Bulkstoremen and Shelf-fillers respectively. This discrepancy could be due to the fact that the Bulkstoremen manually lifted heavier containers, as compared to the unpacking and lifting of the smaller, lighter items by the Shelf-fillers when lifting goods onto the shelves in the selling area.

It has been outlined that lifting containers of varying sizes and masses to differing heights and at different frequencies puts a great strain on the lower back (Chaffin and Park, 1973; Frankel and Nordin, 1980; Grandjean, 1980; Mital and Manivasagan, 1983; Mital, 1984b; Habes *et al.*, 1985) In the present study ratings for the lower back ranged from 13 to 16 for the Bulkstoremen (averaging 15: 'hard'), and from 11 to 19 for the Shelf-fillers (also averaging 15). Additional sites, demarcated as being fatigued or painful by the Bulkstoremen, were their legs (15) and feet (15), probably attributable to the fact that they were involved in standing and walking activities for what totalled 43.7% of their working day (lifting containers from trolleys to shelves, adjusting containers on the shelves, transferring goods from pallets to trolleys and pushing/pulling pallets).

Care must be taken when attempting to rate the extent of fatigue or pain perceived within a selected part of the body using the RPE scale, as the terminology is not totally adequate. When rating with the Borg scale, the value of 6 was equated to 'standing quietly with no fatigue' and 20 with 'inability to lift any more cartons due to exhaustion'. In order that the workers understood the concept, the anchors were related to their specific task performance, a revision that had not wholly been validated although Hogan and associates (1980) had established that behavioural task anchors are highly reliable and correlate well with physiological and physical measure of effort (Scott, 1986). Relating the anchors to the actual task performance of the workers did, however, provide a means of objectively identifying fatigued areas of the body, and pinpointing those areas which were subjectively perceived to be more fatigued than others.

GENERAL CONCLUSION

Manual lifting is said to comprise approximately 30% of all jobs in industry today (NIOSH, 1981), and for this particular study it was found to comprise 25% of the working activities of the Bulkstoremen at the worksite under investigation. There is increasing evidence that lifting and overstraining are major causative factors related to lower back pain and other musculoskeletal injuries (Frankel and Nordin, 1980; Garg et al., 1983; Sperryn, 1983; Nicholson, 1985). The Bulkstoremen in the present study identified the neck, shoulders, arms and lower back regions as being sites of fatigue and pain after a days work, indicating that there is an obvious need for the development of suitable guidelines for the control of MMH lifting activities in industry. Ultimately this depends on the interaction between industry and scientific research for the development of injury prevention data and techniques (Nordin, 1987).

The use of the NIOSH model in this investigation revealed that on the whole the workers were not being overly stressed in terms of their capabilities and the tasks that had to be performed. Frequency of lifting appeared to be the major problem in certain instances, with container size limiting task performance in others. However, the lifting tasks were no longer than 10 minutes duration at a time, and lifting only lasted 1 hour 45 minutes per day on average, amounting to approximately 10 lifting sessions per day. Task diversification is an optimal situation in terms of varying the demands imposed on the body but if the majority of tasks performed are manual, then the overall accumulative effects of all manual tasks performed could be injurious.

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Manual Materials Handling activities such as lifting, lowering, pushing, pulling, holding and carrying are inherent in many different tasks in Commerce and Industry and may prove to be hazardous to the worker. The aim of this investigation was to make appropriate *in situ* quantification of the stresses imposed on the individual with particular attention being paid to two-handed lifting in the sagittal plane within a selected workforce in a commercial warehouse. The evaluation was based on 'Work Practices Guide to Manual Lifting' (NIOSH, 1981), which was used as the primary guide to developing theoretical recommendations with respect to probable MMH risk areas for the workers involved.

Due to the fact that the model focuses on task and container aspects that best define a hazardous lifting act, a comprehensive analysis was made of lifting task performance *in situ*, taking into consideration the task factors of frequency, duration and height of lift, and the container characteristics of mass and width (which identifies the horizontal distance between the centre of mass of the container and that of the worker during lifting). This analysis, coupled with a detailed Activity and Time Analysis of the selected workforce, enabled the identification of possible stressful situations and the proposal of appropriate ergonomically-based recommendations for consideration in the alleviation of potential risk factors for the worker, as well as recommendations for future research.

The following research hypothesis was developed for investigation ($p < 0.05$ level of significance):

There are no differences between the actual load masses lifted and the recommended load masses (Maximal Permissible Limit, or MPL) of the selected MMH tasks, as a function of lift height, reach distance and frequency as established using NIOSH (1981), for the following:

1) *Basic task performance as observed at Worksite 1.*
2) *Hypothetically optimised tasks (i.e. task factors adjusted to ensure Actual Load is less than MPL).*

METHODS

Two worksites agreed to participate in this study one of which (W1) was utilised for detailed MMH assessment within the Bulkstores storage section, with particular focus on the representative task identified as the lifting of containers from the trolleys onto the shelves . There were three workers (mean age 34 ± 8.5 years; body mass 73.6 ± 5.5 kg; Stature 176 ± 2.2 cm) assigned as Bulkstoremen, two of whom regularly performed two-handed lifting in the sagittal plane when lifting the containers. Several anthropometric measurements were taken (reach height 205 ± 3.3 cm; shoulder height 146 ± 1.6 cm; waist height 100 ± 7.1 cm) which aided in the identification of sub-tasks during the process of lifting the containers from trolley to shelf. During data collection *in situ* the workers were required to continue working through their normal daily routine and an observational methodology for data collection was selected in order to alleviate the amount of interference with the workers' performance.

The worksite (W1) was visited on several occasions during which 191 cartons and carton-like containers were measured (dimensions and mass), as were the heights and layout of the shelving units to which the containers were lifted. The containers were categorised into four groups according to their volume. During three subsequent visits a detailed Activity and Time Analysis was carried out on the tasks performed by the Bulkstoremen as part of their normal daily routine and average lifting frequencies and task durations were obtained. Based on the data collected *in situ* a comprehensive NIOSH analysis was performed using a modified computer programme. At random intervals ratings of perceived exertion were measured with respect to the lifting task analysed, and on completion of a full working day the workers identifed (on a schematic diagram of a human body) areas of localised fatigue and/or pain which they quantified using the RPE scale.

The results were analysed using two-way analysis of variance, Scheff tests and Student t-tests for related samples. A 0.05 level of probability was selected ($p < 0.05$).

RESULTS AND CONCLUSIONS

1) When looking at the distribution of containers as they were lifted to each assigned shelf, it was established that on average the heaviest and second to largest containers were lifted to Shelf 3 (220 cm from the floor) which was out of the average normal reach range of the workers (205 cm, as against the reach height built into the NIOSH model, 175 cm). Care should be taken when lifting heavy containers to extreme heights (Habes *et al.*, 1985), and it is recommended that the lighter containers be stored on the higher shelves, with the larger, heavier containers at a more accessible level.

2) The Activity and Time Analysis established that the Bulkstoremen lifted containers onto shelves for approximately 25% of their allotted 7 working hours of the 8 hour shift. This was, however, not a continuous lifting period of 1 3/4 hours. The workers generally performed repeated lifts for no greater than 10 continuous minutes, with these lifting tasks being interspersed with periods of rest when it was deemed necessary by the workers, along with carrying out their other duties as established during the activity analysis.

3) The lifting of containers from the trolleys to the shelves was not the only lifting performed by the Bulkstoremen. It was, however, the only lifting which had a relatively standardised format (being two-handed and in the sagittal plane). Other lifting occurred when the Bulkstoremen transferred containers, once the goods had been checked in, from the in-coming pallets to the trolleys where a great deal of twisting and horizontal lifting was evident. When adjusting and restacking the containers already on the shelves the Bulkstoremen worked with enforced stooped postures due to the vertical spatial constraints between the shelves and here they often combined lifting with pushing and pulling.

4) The fatigue and/or pain reported by the Bulkstoremen at the

end of each working day may have been the result of a cumulative response to the varying MMH activities performed during each working shift and not only as a result of the lifting task under direct investigation.

5) The worst case identified by NIOSH for the lifting tasks studied occurred when grasping and lifting a container from the base of the trolley which required a stooped posture. Raising the height of the trolley from 21 to 40 cm from the floor (a height at which Grandjean (1973) maintains the individual has maximum power for lifting a load) significantly reduced the demands imposed on the worker based on the NIOSH analysis and the MPL limit. Although it could be recommended that the trolley height be raised, care must be taken when loading the trolley due to the fact that if too many containers are placed on top of one another, the containers at the top would now impose great demands on the body due to the excessive upward reach or vertical component of the lift.

6) The overall average values for Actual Mass (ACT), Action Limit (AL) and Maximal Permissible Limit (MPL) for all 191 tasks analysed (based on the initial NIOSH analysis prior to any necessary adjustments being made to task factors) revealed no significant differences between the ACT and MPL. Both the ACT and MPL were significantly greater than the AL. In focusing only on the 103 tasks requiring some form of task-factor adjustment, the ACT was found to be significantly greater than the MPL prior to adjustment, which justified the need for task modification.

7) Once the necessary task related factors had been adjusted as recommended by the NIOSH model, there was a significant difference ($p < 0.05$) between all three variables of ACT, AL and MPL. The ACT was significantly lower than the MPL indicating that the adjustments resulted in a significant reduction in the risk factor for the workers. Again both the ACT and MPL were significantly greater than the AL.

8) Lift frequency exerts a major influence on the capability of the worker in that, with an increase in frequency, there is a

resultant increase in the physiological demands imposed on the individual. Generally, lighter loads are deemed acceptable at the increased work rates. Alternatively, with the heavier loads it is generally acceptable to work at slower rates. The workers in the present study tended to operate at a faster rate than recommended by NIOSH for a each given mass lifted. Based on the NIOSH analysis a significant reduction in the rate of lift was initiated.

9) The larger the container the greater the load moment acting on the L_5S_1 disc. In order to reduce the H-factor NIOSH (1981) recommends the introduction of a second person, a solution which may not always be possible due to spatial constraints between the working aisles. Reductions in the frequency factor, even when the H-factor was limiting, brought the majority of the tasks to within the acceptable levels of the NIOSH model. However, it is recommended that the larger, heavier containers be handled by two people within W1, as reductions in frequency alone to levels deemed physiologically inefficient would not prove to be feasible.

10) Many task factors are known to influence task performance (Herrin *et al.*, 1974), however, within these factors themselves there is a great variability. The majority of these factors were prevalent in the situation under investigation where there was great variety in the sizes and masses of containers handled and varying task characteristics of frequency, duration and height of lift. It was deemed impossible to view one particular factor in isolation. Two important factors of size and mass influence the loads on the spine and in the present study it was found that larger containers of a lighter mass produced less torque than smaller containers of a heavier mass. However, height and frequency of lift also influence the stress on the lower lumbar region, as well as the mass which is deemed acceptable for lift. Larger, heavier containers should therefore be lifted to acceptable heights (probably between knuckle and shoulder height) based on the capabilites of the workers.

11) Generally the ambient working conditions within the

Bulkstores were positive, as were relations between the workers themselves and between workers and management. If a large consignment of containers arrived, other workers would assist in the lifting of the containers onto the shelves eliciting a spirit of teamwork. When lifting to the higher shelves one worker would stand on a ladder or astride the shelves while the second either passed or threw the containers up to him. Such teamwork and assistance may help to create a positive working environment.

HYPOTHESIS ACCEPTANCE/REJECTION

The findings of this study lead one to reject the research hypothesis ($p < 0.05$) that:

no differences exist between the actual masses lifted and the recommended load (Maximal Permissible Limit, or MPL) of the selected MMH tasks, as a functin of lift height, reach distance and frequency as established using NIOSH (1981), for the following:

1) *Basic task performance as observed at Worksite 1.*
2) *Hypothetically optimised tasks (i.e. task factors adjusted to ensure Actual Load is less than MPL.*

RECOMMENDATIONS

1) When assessing the demands imposed on the worker *in situ* all the various tasks performed during the entire work shift should be evaluated. Although one particular task may be performed for a greater percentage of the working day, other MMH activities of shorter duration may ultimately predispose the worker to a greater risk of injury. One also needs to consider the cumulative fatiguing effect of the various tasks performed by the workers during their working shift.

2) Considering that the NIOSH model was developed to suite European and North American standards for worker capabilities, the model should be examined further with respect to its applicability for the manual labour workforce populations within South Africa. In developed countries there has been a trend towards a reduction in the amount of work regarded as 'heavy' with a resultant decrease in the number of work-related

injuries when compared to the number of accidental deaths and injuries which constitutes a serious and growing problem in developing nations (Asogwa, 1987; Jardel, 1987). With adequate understanding and interpretation of the situation prevalent in developing countries, the opportunity exists for the adaptation and modification of modern technologies to suit the requirements of the less developed countries.

3) It is deemed essential that the NIOSH (1981) model not be used in isolation but in conjunction with some physiological and/or biomechanical parameter(s) when assessing the demands imposed on the workers during MMH task performance *in situ*. This would provide an assessment that is specific to the actual workforce being evaluated and not purely based on the model criteria. The problem here arises in the collection of physiological and biomechanical data *in situ* without interferring with the normal working routine of the workers. It is suggested for future research within the same field that laboratory simulations of task performance also be performed, based on the specific task requirements under investigation, in order to obtain physiological and biomechanical standards specific to the performance to be examined *in situ*.

4) Assessing the nature of lifting tasks performed within a warehouse situation is relatively complex due to the large variety of shape, size and mass of the containers and varying shelf heights for storage. Bearing this in mind, attempts should be made under laboratory simulation to develop a set of standards to be used as guidelines. These should take into consideration the particular sizes and masses of the containers to be lifted, the frequencies and given heights of lift for a relatively short duration per task (of not greater than 15 minutes for small warehouse operations such as Worksite 1).

5) Frequency is an important task factor to consider when assessing the physical demands of a lifting task *in situ*. In the present study frequency, which was the major task factor to require adjustment according to the NIOSH model, was obtained as an average value for each group into which the containers were categorised. It is suggested that in future research only

those specific tasks be assessed for which their particular frequency has actually been measured. This implies that a great amount of field work needs to be carried out in order that the evaluation be more precise for each individual task.

6) Perceived exertion can be viewed as a psychological evaluation of the physical demands made on the body during physical activity (Scott, 1986). However, consistency in the individuals' understanding of the concept of 'rating' perceived exertion when using a rating scale is a factor in RPE reliability. In order to ensure that the individuals understand the concept related to their task performance situation *in situ*, the explanation of the rating procedure and the particular adjective or behavioural anchors for the rating scale should be specifically related to their task performance.

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APPENDIX A

SOUTH AFRICA

The Republic of South Africa is located on the southern most tip of the African continent, occupying a total of 122 042 square kilometers. This area extends from the Limpopo river in the north to Cape Agulhas in the south, and shares common boundaries with Mozambique, Swaziland, Zimbabwe, Botswana and South West Africa/Namibia. The independent state of Lesotho is encircled by South African territory, as are those of the Ciskei and Bophuthatswana, with Transkei adjoining Lesotho to the south-west These areas and others designated as "homelands" (now termed National States) occupy about 12% of the total land area (Omer-Cooper, 1978).

South African Population Dispersion

Nattrass (1981) classifies four main populatino groups within South AFrica which are as follows, in order of number according to a 1985 mid-year population census supplied by the Department of Statistics, Pretoria (figures presented as total number and then as percentages of the total population):

- Black: those speaking Bantu languages (20 004 or 72%)
- White: mainly people of European descent (4 525 or 16%)
- Coloureds: of mixed racial origin (2 554 or 9%), and
- Asian: individuals of Indian descent (802 or 3%)

Of these population groups, the Blacks' comprised 72% of the workforce in South AFrica, the Whites 18%, Coloureds 8% and Asians 2%. Looking at the occupational distributions of the population groups as in 1977, in the area of unprofessional labour (a category under which certain manual labour falls) Blacks' constituted 85.5%, Coloureds' 10.6%, Asians' 3.1% and Whites 0.5% (Department of Labour Manpower Survey No. 12, 1977). Subsequent to this survey, South African Blacks' have entered the higher job categories in increasing numbers, evidence that labour migration is occuring. However, there is still a great percentage of manual labour prevalent in South

African industries, and as such, relevant guidelines should be developed and adapted for the target workforce population.

From 1970 to 1980, the total population of South Africa (excluding the Independent States) increased by an average of 2.8%, while the black population increased by 3.2% (Walton, 1984). 46% of the country's people live in the Transvaal (TVL), 28% in the Cape Province, most of them in South-West and Eastern Cape, while 15% live in Natal, and 11% in the Orange Free State (Table 1).

There has been a steady increase in urban population, for which the development of industry and commerce and job opportunities have been mainly responsible. Walton (1984) proposes that a greater increase would have been experienced if national and independent states had not been established for the blacks, with the government setting up strict influx control and residency rules.

Nattrass (1981) sums up the situation within South Africa adequately, bearing in mind that the rate of economic growth is an important factor for the development of a country:

"South Africa has the somewhat unhappy reputation of being one of the most unequal societies in the world, yet one that has, over the past sixty years, enjoyed one of the fastest rates of economic growth".

TABLE 1: Provincial population distribution by group in SA (from: Walton, 1984)

PROVINCIAL POPULATION DISTRIBUTION (per 1000)					
Pop. grp.	Cape	OFS	Natal	TVL	TOTAL
Black	1 569	1 550	1 358	5 645	16 924
White	1 264	326	562	2 362	4 528
Coloured	2 226	56	91	228	2 613
Asian	32		665	116	821
TOTAL	5 091	1 932	2 676	8 351	24 886
% tot. pop	28	11	15	46	

APPENDIX B

Characteristics of Major Components Affecting Manual Materials Handling System (Herrin *et al.*, 1974)

==

Worker Characteristics

Physical: include general worker measures, such as age, sex, anthropometry, postures.

Sensory: measures of worker sensory processing capabilities, such as visual, auditory, tactual, kinesthetic, vestibular, proprioceptive.

Motor: measures of worker motor capabilities, such as strength, endurance, range of movement, kinematic characteristics, muscle training state.

Psychomotor: measures of worker capabilities interfacing mental and motor processes, such as, information processing, reaction/response time, coordination.

Personality: Measures of worker values and job satisfaction by attitude profiles, attribution, risk acceptance, perceived economic need.

Training/experience: measures of the worker education level in terms of formal training or instruction in manual material handling skills, informal training, work experience.

Health status: measures from worker general health appraisal, such as, previous medical complaints, diagnosed medical status, emotional status, regular drug usage, pregnancy, diurnal variations, deconditioning.

Leisure time activities: measures of the person choosing to be involved in physical activities during leisure hours, such as, holding a second job or regular participation in sports.

Material/Container Characteristics

Load: measures of force, weight, pushing/pulling force requirements, mass moment of inertia.

Dimensions: measures of size of unit workload, such as, height, width, breadth when indicating the form as rectangular, cylindrical, spherical etc.

Materials/Container Characteristics (Cont.)

Distribution of load: measure of the location of the unit load CG with respect to the worker for one handed or two handed carrying.

Couplings: measures of simple devices used to aid in grasping and manually manipulating the unit load, such as, texture and handle size, shape and location.

Stability of load: measures of load CM location consistency as a concern in handling liquids and bulk materials.

Task Characteristics

Workplace geometry: measures of the spatial properties of the task, such as, movement distance, direction and extent of path, obstacles, nature of destination.

Frequency duration/pace: measures of the time dimensions of the handling task including frequency, duration, and required dynamics of activity over the short term and long term.

Complexity: measures of combined or compounding demands of the load, such as, manipulation requirements of movement, objective of activity, precision of motion tolerance, number of kinetic components.

Environment: measures of added deteriorative environment factors, such as, temperature, humidity, lighting, noise, vibration, foot traction, seasonal toxic agents.

Work Practices Characteristics

Individual: measures of operating practises under the control of the individual worker, such as, speed and accuracy in moving objects, postures (i.e. lifting techniques) used in moving objects.

Organizational: measures of work organization, such as, physical plant size, staffing of medical/hygiene/engineering and safety functions, and utilization of teamwork.

Administrative: measures of administration of operating practises, such as, work and safety incentive system, compensation scheme, safety training and control, hygiene and safety surveys, and medical aid and rescue, long work shifts, rotation, personal protective devices.

APPENDIX C

RHODES UNIVERSITY

DEPARTMENT OF HUMAN MOVEMENT STUDIES

SUBJECT/INDUSTRY CONSENT FORM

I certify that I, and the workers, have been informed of the research entitled **IDENTIFICATION AND ANALYSIS OF MANUAL MATERIALS HANDLING TASKS WITHIN A COMMERCIAL WAREHOUSE IN SOUTH AFRICA**, and have voluntarily agreed to participate in the project.

PROCEDURES, RISKS AND BENEFITS

Selected workers will act as subjects in the above-mentioned research, as decided upon by the nature of their daily activities. The subjects will be required to continue working as in their normal daily working routine as established for their particular working task. Their performance will be interrupted as little as possible, and will not be adapted in any way. Personal information that will be required are the subjects' age, body mass, stature, reach, shoulder and waist heights, the presence of any ailments and a rating of perceived exertion for a given task will be taken. Task information that will be gathered include size and mass of containers handled, heights, frequency and duration of lifting or lowering, and general layout of the working area.

There are no additional risks that may be encountered during this data collection session, to those that may occur during the normal daily working routine. In the event of a video tape recording being made, the recordings wil be used solely for the purpose of analysing performance on the specified task, and confidentiality maintained at all times.

The benefits to be obtained from this research are founded in your contribution towards the advancement of our knowledge in an area that is relatively underdeveloped within the South African industrial environment. Where the demands of a task, as established by model guidelines, exceed the workers' capabilities, recommendations can be made with respect to probable alleviation of this potential mismatch. The aim being to reduce the chance of lower back pain and other such ailments that prevail in tasks of this nature in industries world-wide.

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(MANAGER)	(DATE)

I am fully aware of the procedures involved as well as the potential risks and benefits attendant to my participation as explained to me verbally and in writing. In agreeing to participate in this research, I waive any legal recourse against the researchers or Rhodes University, from any and all claims resulting from personal injuries sustained. This waiver shall be binding upon my heirs and personal representatives. I realize that it is necessary for me to promptly report to the research any signs or symptoms of discomfort indicating any abnormality or distress.

I am aware that I may withdraw my consentand withdraw from participation in the research at any time. I am aware that my anonymity will be protected at all times, and agree that the informatin collected may be used and published for statistical or scientific purposes.

I have read the foregoing and I understand it. Any questions which may have occurred to me have been answered to my satisfaction.

MANAGER

---------------------- ---------------------- -----------
(Print Name) (Signature) (Date)

PERSON ADMINISTERING INFORMED CONSENT

---------------------- ---------------------- -----------
(Print Name) (Signature) (Date)

WITNESS

---------------------- ---------------------- -----------
(Print Name) (Signature) (Date)

PROJECT SUPERVISOR

---------------------- ---------------------- -----------
(Print Name) (Signature) (Date)

APPENDIX D

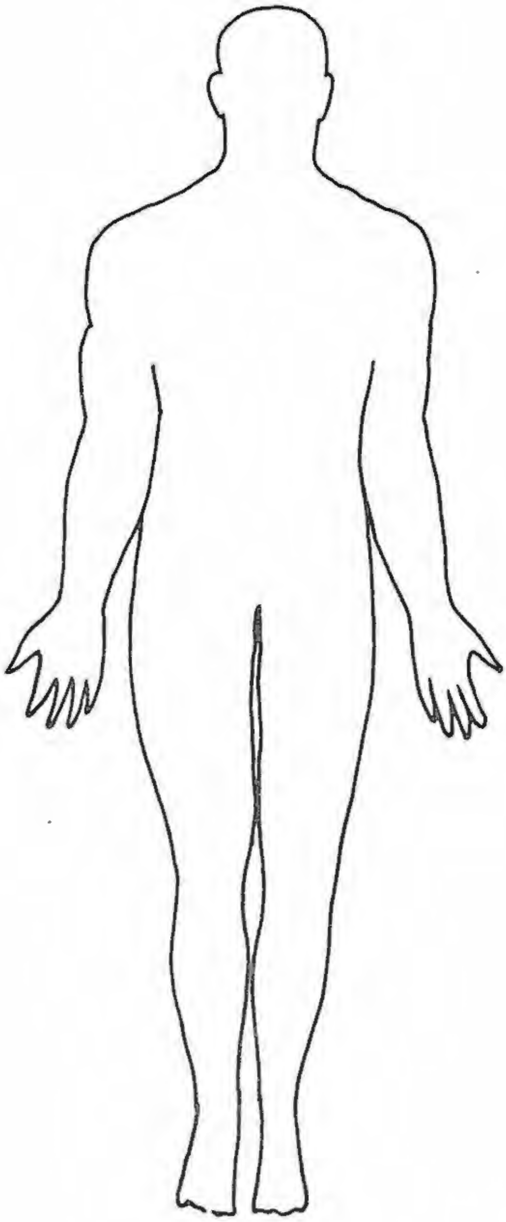
Date:....................

Name/Code:................

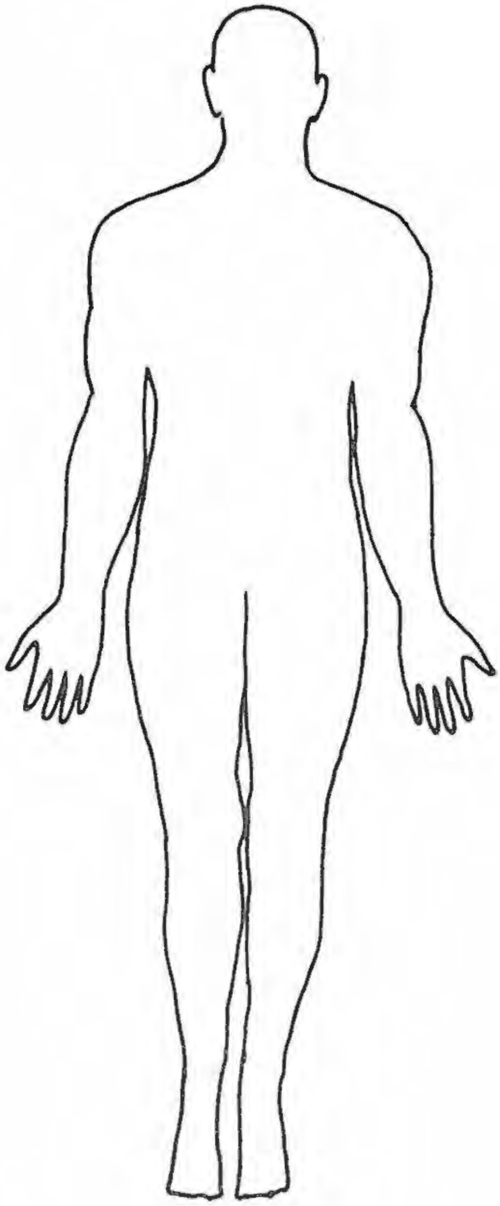
Occupation:...............

RPE scale (Borg, 1970)

6	
7	Very, very light
8	
9	Very light
10	
11	Fairly light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Very, very hard
20	



ANTERIOR



POSTERIOR

APPENDIX E

LIFTING TASK ANALYSIS USING THE NIOSH MODEL

****

INPUT DATA

TASK CODE A3.1

Task no.	1	1.1	1.2	1.3	1.4
No. of Persons	1.00	1.00	1.00	1.00	1.00
Object Mass (Kg)	4.00	4.00	4.00	4.00	4.00
Hand Ht, Init. (cm)	21.00	21.00	21.00	21.00	21.00
Hand Ht, Final (cm)	100.00	100.00	100.00	100.00	100.00
Horiz. Hand Dist, Init. (cm)	25.00	25.00	25.00	25.00	25.00
Horiz. Hand Dist, Final (cm)	25.00	25.00	25.00	25.00	25.00
Rate of lift (lifts/min)	14.00	13.00	12.00	11.00	10.00
Task Duration (hrs/day)	0.17	0.17	0.17	0.17	0.17

RESULTS OF ANALYSIS

Task No.	1	1.1	1.2	1.3	1.4
Lift Dist. (cm)	79.00	79.00	79.00	79.00	79.00
Mass/Person (Kg)	4.00	4.00	4.00	4.00	4.00
ACTION LIMIT (Kg)	1.00	1.99	2.99	3.99	4.99
MAX. PERMISSIBLE LIMIT	2.99	5.98	8.97	11.97	14.96
Mass/Pers as of % AL	401.14	200.57	133.71	100.28	80.23
Fmax (lifts/min)	15.00	15.00	15.00	15.00	15.00
H Factor	0.60	0.60	0.60	0.60	0.60
V Factor	0.78	0.78	0.78	0.78	0.78
D Factor	0.79	0.79	0.79	0.79	0.79
F Factor	0.07	0.13	0.20	0.27	0.33

LIFTING TASK ANALYSIS USING THE NIOSH MODEL

****

INPUT DATA

TASK CODE D20.4

Task no.	1	1.1
No. of Persons	1.00	2.00
Object Mass (Kg)	16.00	8.00
Hand Ht, Init. (cm)	146.00	146.00
Hand Ht, Final (cm)	200.00	200.00
Horiz. Hand Dist, Init. (cm)	43.50	25.00
Horiz. Hand Dist, Final (cm)	43.50	25.00
Rate of lift (lifts/min)	7.00	7.00
Task Duration (hrs/day)	0.08	0.08

RESULTS OF ANALYSIS

Task No.	1	1.1
Lift Dist. (cm)	54.00	54.00
Mass/Person (Kg)	16.00	4.00
ACTION LIMIT (Kg)	5.06	8.81
MAX. PERMISSIBLE LIMIT	15.19	26.43
Mass/Pers as of % AL	316.02	45.41
Fmax (lifts/min)	18.00	18.00
H Factor	0.34	0.60
V Factor	0.72	0.72
D Factor	0.84	0.84
F Factor	0.61	0.61

APPENDIX F

RELEVANT INFORMATION PERTAINING TO THE 191 CONTAINERS
MEASURED AND RECORDED FOR DETAILED TASK ANALYSIS

CODE	LENGTH [cm]	WIDTH [cm]	HEIGHT [cm]	MASS [kg]	VOL [cm3]	DESCRIPTION
A1.1	17.0	18.0	12.0	2.0	3672.0	CLIFTON
A2.2	22.0	18.0	13.0	5.0	5148.0	SPICES
A3.1	26.0	20.0	12.0	4.0	6240.0	INSTANT POSTUM
A4.3	31.0	25.0	9.0	4.0	6975.0	PULVEX DOG POWDER
A5.1	35.0	23.0	10.0	7.0	8050.0	PURITY BABY APPLES
A6.2	27.0	20.0	15.0	7.0	8100.0	BAKED BEANS
A7.4	31.0	17.0	16.0	4.0	8432.0	SELF SHINE
A8.3	27.0	19.0	17.0	6.0	8721.0	COOPER DOG SHAMPOO
A9.4	22.0	17.0	25.0	6.0	9350.0	GLAD BAGS
A10.4	26.0	19.0	20.0	5.0	9880.0	GLAD BAGS
A11.1	29.0	22.0	16.0	6.0	10208.0	SUN RINSE AID
A12.4	39.0	26.0	11.0	9.0	11154.0	GILLETTES CLEANER
A13.2	29.0	26.0	15.0	5.0	11310.0	CADBURYS SNACKER
B01.2	34.0	23.0	15.0	10.0	11730.0	PURITY JUICE
B02.2	35.0	17.0	20.0	5.0	11900.0	ROYAL JELLY
B03.W	50.0	30.0	8.0	14.0	12000.0	SUGAR *
B1.4	36.0	27.0	13.0	5.0	12636.0	HARPIC FLUSHMATIC
B2.1	30.0	22.0	21.0	13.0	13860.0	POG BAKED BEANS
B3.4	35.0	25.0	16.0	5.0	14000.0	PYOTTS DELIGHTS
B4.4	37.0	20.0	20.0	3.0	14800.0	HARPIC POP-IN
B5.2	43.0	23.0	15.0	4.0	14835.0	PURITY RICE CEREAL
B6.1	27.0	21.0	27.0	3.0	15309.0	FILTERA PAPERS
B7.3	31.0	19.0	26.0	8.0	15314.0	BAKERS EET SOM MORE
B8.4	30.0	22.0	24.0	11.0	15840.0	BROOKES OROS
B9.2	36.0	15.0	30.0	7.0	16200.0	BAKERS CARAM.RIPPLES
B10.1	31.0	23.0	23.0	13.0	16399.0	POG SARDYNE
B11.2	45.0	37.0	10.0	21.0	16650.0	POG RICE *
B12.4	32.0	21.0	25.0	7.0	16800.0	BAUMANN GINGERNUTS
B13.2	32.0	19.0	28.0	8.0	17024.0	BAKERS GINGERNUTS
B14.4	32.0	18.0	30.0	8.0	17280.0	BAUMANNS TENNIS
B15.1	31.0	18.0	31.0	7.0	17298.0	BAKERS TENNIS
B16.2	39.0	24.0	19.0	6.0	17784.0	POG BISCUITS
B17.4	31.0	24.0	24.0	10.0	17856.0	SUNLIGHT FAB.SOFTEN.
B18.2	30.0	23.0	26.0	13.0	17940.0	FORTRUS JUICE
B19.1	45.0	19.0	21.0	8.0	17955.0	BAKER ROYAL CREAMS
B20.2	32.0	29.0	20.0	4.0	18560.0	PURITY BABY FOOD
B21.4	29.0	23.0	28.0	11.0	18676.0	JIK
B22.1	33.0	21.0	27.0	12.0	18711.0	PLAINWRAP CANDLES
B23.1	33.0	21.0	27.0	12.0	18711.0	POG CANDLES
B24.4	38.0	19.0	26.0	10.0	18772.0	NUGGET
B25.1	41.0	27.0	17.0	14.0	18819.0	MONIS
B26.2	39.0	23.0	21.0	7.0	18837.0	SCOTCH SHORTBREAD
B27.3	35.0	30.0	18.0	19.0	18900.0	BULL BRAND
B28.1	33.0	36.0	16.0	8.0	19008.0	BRAN HIGH FIBRE
B29.4	35.0	24.0	23.0	12.0	19320.0	ZEB
B30.2	32.0	21.0	29.0	7.0	19488.0	BAKERS PROVITA
B31.2	42.0	26.0	18.0	13.0	19656.0	KOFEEHUIS
B32.4	36.0	22.0	25.0	5.0	19800.0	BAUMANNS BISCUITS
B33.4	33.0	25.0	24.0	14.0	19800.0	LECOL
B34.4	33.0	25.0	24.0	15.0	19800.0	SQUEEZE A DRINK
B35.2	37.0	30.0	18.0	7.0	19980.0	NON DAIRY CREAM

CODE	LENGTH [cm]	WIDTH [cm]	HEIGHT [cm]	MASS [kg]	VOL [cm3]	DESCRIPTION
B36.4	34.0	19.0	32.0	8.0	20672.0	BAUMANNS BISCUITS
B37.1	42.0	29.0	17.0	8.0	20706.0	EB COFFEE CREAM
B38.1	30.0	24.0	29.0	13.0	20880.0	HORLICKS
B39.1	49.0	31.0	14.0	8.0	21266.0	GOLDEN HARVEST
B40.1	35.0	22.0	28.0	6.0	21560.0	BAKERS TANNER
B41.2	29.0	24.0	31.0	17.0	21576.0	SUNLIGHT SOAP
B42.4	29.0	24.0	31.0	17.0	21576.0	SUNLIGHT SOAP
B43.2	45.0	30.0	16.0	22.0	21600.0	CONDENSED MILK
B44.1	35.0	24.0	26.0	15.0	21840.0	OROS
B45.1	28.0	26.0	30.0	16.0	21840.0	COBRA DRI BRITE
B46.1	34.0	25.0	26.0	16.0	22100.0	SODA STREAM
B47.4	34.0	25.0	26.0	16.0	22100.0	SODA STREAM
B48.2	35.0	20.0	32.0	7.0	22400.0	BAUMANNS BISCUITS
B49.4	35.0	20.0	32.0	8.0	22400.0	BAUMANNS MARIE
B50.1	36.0	24.0	26.0	15.0	22464.0	BROOKES JUICE
B51.1	45.0	23.0	22.0	18.0	22770.0	HUSKY
B52.1	41.0	31.0	18.0	14.0	22878.0	HINDS BREAKFAST
B53.3	40.0	26.0	22.0	19.0	22880.0	GANT'S CHUTNEY
B54.1	45.0	30.0	17.0	18.0	22950.0	NESTLE PURE CREAM
B55.4	39.0	18.0	33.0	8.0	23166.0	BAUMANNS CRACKERS
B56.1	50.0	37.0	13.0	10.0	24050.0	ZAPPER
B57.1	30.0	30.0	27.0	9.0	24300.0	COMPLAN
B58.2	35.0	26.0	27.0	15.0	24570.0	SUPER SYRUP
B59.1	41.0	20.0	30.0	7.0	24600.0	BELLS ASSORTED
B60.1	67.0	26.5	14.0	8.0	24857.0	GHC BIZZIBAR
B61.2	39.0	20.0	32.0	8.0	24960.0	BAKERS CRACKERS
B62.2	39.0	28.0	23.0	11.0	25116.0	CARNATION [1451]
B63.1	44.0	32.0	18.0	26.0	25344.0	NILS SOAP
B64.1	34.0	26.0	30.0	16.0	26520.0	LUCOZADE
B65.2	33.0	23.0	35.0	25.0	26565.0	PURE SOAP BAR
B66.2	39.0	23.0	30.0	14.0	26910.0	JUNGLE OATS
B67.W	55.0	28.0	18.0	26.0	27720.0	HULETTS SUGAR *
B68.1	47.0	30.0	20.0	9.0	28200.0	OUMA SLICED RUSKS
B69.1	41.0	30.0	23.0	20.0	28290.0	SUPER KOOL-AID
B70.W	52.0	42.0	13.0	26.0	28392.0	HULETTS SUGAR *
B71.1	34.0	28.0	30.0	11.0	28560.0	WINDOLENE
B72.2	41.0	27.0	26.0	15.0	28782.0	SANPIC DISINFECT.
B73.4	35.0	23.0	36.0	8.0	28980.0	PYOTTS ANGEL DEL.
B74.4	36.0	28.0	29.0	6.0	29232.0	PYOTTS TEA DEL.
B75.2	41.0	31.0	23.0	28.0	29233.0	POG SYRUP
B76.4	39.0	28.0	27.0	8.0	29484.0	BAUMANNS ASSORTED
B78.4	41.0	28.0	26.0	26.0	29848.0	SUNLIGHT SOAP
B77.1	41.0	28.0	26.0	26.0	29848.0	SUNLIGHT SOAP
B79.2	45.0	28.0	24.0	27.0	30240.0	CAKE FLOUR *
B80.1	41.0	31.0	24.0	24.0	30504.0	POG PEACHES
B81.2	42.0	28.0	26.0	8.0	30576.0	PLAIN WRAP BISC.
B82.2	43.0	34.0	21.0	11.0	30702.0	GHC HUESLI
B83.2	43.0	33.0	22.0	13.0	31218.0	GHC HONEY CRUNCH
B84.4	40.0	27.0	29.0	17.0	31320.0	GILLETTES JAVEL
B85.4	44.0	23.0	31.0	6.0	31372.0	ROYAL CHELLO JET
B90.4	43.0	30.0	26.0	14.0	33540.0	PREEN
B91.1	47.0	25.0	29.0	13.0	34075.0	EVERYDAY TEA
B92.2	48.0	21.0	34.0	9.0	34272.0	BAKERS ASSORTED
B93.4	41.0	29.0	29.0	9.0	34481.0	BAUMANNS CRUNCHY
B94.1	54.0	27.0	24.0	22.0	34992.0	GHC TASTEE WHEAT
B95.2	37.0	28.0	34.0	2.0	35224.0	BAKERS BITZAPITZA

CODE	LENGTH [cm]	WIDTH [cm]	HEIGHT [cm]	MASS [kg]	VOL [cm3]	DESCRIPTION
B96.4	63.0	28.0	20.0	14.0	35280.0	TARGET
B97.1	47.0	26.0	29.0	14.0	35438.0	BECKET PLAIN WRAP
B86.2	39.0	31.0	26.0	14.0	31434.0	CARNATION [1454]
B87.2	49.0	31.0	21.0	13.0	31899.0	EB COFFEE
B88.1	40.0	26.0	31.0	15.0	32240.0	SMA BABY FOOD
B89.2	60.0	32.0	17.0	12.0	32640.0	FARMERS PRIDE
B98.3	37.0	30.0	32.0	12.0	35520.0	CARNATION [1304]
B99.1	47.0	36.0	21.0	8.0	35532.0	CHOICE ASSORTED
C1.2	47.0	21.0	38.0	13.0	37506.0	NON DAIRY CREAMER
C01.3	63.0	25.0	24.0	14.0	37800.0	CARNATION [1458]
C2.3	68.0	17.0	33.0	6.0	38148.0	DINU PAPER PROD.
C3.1	50.0	35.0	22.0	16.0	38500.0	FARMERS PRIDE
C4.2	48.0	38.0	22.0	13.0	40128.0	POG FATFREE CREM.
C5.3	53.0	33.0	23.0	9.0	40227.0	PYOTTS CRACKERS
C6.2	43.0	26.0	36.0	11.0	40248.0	SKOONPAK TAGLESS TEA
C7.4	42.0	32.0	30.0	8.0	40320.0	NESTUM
C8.1	39.0	40.0	26.0	22.0	40560.0	POG SUPA
C9.4	36.0	29.0	39.0	7.0	40716.0	HOMEPRIDE PAPER CUPS
C10.1	50.0	34.0	24.0	11.0	40800.0	PRONUTRO
C11.1	48.0	33.0	26.0	5.0	41184.0	BAKERS SNACK BREAD
C12.1	50.0	35.0	24.0	11.0	42000.0	PRONUTRO
C13.2	56.0	27.0	28.0	9.0	42336.0	FRESHPAK ROOIBOS
C14.4	53.0	40.0	20.0	13.0	42400.0	KOFFIEHUIS
C15.1	37.0	28.0	41.0	15.0	42476.0	CREMORA
C16.4	54.0	40.0	20.0	13.0	43200.0	RICOFFY **
C17.1	50.0	30.0	29.0	20.0	43500.0	POG SUPA SOFT
C18.1	38.0	36.0	32.0	12.0	43776.0	CREMORA
C21.1	45.0	29.0	34.0	20.0	44370.0	STA SOFT
C20.2	45.0	29.0	34.0	20.0	44370.0	STA SOFT
C19.2	45.0	29.0	34.0	20.0	44370.0	COUNTRY PRIDE
C22.3	50.0	37.0	24.0	8.0	44400.0	NESTLE JUNIOR
C23.4	55.0	27.0	30.0	21.0	44550.0	BIOTEX
C24.2	51.0	35.0	25.0	15.0	44625.0	GHC YOGI CRUNCH
C25.1	44.0	38.0	27.0	27.0	45144.0	PLAINWRP SCOUR.POWD.
C26.2	54.0	27.0	31.0	7.0	45198.0	WAXWRAP
C27.4	46.0	41.0	24.0	21.0	45264.0	BIOTEX
C28.2	52.0	38.0	23.0	18.0	45448.0	KLOOF COFFEE
C29.2	34.0	29.0	46.5	14.0	45849.0	BOKOMO HONEY FLAKES
C30.1	51.0	31.0	29.0	23.0	45849.0	POG SUPA KLEEN
C32.1	45.0	30.0	34.0	17.0	45900.0	ELITE MILK POWDER
C31.1	45.0	30.0	34.0	17.0	45900.0	NUMEL
C33.1	46.0	32.0	32.0	20.0	47104.0	COMFORT
C34.2	48.0	27.5	36.0	17.0	47520.0	BOKOMO WEETBIX
C35.1	37.5	32.0	40.0	12.0	48000.0	OATSO EASY
C36.1	47.0	29.0	37.0	22.0	50431.0	BORDEN MAKE A LITRE
C37.2	40.0	31.0	41.0	15.0	50840.0	CARNATION [1335]
C38.1	57.0	45.0	20.0	20.0	51300.0	NUMEL
C39.1	47.0	31.0	36.0	23.0	52452.0	CARNATION [1455]
C40.3	45.0	37.0	33.0	27.0	54945.0	POLGARIC FAB.SOFTEN.
C41.1	48.0	27.0	43.0	22.0	55728.0	SURF
C42.3	48.0	27.0	43.0	22.0	55728.0	OMO
C43.3	57.0	34.0	29.0	22.0	56202.0	SURF
C44.2	57.0	34.0	29.0	22.0	56202.0	OMO
C45.3	57.0	33.0	30.0	21.0	56430.0	SKIP
C46.2	57.0	32.0	31.0	22.0	56544.0	PLAINWRAP HI FOAM
C47.1	57.0	32.0	31.0	22.0	56544.0	PLAINWRAP HI-FOAM

CODE	LENGTH [cm]	WIDTH [cm]	HEIGHT [cm]	MASS [kg]	VOL [cm3]	DESCRIPTION
C48.2	62.0	27.0	34.0	13.0	56916.0	POG STRINGLESS TBAGS
C49.1	56.0	34.0	30.0	23.0	57120.0	SURF
C50.2	57.0	34.0	30.0	21.0	58140.0	GOOD CLEAN FRESH
C51.3	41.0	35.0	41.0	26.0	58835.0	JUNGLE OATS CEREAL
C52.2	48.0	41.0	30.0	14.0	59040.0	OUTSPAN RUSKS
C53.2	47.0	44.0	29.0	18.0	59972.0	PRONUTRO
C54.1	52.0	40.0	29.0	10.0	60320.0	JOKO TEA
C55.3	59.0	33.0	31.0	22.0	60357.0	BINGO
D1.1	47.0	32.0	42.0	23.0	63168.0	GOLD CROSS CREAMER
D2.2	59.0	36.0	30.0	17.0	63720.0	ABC HEAVY DUTY
D4.4	59.0	36.0	30.0	22.0	63720.0	PUNCH
D3.3	59.0	36.0	30.0	22.0	63720.0	PUNCH
D5.1	44.0	31.0	47.0	14.0	64108.0	OUMA MUESLI RUSKS
D6.2	46.0	30.0	47.0	15.0	64860.0	OUMA BUTMLK RUSKS
D7.2	47.0	30.0	48.0	15.0	67680.0	BOKOMO BISCUITS
D8.4	41.0	31.0	54.0	17.0	68634.0	LION MATCHES
D9.2	48.0	43.0	34.0	23.0	70176.0	CARNATION [1306]
D10.1	49.0	38.0	38.0	13.0	70756.0	LAAGER ROOIBOS
D11.4	55.0	46.0	29.0	12.0	73370.0	HULETTS FOIL
D12.4	55.0	36.0	38.0	11.0	75240.0	KELLOGS FRST/FLKS
D13.2	52.0	43.0	35.0	16.0	78260.0	FIVE ROSES
D14.2	60.0	32.0	47.0	8.0	90240.0	DINU PAPER PRODUCT
D15.1	52.0	34.0	57.0	7.0	100776.0	PURITY PARTY CONES
D16.4	60.0	48.0	43.0	18.0	123840.0	KELLOGS RICE CRISP
D17.4	58.0	48.0	49.0	10.0	136416.0	TWINSAVER
D18.4	64.0	41.0	55.0	10.0	144320.0	JOB SQUAD TOWELS
D19.4	62.0	55.0	43.0	13.0	146630.0	KELLOGS CORNFLAKES
D20.4	62.0	57.0	44.0	16.0	155496.0	KELLOGS ALL BRAN
AVG	42.8	28.8	27.4	13.4	36496.5	
STD	10.0	7.3	9.1	6.3	24792.8	N = 191

[Column 1 denotes carton code by group, group number and shelf]

* Packets that contain relatively solid contents and take the form of a carton, maintaining a constant shape.

* Packaging with solid cardboard base and plastic covering

APPENDIX G

SUMMARY OF THE CONTAINER CHARACTERISTICS PER GROUP

GROUP		LENGTH [cm]	WIDTH [cm]	HEIGHT [cm]	MASS [kg]	VOL [cm3]	NO. OF CONTAINERS
A	AVE	27.8	20.8	14.7	5.4	8249.2	
	STD	5.5	3.2	4.2	1.7	2184.9	N = 13
B	AVE	39.0	25.8	24.2	12.4	23575.8	
	STD	7.5	4.9	6.0	6.1	6422.8	N = 102
C	AVE	49.2	32.5	30.9	16.6	47745.2	
	STD	7.1	5.4	6.3	5.7	6916.0	N = 56
D	AVE	54.0	39.2	42.0	15.1	89256.5	
	STD	6.7	8.0	8.5	4.7	31856.4	N = 20

APPENDIX H

Activity and time analysis of two Bulkstoremen S1 and S2 where time spent on each particular task is presented in minutes, and as a percentage of the working period, for morning and afternoon periods and averaged for both Bulkstoremen for the full-day working period

Day 1 of Observation - time (mins and %) spent on each task

	Morning				Afternoon				Full-day totals					
	S1		S2		S1		S2		S1		S2		OVERALL	
TASK	min	%	min	%	min	%	min	%	min	%	min	%	min	%
Clt Plt	12	6	12	6	-	-	-	-	12	3	12	3	12	3
Trns Gds	7	3	7	3	13	6	5	2	20	5	12	3	16	4
Lift/Slv	89	42	89	42	57	27	5	2	146	35	94	22	120	29
Adj Slvs	45	21	57	27	-	-	-	-	45	11	57	14	51	12
Check-in	14	7	14	7	65	31	10	5	79	19	24	6	52	12
Stk-take	-	-	-	-	-	-	150	71	-	-	150	36	75	18
Clean-up	12	6	-	-	28	13	-	-	40	10	-	-	20	5
Other	14	7	14	7	31	15	16	8	45	11	30	7	38	9
Total	193	93	193	93	194	93	186	89	387	93	379	90	384	91

Day 2 of Observation - time (mins and %) spent on each task

	Morning				Afternoon				Full-day totals					
	S1		S2		S1		S2		S1		S2		OVERALL	
TASK	min	%	min	%	min	%	min	%	min	%	min	%	min	%
Clt Plt	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Trns Gds	10	5	13	6	11	5	-	-	21	5	13	3	17	4
Lift/Slv	72	34	69	33	40	19	-	-	112	27	69	16	91	22
Adj Slvs	33	16	34	16	19	9	35	17	52	12	69	16	61	14
Check-in	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Stk-take	20	10	-	-	-	-	145	69	20	5	145	35	83	20
Clean-up	-	-	26	12	50	24	15	7	50	12	41	10	46	11
Other	59	28	56	27	72	34	-	-	131	31	56	13	94	22
Total	194	92	198	94	192	91	195	93	386	92	393	94	390	93

Morning and Afternoon working periods lasted 210 minutes each giving a total working time of 420 minutes (7 hours from an 8 hour working day as tea and lunch breaks have been subtracted)

Activity and time analysis continued for the two Bulkstoremen S1 and S2 where time spent on each particular task is presented in minutes, and as a percentage of the working period, for morning and afternoon periods and averaged for both Bulkstoremen for the full-day working period

Day 3 of Observation - time (mins and %) spent on each task

	Morning				Afternoon				Full-day totals					
	S1		S2		S1		S2		S1		S2		OVERALL	
TASK	min	%	min	%	min	%	min	%	min	%	min	%	min	%
Clt Plt	2	1	-	-	-	-	-	-	-	-	-	-	1	0
Trns Gds	10	5	12	6	-	-	-	-	-	-	-	-	11	5
Lift/Slv	88	42	106	50	-	-	-	-	-	-	-	-	97	46
Adj Slvs	14	7	22	10	-	-	-	-	-	-	-	-	18	9
Check-in	9	4	12	6	-	-	-	-	-	-	-	-	11	5
Stk-take	13	6	-	-	-	-	-	-	-	-	-	-	7	3
Clean-up	36	17	-	-	-	-	-	-	-	-	-	-	18	9
Other	32	15	29	14	-	-	-	-	-	-	-	-	31	15
Total	204	97	181	86	0	0	0	0	0	0	0	0	193	92

Note: The workers were given the afternoon off

NAME/CODE:............................. DATE:..............

RPE Ratings (At random): TIME RATING

....

....

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....

....

Duration of performance: Start shift:....... End shift:.......

ACTIVITY AND TIME ANALYSIS DATA SHEET

TIME	TASK		DURATION	FREQUENCY	CONTAINER
	LIFT	OTHER	(minutes)	(lift/min)	DESCRIPTION

APPENDIX I

TASK CHARACTERISTICS PERTAINING TO THE NIOSH MODEL
FOR EACH "WORST-CASE" SUB-TASK PER TASK

SUB-TASK	No.of People	MASS kg	Vi cm	Vf cm	Hi cm	Hf cm	lift/ minute	Duration hrs/day
A1.1	1	2	21	100	24.0	24.0	14	0.17
B95.2	1	2	21	100	29.0	29.0	11	0.17
B6.1	1	3	21	100	25.5	25.5	11	0.17
B4.4	1	3	21	146	25.0	25.0	11	0.17
B20.2	1	4	21	100	29.5	29.5	11	0.17
A7.4	1	4	21	146	23.5	23.5	14	0.17
B5.2	1	4	21	100	26.5	26.5	11	0.17
A4.3	1	4	21	146	27.5	27.5	14	0.17
A3.1	1	4	21	100	25.0	25.0	14	0.17
B32.4	1	5	21	146	26.0	26.0	11	0.17
A13.2	1	5	21	100	28.0	28.0	14	0.17
A2.2	1	5	21	100	24.0	24.0	14	0.17
B02.2	1	5	21	100	23.5	23.5	11	0.17
B1.4	1	5	21	146	28.5	28.5	11	0.17
C11.1	1	5	21	100	31.5	30.5	8	0.07
B3.4	1	5	21	146	27.5	27.5	11	0.17
A10.4	1	5	21	146	24.5	24.5	14	0.17
B40.1	1	6	21	100	26.0	26.0	11	0.17
B85.4	1	6	21	146	26.5	26.5	11	0.17
B74.4	1	6	21	146	29.0	29.0	11	0.17
B16.2	1	6	21	100	27.0	27.0	11	0.17
A11.1	1	6	21	100	26.0	26.0	14	0.17
A8.3	1	6	21	146	24.5	24.5	14	0.17
C2.3	1	6	21	146	23.5	23.5	8	0.07
A9.4	1	6	21	146	23.5	23.5	14	0.17
B9.2	1	7	21	100	22.5	22.5	11	0.17
B12.4	1	7	21	146	25.5	25.5	11	0.17
B48.2	1	7	21	100	25.0	25.0	11	0.17
B30.2	1	7	21	100	25.5	25.5	11	0.17
A5.1	1	7	21	100	26.5	26.5	14	0.17
B26.2	1	7	21	100	26.5	26.5	11	0.17
D15.1	1	7	21	100	32.0	32.0	7	0.08
B15.1	1	7	21	100	24.0	24.0	11	0.17
C26.2	1	7	21	100	28.5	28.5	8	0.07
A6.2	1	7	21	100	25.0	25.0	14	0.17
B59.1	1	7	21	100	25.0	25.0	11	0.17
B35.2	1	7	21	100	30.0	30.0	11	0.17
C9.4	1	7	21	146	29.5	29.5	8	0.07
B19.1	1	8	21	100	24.5	24.5	11	0.17
B61.2	1	8	21	100	25.0	25.0	11	0.17
B36.4	1	8	21	146	24.5	24.5	11	0.17
B60.1	1	8	21	100	28.5	28.5	11	0.17
B73.4	1	8	21	146	26.5	26.5	11	0.17
B28.1	1	8	21	100	33.0	33.0	11	0.17
D14.2	1	8	21	100	31.0	31.0	7	0.08
B7.3	1	8	21	146	24.5	24.5	11	0.17
B76.4	1	8	21	146	29.0	29.0	11	0.17
B99.1	1	8	21	100	33.0	33.0	11	0.17
B39.1	1	8	21	100	30.5	30.5	11	0.17
B37.1	1	8	21	100	29.5	29.5	11	0.17
C22.3	1	8	21	146	33.5	33.5	8	0.07

SUB-TASK	No.of People	MASS kg	Vi cm	Vf cm	Hi cm	Hf cm	lift/ minute	Duration hrs/day
B14.4	1	8	21	146	24.0	24.0	11	0.17
B81.2	1	8	21	100	29.0	29.0	11	0.17
B49.4	1	8	21	146	25.0	25.0	11	0.17
B13.2	1	8	21	100	24.5	24.5	11	0.17
B55.4	1	8	21	146	24.0	24.0	11	0.17
C7.4	1	8	21	146	31.0	31.0	8	0.07
B57.1	1	9	21	100	30.0	30.0	11	0.17
B68.1	1	9	21	100	30.0	30.0	11	0.17
A12.4	1	9	21	146	28.0	28.0	14	0.17
C13.2	1	9	21	100	28.5	28.5	8	0.07
C5.3	1	9	21	146	31.5	31.5	8	0.07
B92.2	1	9	21	100	25.5	25.5	11	0.17
B93.4	1	9	21	146	29.5	29.5	11	0.17
B24.4	1	10	21	146	24.5	24.5	11	0.17
B56.1	1	10	21	100	33.5	33.5	11	0.17
B17.4	1	10	21	146	27.0	27.0	11	0.17
C54.1	1	10	21	100	35.0	35.0	8	0.07
D17.4	1	10	21	146	39.0	39.0	7	0.08
D18.4	1	10	21	146	35.5	35.5	7	0.08
B01.2	1	10	21	100	26.5	26.5	11	0.17
B21.4	1	11	21	146	26.5	26.5	11	0.17
B62.2	1	11	21	100	29.0	29.0	11	0.17
B8.4	1	11	21	146	26.0	26.0	11	0.17
C10.1	1	11	21	100	32.0	32.0	8	0.07
B71.1	1	11	21	100	29.0	29.0	11	0.17
B82.2	1	11	21	100	32.0	32.0	11	0.17
C6.2	1	11	21	100	28.0	28.0	8	0.07
C12.1	1	11	21	100	32.5	32.5	8	0.07
D12.4	1	11	21	146	33.0	33.0	7	0.08
B23.1	1	12	21	100	25.5	25.5	11	0.17
B22.1	1	12	21	100	25.5	25.5	11	0.17
D11.4	1	12	21	146	38.0	38.0	7	0.08
B89.2	1	12	21	100	31.0	31.0	11	0.17
C18.1	1	12	21	100	33.0	33.0	8	0.07
C35.1	1	12	21	100	31.0	31.0	8	0.07
B98.3	1	12	21	146	30.0	30.0	11	0.17
B29.4	1	12	21	146	27.0	27.0	11	0.17
B91.1	1	13	21	100	27.5	27.5	11	0.17
B31.2	1	13	21	100	28.0	28.0	11	0.17
B83.2	1	13	21	100	31.5	31.5	11	0.17
B18.2	1	13	21	100	26.5	26.5	11	0.17
B38.1	1	13	21	100	27.0	27.0	11	0.17
C14.4	1	13	21	146	35.0	35.0	8	0.07
B87.2	1	13	21	100	30.5	30.5	11	0.17
C16.4	1	13	21	146	35.0	35.0	8	0.07
C1.2	1	13	21	100	25.5	25.5	8	0.07
B2.1	1	13	21	100	26.0	26.0	11	0.17
D19.4	1	13	21	146	42.5	42.5	7	0.08
C4.2	1	13	21	100	34.0	34.0	8	0.07
C48.2	1	13	21	100	28.5	28.5	8	0.07
B10.1	1	13	21	100	26.5	26.5	11	0.17
D10.1	1	13	21	100	34.0	34.0	7	0.08
B33.4	1	14	21	146	27.5	27.5	11	0.17
B52.1	1	14	21	100	30.5	30.5	11	0.17
B66.2	1	14	21	100	26.5	26.5	11	0.17
B03.W	1	14	21	100	30.0	30.0	11	0.17

SUB-TASK	No.of People	MASS kg	Vi cm	Vf cm	Hi cm	Hf cm	lift/ minute	Duration hrs/day
C29.2	1	14	21	100	29.5	29.5	8	0.07
C01.3	1	14	21	146	27.5	27.5	8	0.07
B96.4	1	14	21	146	29.0	29.0	11	0.17
B97.1	1	14	21	100	28.0	28.0	11	0.17
C52.2	1	14	21	100	35.5	35.5	8	0.07
B90.4	1	14	21	146	30.0	30.0	11	0.17
D5.1	1	14	21	100	30.5	30.5	7	0.08
B86.2	1	14	21	100	30.5	30.5	11	0.17
B25.1	1	14	21	100	28.5	28.5	11	0.17
C15.1	1	15	21	100	29.0	29.0	8	0.07
D6.2	1	15	21	100	30.0	30.0	7	0.08
B44.1	1	15	21	100	27.0	27.0	11	0.17
B58.2	1	15	21	100	28.0	28.0	11	0.17
B88.1	1	15	21	100	28.0	28.0	11	0.17
B50.1	1	15	21	100	27.0	27.0	11	0.17
B34.4	1	15	21	146	27.5	27.5	11	0.17
D7.2	1	15	21	100	30.0	30.0	7	0.08
B72.2	1	15	21	100	28.5	28.5	11	0.17
C24.2	1	15	21	100	32.5	32.5	8	0.07
C37.2	1	15	21	100	30.5	30.5	8	0.07
D20.4	1	16	21	146	43.5	43.5	7	0.08
B47.4	1	16	21	146	27.5	27.5	11	0.17
B64.1	1	16	21	100	28.0	28.0	11	0.17
B45.1	1	16	21	100	28.0	28.0	11	0.17
D13.2	1	16	21	100	36.5	36.5	7	0.08
B46.1	1	16	21	100	27.5	27.5	11	0.17
C3.1	1	16	21	100	32.5	32.5	8	0.07
B84.4	1	17	21	146	28.5	28.5	11	0.17
C34.2	1	17	21	100	29.0	29.0	8	0.07
C32.1	1	17	21	100	30.0	30.0	8	0.07
B42.4	1	17	21	146	27.0	27.0	11	0.17
D8.4	1	17	21	146	30.5	30.5	7	0.08
B41.2	1	17	21	100	27.0	27.0	11	0.17
D2.2	1	17	21	100	33.0	33.0	7	0.08
C31.1	1	17	21	100	30.0	30.0	8	0.07
D16.4	1	18	21	146	39.0	39.0	7	0.08
C53.2	1	18	21	100	37.0	37.0	8	0.07
C28.2	1	18	21	100	34.0	34.0	8	0.07
B54.1	1	18	21	100	30.0	30.0	11	0.17
B51.1	1	18	21	100	26.5	26.5	11	0.17
B27.3	1	19	21	146	30.0	30.0	11	0.17
B53.3	1	19	21	146	28.0	28.0	11	0.17
C21.1	1	20	21	100	29.5	29.5	8	0.07
C19.2	1	20	21	100	29.5	29.5	8	0.07
C33.1	1	20	21	100	31.0	31.0	8	0.07
C17.1	1	20	21	100	30.0	30.0	8	0.07
B69.1	1	20	21	100	30.0	30.0	11	0.17
C38.1	1	20	21	100	37.5	37.5	8	0.07
C41.1	1	22	21	100	28.5	28.5	8	0.07
C8.1	1	22	21	100	35.0	35.0	8	0.07
C42.3	1	22	21	146	28.5	28.5	8	0.07
C55.3	1	22	21	146	31.5	31.5	8	0.07
C46.2	1	22	21	100	31.0	31.0	8	0.07
C47.1	1	22	21	100	31.0	31.0	8	0.07
D3.3	1	22	21	146	33.0	33.0	7	0.08
C44.2	1	22	21	100	32.0	32.0	8	0.07

SUB-TASK	No.of People	MASS kg	Vi cm	Vf cm	Hi cm	Hf cm	lift/ minute	Duration hrs/day
C43.3	1	22	21	146	32.0	32.0	8	0.07
D4.4	1	22	21	146	33.0	33.0	7	0.08
C20.2	1	20	21	100	29.5	29.5	8	0.07
B11.2	1	21	21	100	33.5	33.5	11	0.17
C50.2	1	21	21	100	32.0	32.0	8	0.07
C23.4	1	21	21	146	28.5	28.5	8	0.07
C27.4	1	21	21	146	35.5	35.5	8	0.07
C45.3	1	21	21	146	31.5	31.5	8	0.07
C36.1	1	22	21	100	29.5	29.5	8	0.07
B43.2	1	22	21	100	30.0	30.0	11	0.17
B94.1	1	22	21	100	28.5	28.5	11	0.17
C49.1	1	23	21	100	32.0	32.0	8	0.07
C30.1	1	23	21	100	30.5	30.5	8	0.07
D9.2	1	23	21	100	36.5	36.5	7	0.08
C39.1	1	23	21	100	30.5	30.5	8	0.07
D1.1	1	23	21	100	31.0	31.0	7	0.08
B80.1	1	24	21	100	30.5	30.5	11	0.17
B65.2	1	25	21	100	26.5	26.5	11	0.17
B63.1	1	26	21	100	31.0	31.0	11	0.17
B70.W	1	26	14	146	36.0	36.0	11	0.17
C51.3	1	26	21	146	32.5	32.5	8	0.07
B78.4	1	26	21	146	29.0	29.0	11	0.17
B67.W	1	26	14	146	29.0	29.0	11	0.17
B77.1	1	26	21	100	29.0	29.0	11	0.17
B79.2	1	27	21	100	29.0	29.0	11	0.17
C40.3	1	27	21	146	33.5	33.5	8	0.07
C25.1	1	27	21	100	34.0	34.0	8	0.07
B75.2	1	28	21	100	30.5	30.5	11	0.17
AVERAGE:		13.4	20.9	115.7	29.4	29.4	9.9	0.13
STD :		6.3	0.7	21.8	3.6	3.6	1.9	0.05

APPENDIX J

NIOSH RESULTS BEFORE ADJUSTMENTS WERE MADE TO THE 191 TASKS. DATA CORRESPONDS TO FIGURES 21, 22 AND 23.

TASK	MASS ACT	LOAD LIMITS AL	MPL
B75.2	28.0	3.27	9.81
B79.2	27.0	3.44	10.32
C40.3	27.0	4.98	14.94
C25.1	27.0	5.13	15.40
B70.W	26.0	2.54	7.63
B67.W	26.0	3.16	9.47
B63.1	26.0	3.22	9.65
B78.4	26.0	3.29	9.86
B77.1	26.0	3.44	10.32
C51.3	26.0	5.13	15.40
B65.2	25.0	3.76	11.29
B80.1	24.0	3.27	9.81
C49.1	23.0	5.45	16.36
D9.2	23.0	5.46	16.39
C30.1	23.0	5.72	17.16
C39.1	23.0	5.72	17.16
D1.1	23.0	6.43	19.30
B43.2	22.0	3.32	9.97
B94.1	22.0	3.50	10.50
C8.1	22.0	4.99	14.96
C43.3	22.0	5.21	15.64
C55.3	22.0	5.30	15.89
C44.2	22.0	5.45	16.36
C46.2	22.0	5.63	16.89
C47.1	22.0	5.63	16.89
D3.3	22.0	5.78	17.33
D4.4	22.0	5.78	17.33
C42.3	22.0	5.85	17.56
C36.1	22.0	5.92	17.75
C41.1	22.0	6.12	18.37
B11.2	21.0	2.98	8.93
C27.4	21.0	4.70	14.10
C45.3	21.0	5.30	15.89
C50.2	21.0	5.45	16.36
C23.4	21.0	5.85	17.56
B69.1	20.0	3.32	9.97
C38.1	20.0	4.65	13.96
C33.1	20.0	5.63	16.89
C17.1	20.0	5.82	17.45
C20.2	20.0	5.92	17.75
C21.1	20.0	5.92	17.75
C19.2	20.0	5.92	17.75
B27.3	19.0	3.18	9.53
B53.3	19.0	3.40	10.21
B54.1	18.0	3.32	9.97
B51.1	18.0	3.76	11.29
C53.2	18.0	4.72	14.15
D16.4	18.0	4.89	14.67

TASK	MASS ACT	LOAD LIMITS AL	MPL
C28.2	18.0	5.13	15.40
B84.4	17.0	3.35	10.04
B42.4	17.0	3.53	10.59
B41.2	17.0	3.69	11.08
C32.1	17.0	5.82	17.45
C31.1	17.0	5.82	17.45
C34.2	17.0	6.02	18.05
D2.2	17.0	6.04	18.13
D8.4	17.0	6.25	18.75
B47.7	16.0	3.47	10.40
B45.1	16.0	3.56	10.68
B64.1	16.0	3.56	10.68
B46.1	16.0	3.63	10.88
D20.4	16.0	4.38	13.15
C3.1	16.0	5.37	16.11
D13.2	16.0	5.46	16.39
B34.4	15.0	3.47	10.40
B72.2	15.0	3.50	10.50
B88.1	15.0	3.56	10.68
B58.2	15.0	3.56	10.68
B44.1	15.0	3.69	11.08
B50.1	15.0	3.69	11.08
C24.2	15.0	5.37	16.11
C37.2	15.0	5.72	17.16
C15.1	15.0	6.02	18.05
D7.2	15.0	6.65	19.94
D6.2	15.0	6.65	19.94
B90.4	14.0	3.18	9.53
B03.W	14.0	3.18	9.53
B86.2	14.0	3.27	9.81
B52.1	14.0	3.27	9.81
B96.4	14.0	3.29	9.86
B33.4	14.0	3.47	10.40
B25.1	14.0	3.50	10.50
B97.1	14.0	3.56	10.68
B66.2	14.0	3.76	11.29
C52.2	14.0	4.92	14.75
C29.2	14.0	5.92	17.75
C01.3	14.0	6.07	18.20
D5.1	14.0	6.54	19.62
B83.2	13.0	3.17	9.50
B87.2	13.0	3.27	9.81
B31.2	13.0	3.56	10.68
B91.1	13.0	3.63	10.88
B38.1	13.0	3.69	11.08
B10.1	13.0	3.76	11.29
B18.2	13.0	3.76	11.29
B2.1	13.0	3.84	11.51
D19.4	13.0	4.49	13.46
C14.4	13.0	4.77	14.30
C16.4	13.0	4.77	14.30
C4.2	13.0	5.13	15.40
D10.1	13.0	5.87	17.60
C48.2	13.0	6.12	18.37
C1.2	13.0	6.84	20.53
B98.3	12.0	3.18	9.53

TASK	MASS ACT	LOAD LIMITS AL	MPL
B89.2	12.0	3.22	9.65
B29.4	12.0	3.53	10.59
B23.1	12.0	3.91	11.73
B22.1	12.0	3.91	11.73
D11.4	12.0	5.02	15.05
C18.1	12.0	5.29	15.86
C35.1	12.0	5.63	16.89
B82.2	11.0	3.12	9.35
B71.1	11.0	3.44	10.32
B62.2	11.0	3.44	10.32
B21.4	11.0	3.60	10.79
B8.4	11.0	3.67	11.00
C12.1	11.0	5.37	16.11
C10.1	11.0	5.45	16.36
D12.4	11.0	5.78	17.33
C6.2	11.0	6.23	18.70
B56.1	10.0	2.98	8.93
B17.4	10.0	3.53	10.59
B01.2	10.0	3.76	11.29
B24.4	10.0	3.89	11.67
D17.4	10.0	4.89	14.67
C54.1	10.0	4.99	14.96
D18.4	10.0	5.37	16.11
A12.4	9.0	0.85	2.55
B93.4	9.0	3.23	9.70
B57.1	9.0	3.32	9.97
B68.1	9.0	3.32	9.97
B92.2	9.0	3.91	11.73
C5.3	9.0	5.30	15.89
C13.2	9.0	6.12	18.37
B28.1	8.0	3.02	9.07
B99.1	8.0	3.02	9.07
B39.1	8.0	3.27	9.81
B76.4	8.0	3.29	9.86
B37.1	8.0	3.38	10.14
B81.2	8.0	3.44	10.32
B60.1	8.0	3.50	10.50
B73.4	8.0	3.60	10.79
B49.4	8.0	3.81	11.44
B7.3	8.0	3.89	11.67
B36.4	8.0	3.89	11.67
B55.4	8.0	3.97	11.92
B61.2	8.0	3.99	11.97
B19.1	8.0	4.07	12.21
B13.2	8.0	4.07	12.21
B14.4	8.0	4.15	12.46
C22.3	8.0	4.98	14.94
C7.4	8.0	5.38	16.15
D14.2	8.0	6.43	19.30
A5.1	7.0	0.94	2.82
A6.2	7.0	1.00	2.99
B35.2	7.0	3.32	9.97
B12.4	7.0	3.74	11.22
B26.2	7.0	3.76	11.29
B30.2	7.0	3.91	11.73
B59.1	7.0	3.99	11.97

TASK	MASS ACT	LOAD LIMITS AL	MPL
B48.2	7.0	3.99	11.97
B15.1	7.0	4.15	12.46
B9.2	7.0	4.43	13.30
C9.4	7.0	5.66	16.97
C26.2	7.0	6.12	18.37
D15.1	7.0	6.23	18.70
A11.1	6.0	0.96	2.88
A8.3	6.0	0.97	2.92
A9.4	6.0	1.01	3.04
B74.4	6.0	3.29	9.86
B85.4	6.0	3.60	10.79
B16.2	6.0	3.69	11.08
B40.1	6.0	3.84	11.51
C2.3	6.0	7.10	21.30
A13.2	5.0	0.89	2.67
A10.4	5.0	0.97	2.92
A2.2	5.0	1.04	3.12
B1.4	5.0	3.35	10.04
B3.4	5.0	3.47	10.40
B32.4	5.0	3.67	11.00
B02.2	5.0	4.24	12.73
C11.1	5.0	5.54	16.62
A4.3	4.0	0.87	2.60
A3.1	4.0	1.00	2.99
A7.4	4.0	1.01	3.04
B20.2	4.0	3.38	10.14
B5.2	4.0	3.76	11.29
B4.4	3.0	3.81	11.44
B6.1	3.0	3.91	11.73
A1.1	2.0	1.04	3.12
B95.2	2.0	3.44	10.32
SUM	2288	735.2	2205.57
AVG	13.38	4.30	12.90

APPENDIX K

Task analysis of the 191 tasks performed, listing those that were adjusted or unadjusted with their load limits. Data is presented in descending order of mass (kg) and corresponds with Figures 26, 27 and 28

TASK	MASS ACT	LOAD LIMITS AL	MPL
B65.2(f)	25.0	8.47	25.40
C42.3(f)	22.0	7.53	22.58
B94.1(f)	22.0	7.87	23.62
C41.1(f)	22.0	7.87	23.62
C23.4(f)	21.0	7.53	22.58
C20.2(f)	20.0	6.76	20.28
C19.2(f)	20.0	6.76	20.28
C21.1(f)	20.0	6.76	20.28
B27.3(f)	19.0	6.36	19.07
B53.3(f)	19.0	6.81	20.43
B51.1(f)	18.0	6.59	19.76
B54.1(f)	18.0	6.65	19.94
C31.1*	17.0	5.82	17.45
C32.1*	17.0	5.82	17.45
B84.4(f)	17.0	5.85	17.56
C34.2*	17.0	6.02	18.05
D2.2*	17.0	6.04	18.13
B42.4(f)	17.0	6.18	18.54
D8.4*	17.0	6.25	18.75
B41.2(f)	17.0	6.46	19.39
B45.1(f)	16.0	5.34	16.03
B64.1(f)	16.0	5.34	16.03
C3.1*	16.0	5.37	16.11
B46.1(f)	16.0	5.44	16.32
D13.2*	16.0	5.46	16.39
B47.4(f)	16.0	6.07	18.20
B34.4(f)	15.0	5.20	15.60
B72.2(f)	15.0	5.25	15.74
B58.2(f)	15.0	5.34	16.03
B88.1(f)	15.0	5.34	16.03
C24.2*	15.0	5.37	16.11
B44.1(f)	15.0	5.54	16.62
B50.1(f)	15.0	5.54	16.62
C37.2*	15.0	5.72	17.16
C15.1*	15.0	6.02	18.05
D6.2*	15.0	6.65	19.94
D7.2*	15.0	6.65	19.94
B66.2(f)	14.0	4.70	14.11
B90.4(f)	14.0	4.77	14.30
B86.2(f)	14.0	4.90	14.71
B52.1(f)	14.0	4.90	14.71
C52.2*	14.0	4.92	14.75
B96.4(f)	14.0	4.93	14.79
B33.4(f)	14.0	5.20	15.60
B25.1(f)	14.0	5.25	15.74

TASK	MASS ACT	LOAD LIMITS AL	MPL
B97.1(f)	14.0	5.34	16.03
C29.2*	14.0	5.92	17.75
C01.3*	14.0	6.07	18.20
B03.W(f)	14.0	6.07	18.20
D5.1*	14.0	6.54	19.62
B75.2(H)	14.0	7.98	23.93
C40.3(h)	13.5	6.67	20.02
C25.1(h)	13.5	6.98	20.94
B79.2(H)	13.5	7.98	23.93
B31.2(f)	13.0	4.45	13.35
D19.4*	13.0	4.49	13.46
B91.1(f)	13.0	4.53	13.60
B38.1(f)	13.0	4.62	13.85
B18.2(f)	13.0	4.70	14.11
B10.1(f)	13.0	4.70	14.11
B83.2(f)	13.0	4.75	14.25
C16.4*	13.0	4.77	14.30
C14.4*	13.0	4.77	14.30
B2.1(f)	13.0	4.79	14.38
B87.2(f)	13.0	4.90	14.71
C4.2*	13.0	5.13	15.40
D10.1*	13.0	5.87	17.60
C48.2*	13.0	6.12	18.37
B70.W(H)	13.0	6.41	19.22
C51.3(h)	13.0	6.67	20.02
C1.2*	13.0	6.84	20.53
B63.1(H)	13.0	6.98	20.94
B67.W(H)	13.0	7.32	21.97
B78.4(H)	13.0	7.63	22.88
B77.1(H)	13.0	7.98	23.93
B89.2(f)	12.0	4.02	12.06
B29.4(f)	12.0	4.41	13.24
B98.3(f)	12.0	4.77	14.30
B22.1(f)	12.0	4.89	14.66
B23.1(f)	12.0	4.89	14.66
D11.4*	12.0	5.02	15.05
C18.1*	12.0	5.29	15.86
C35.1*	12.0	5.63	16.89
B80.1(H)	12.0	7.98	23.93
D9.2(h)	11.5	7.98	23.93
C39.1(H)	11.5	7.98	23.93
D1.1(h)	11.5	7.98	23.93
C30.1(H)	11.5	7.98	23.93
B82.2(f)	11.0	3.90	11.69
B71.1(f)	11.0	4.30	12.89
B62.2(f)	11.0	4.30	12.89
B21.4(f)	11.0	4.50	13.49
B8.4(f)	11.0	4.58	13.75
C12.1*	11.0	5.37	16.11
C10.1*	11.0	5.45	16.36
D12.4*	11.0	5.78	17.33
C6.2*	11.0	6.23	18.70
C49.1(h)	11.0	6.98	20.94
C8.1(h)	11.0	6.98	20.94
C55.3(H)	11.0	7.63	22.88
D4.4(h)	11.0	7.63	22.88

TASK	MASS ACT	LOAD AL	LIMITS MPL
D3.3(h)	11.0	7.63	22.88
C43.3(H)	11.0	7.63	22.88
C46.2(H)	11.0	7.98	23.93
C47.1(H)	11.0	7.89	23.93
C36.1(H)	11.0	7.98	23.93
C44.2(H)	11.0	7.98	23.93
B43.2(H)	11.0	7.98	23.93
C27.4(h)	10.5	6.67	20.02
B11.2(H)	10.5	6.98	20.94
C45.3(H)	10.5	7.63	22.88
C50.2(H)	10.5	7.98	23.93
B17.4*	10.0	3.53	10.59
B56.1(f)	10.0	3.72	11.16
B01.2*	10.0	3.76	11.29
B24.4*	10.0	3.89	11.67
D17.4*	10.0	4.89	14.67
C54.1*	10.0	4.99	14.96
D18.4*	10.0	5.37	16.11
C38.1(h)	10.0	6.98	20.94
B69.1(H)	10.0	7.98	23.93
C17.1(H)	10.0	7.98	23.93
C33.1(H)	10.0	9.08	27.24
B68.1*	9.0	3.32	9.97
B57.1*	9.0	3.32	9.97
A12.4(f)	9.0	3.40	10.21
B92.2*	9.0	3.91	11.73
B93.4*	9.0	4.75	14.25
C5.3*	9.0	5.30	15.89
C13.2*	9.0	6.12	18.37
C28.2(h)	9.0	6.98	20.94
C53.2(h)	9.0	6.98	20.94
D16.4(h)	9.0	7.63	22.88
B28.1*	8.0	3.02	9.07
B99.1*	8.0	3.02	9.07
B39.1*	8.0	3.27	9.81
B76.4*	8.0	3.29	9.86
B37.1*	8.0	3.38	10.14
B81.2*	8.0	3.44	10.32
B60.1*	8.0	3.50	10.50
B73.4*	8.0	3.60	10.79
B49.4*	8.0	3.81	11.44
B7.3*	8.0	3.89	11.67
B36.4*	8.0	3.89	11.67
B55.4*	8.0	3.97	11.92
B61.2*	8.0	3.99	11.97
B19.1*	8.0	4.07	12.21
B13.2*	8.0	4.07	12.21
B14.4*	8.0	4.15	12.46
C22.3*	8.0	4.98	14.94
C7.4*	8.0	5.38	16.15
D14.2*	8.0	6.43	19.30
D20.4(h)	8.0	7.63	22.88
A5.1(f)	7.0	2.82	8.47
A6.2(f)	7.0	2.99	8.97
B35.2*	7.0	3.32	9.97
B12.4*	7.0	3.74	11.22

TASK	MASS ACT	LOAD LIMITS AL	MPL
B26.2*	7.0	3.76	11.29
B30.2*	7.0	3.91	11.73
B48.2*	7.0	3.99	11.97
B59.1*	7.0	3.99	11.97
B15.1*	7.0	4.15	12.46
B9.2*	7.0	4.43	13.30
C9.4*	7.0	5.66	16.97
C26.2*	7.0	6.12	18.37
D15.1*	7.0	6.23	18.70
A9.4(f)	6.0	2.03	6.09
A11.1(f)	6.0	2.88	8.63
A8.3(f)	6.0	2.92	8.76
B74.4*	6.0	3.29	9.86
B85.4*	6.0	3.60	10.79
B16.2*	6.0	3.69	11.08
B40.1*	6.0	3.84	11.51
C2.3*	6.0	7.10	21.30
A13.2(f)	5.0	1.78	5.34
A10.4(f)	5.0	1.95	5.84
A2.2(f)	5.0	2.08	6.23
B1.4*	5.0	3.35	10.04
B3.4*	5.0	3.47	10.40
B32.4*	5.0	3.67	11.00
B02.2*	5.0	4.24	12.73
C11.1*	5.0	5.54	16.62
A4.3(f)	4.0	1.73	5.20
A3.1(f)	4.0	1.99	5.98
A7.4(f)	4.0	2.03	6.09
B20.2*	4.0	3.38	10.14
B5.2*	4.0	3.76	11.29
B4.4*	3.0	3.81	11.44
B6.1*	3.0	3.91	11.73
A1.1*	2.0	1.04	3.12
B95.2*	2.0	3.44	10.32
AVERAGES	11.2	5.32	15.97

* = unaltered task
f = f-factor adjusted
h = H-factor adjusted
H = f and H-factors adjusted