Review of the risks associated with pushing and pulling heavy loads

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Review of the risks associated with pushing and pulling heavy loads

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The aim of this project was to identify the risks associated with the pushing and pulling of heavy loads, in order to provide practical guidance for future updates to HSE's guidance on the Manual Handling Operations Regulations 1992 (L23; HSE, 1998).

The outcomes of this research were:

- A pushing and pulling assessment checklist to be included in HSE's revised guidance on the Manual Handling Operations Regulations 1992 (L23; HSE, 1998); and a
- Criteria guidance for the selection of trolleys and wheeled equipment following a literature review and industry consultation.

Furthermore, the L23 pushing and pulling risk filter guidelines for starting and stopping a load were reduced to 20 kg for men and 15 kg for women. These guidelines assume that the distance of the push or pull is no more than about 20 metres. The revised guidance will also advise that where critical risk factors such as uneven floors, confined spaces, kerbs and trapping hazards are present, a detailed pushing and pulling risk assessment should be undertaken.

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CONTENTS

EXECUTIVE SUMMARY

OBJECTIVES

The overall aim of this project was to identify the risks associated with the pushing and pulling of heavy loads, in order to provide practical guidance for future updates to HSE's guidance on the Manual Handling Operations Regulations 1992 (L23; HSE, 1998).

OUTCOMES

(1) A pushing and pulling assessment checklist was designed for inclusion into HSE guidance on the Manual Handling Operations Regulations 1992 (L23; HSE, 1998). The checklist considers factors of the pushing/pulling task, the load (including equipment such as trolleys), the working environment, individual capability, and work organisation. The inclusion of these factors was justified with evidence in the scientific literature, and a review of HSE's RIDDOR database, as well as practical experience and feedback obtained through industry consultation.

(2) Criteria guidance for the selection of trolleys and wheeled equipment was developed using a literature review and industry consultation. The guidance informs users of the implications to handling operations with respect to design features such as: the type of trolley; trolley dimensions; loading factors; handle characteristics; wheel and castor characteristics; conditions of the work environment; and trolley maintenance. The guidance document is intended to help users make more informed purchases based upon good design principles and knowledge of the various options available.

MAIN FINDINGS

(1) Evaluation revealed that 91% of respondents felt the pushing and pulling assessment checklist benefited their original assessment. Respondents rated the pushing and pulling assessment checklist extremely favourably with respect to its usefulness as a tool to identify, plan and prioritise remedial actions. Some difficulty was reported though when determining levels of risk, as many users did not know how to measure pushing and pulling force.

(2) Approximately 75% of users rated the criteria guidance for the selection of trolleys and wheeled equipment favourably. Respondents reported that it guided users to recognise factors that were previously unconsidered. In combination with the assessment checklist, this fostered an ergonomics approach to pushing and pulling risk assessment.

(3) Differences in methodology, sample characteristics and acceptable force criteria have led to conflicting data on pushing and pulling capabilities. Thus, it is difficult to compare the L23 pushing and pulling guidelines to a general consensus on pushing and pulling capabilities. However, the L23 guidelines exceed the maximal isometric forces suggested by European Standards (BS EN 1005-3:2002) to accommodate the general European working population. The L23 guidelines often exceed well-established psychophysical data of maximum acceptable force limits for 90% of the working population, particularly in the case of initial forces, more frequent exertions, greater distances and high or low hand heights.

(4) The literature review revealed a lack of information on pushing and pulling up ramps with various slopes. Current HSE guidance is based upon static mathematical models that do not consider implications of the dynamic nature of the task, slip potential, human behaviour and perception, and changes in muscle activity, posture, and performance capability.

CONCLUSIONS AND RECOMMENDATIONS

(1) The outcomes from this study will be a valuable addition to HSE's guidance on the Manual Handling Operations Regulations 1992 (L23; HSE, 1998). They should assist in achieving a greater prevention of work-related musculoskeletal disorders as well as the targets set out in the Revitalising Health and Safety strategy document (HSC, 2000).

(2) As a result of consultation between HSL and HSE, the L23 pushing and pulling risk filter guidelines for starting and stopping a load were reduced to 20 kg for men and 15 kg for women. These guidelines assume that the distance of the push or pull is no more than about 20 metres. The revised guidance will also advise that where critical risk factors such as uneven floors, confined spaces, kerbs and trapping hazards are present, a detailed pushing and pulling risk assessment should be undertaken. These changes to the guidance will encourage the use a detailed pushing and pulling risk assessment in many more instances where it would be beneficial, yet is not currently prescribed by HSE guidelines.

(3) It should be recognised that the competency required to assess a pushing or pulling operation may be greater than that required to assess a lifting or carrying operation. Users may require further information on how and why pushing and pulling forces must be measured and how such measurements shall be used.

1 INTRODUCTION

Prevention and control of work-related musculoskeletal disorders is a priority programmes in the Health and Safety Commission's (HSC) strategic plan selected to meet targets set out in the Revitalising Health and Safety strategy document (HSC, 2000). This strategy sets national targets to reduce the number of working days lost per 100 000 workers from work-related injury and ill-health by 30% by 2010 and to reduce the incidence rate of work-related ill-health by 20% by 2010. Manual handling accidents account for more than a quarter of all such incidences reported each year to enforcing authorities, the majority of which result in over-three day injuries (HSE, 1998).

Within the Manual Handling Operations Regulations (MHOR) 1992, Regulation 4(1)(b)(ii) requires the employer to take appropriate steps to reduce the risk of injury from manual handling operations to the lowest level reasonably practicable. HSE guidance in support of this regulation (L23; HSE, 1998) emphasises the importance of *'using the body more efficiently'*. One way of achieving this is said to involve the replacement of lifting activities with ***controlled*** pushing or pulling tasks. However, as the guidance makes clear, ***uncontrolled*** sliding or rolling of heavy loads may introduce fresh risks of injury. For example, such uncontrolled actions could be caused by poor coupling between the foot and floor, leading to a risk of slipping.

Whilst such additional risks are considered important in pushing and pulling tasks, technical and practical information on the extent to which these additional risk factors influence human physical capability was limited. This is despite estimations that nearly half of all manual material handling consists of pushing and pulling (Baril-Gingras and Lortie, 1995). HSE strives to develop and improve its guidance publications in support of its regulatory areas. Thus there was further need to develop practical advice for employers on:

(1) How to meet their duties with respect to pushing and pulling heavy loads

(2) Optimising the design and selection of equipment such as trolleys to suit operator capabilities

2 AIMS & OBJECTIVES

2.1 AIMS

The overall aim of this project was to identify the risks associated with the pushing and pulling of heavy loads, in order to provide practical guidance for future updates to HSE's guidance (L23; HSE, 1998) on the Manual Handling Operations Regulations 1992. More specifically, the study sought to:

(1) Determine the extent to which pushing and pulling capabilities are influenced by characteristics of the task, load, work environment and individual

(2) Investigate how design characteristics of handling aids affect pushing and pulling capabilities

2.2 OBJECTIVES

To achieve these aims, the study adopted the following objectives:

(1) To prepare an updated literature review on pushing and pulling of heavy loads, which builds on that prepared by McPhillips (1997)

(2) To review empirical accident data to identify the proportion of manual handling reports due to pushing and pulling and common factors leading to injury

(3) To undertake a series of visits to industrial premises in order to identify potential hazards, practical problems and solutions

(4) Develop a practical risk approach for assessing pushing and pulling tasks in a work setting

(5) To design and conduct a laboratory study intended to control and manipulate key risk factors such as loads and inclines

(6) Review the findings with respect to current HSE (L23), CEN (BS EN 1005-3) and ISO (CD 11228-2) standards on pushing and pulling

2.3 OUTCOMES

The combined information was used to develop:

- A pushing and pulling assessment checklist to update HSE's guidance on the MHOR 1992 (Appendix A)
- Criteria guidance for the selection of trolleys and wheeled equipment (Appendix B)

The findings of the laboratory study shall be documented in a supplementary technical report and peer-reviewed academic paper.

3 LITERATURE REVIEW

The purpose of this section was to review current guidance and contemporary literature on human force exertions during the actions of pushing and pulling, as well as on the other musculoskeletal risk factors associated with these types of manual force exertions. The literature has been organised accordingly:

- Definitions of pushing and pulling
- Health effects and epidemiological evidence
- Guidance and legislation
- Mathematical modelling

3.1 DEFINITIONS OF MANUAL PUSHING AND PULLING

Few definitions exist which describe the application of human effort involved in pushing and pulling. This may well stem from the considerable variations in bodily actions which these types of force exertion entail. Hoozemans et al. (1998), in a review of musculoskeletal risk factors associated with pushing and pulling, elected to use definitions provided by Martin and Chaffin (1972), and Baril-Gingras and Lortie (1995):

> *"Pushing and pulling could be defined as the exertion of (hand) force, of which the direction of the major component of the resultant force is horizontal, by someone on another object or person. In pushing the (hand) force is directed away from the body and in pulling the force is directed toward the body."*"

They went on to specify that:

> *"The exertion of force is not always directed horizontal to be called a push or a pull force, for instance, in pulling a cord to start a lawn mower engine (Garg et al., 1988)"*

3.2 TYPES OF FORCE EXERTIONS

3.2.1 Force Component

Lee et al. (1991) elected to distinguished between pushing and pulling into activities whereby the object is not moved; and activities that result in a displacement of the object. Others, however, have generally expressed pushing and pulling according to:

(1) The maximum dynamic force that can be exerted to set an object in motion (i.e. the force required to accelerate the object (Snook 1978)) (**initial force**);

(2) The maximum dynamic force that can keep an object in motion (i.e. the force required to keep the object at more or less constant velocity (Snook 1978)) (**sustained force**);

(3) The maximum isometric force that can be exerted while trying to push/pull an object (Mital et al., 1997) (**maximum force**).

As a result, guidance on force limits has often been expressed in these terms.

If guidance is to provide 'protective limits' for the majority of hazardous aspects of pushing and pulling tasks, then it might also be prudent to speak in terms of other components of pushing and pulling forces which present a known risk of injury to the handler. For example, the required force to stop an object when in motion can differ significantly from either the initial or sustained force and may present an entirely different type of risk to the handler. While stopping or retarding forces do not appear to receive much attention in the literature, it is conceivable that, in some situations, retarding peak forces will exceed initial forces due to the often sudden or unexpected nature of the force application. Therefore, an additional proposed pushing and pulling classification is:

(4) The maximum dynamic force that can be exerted to bring an object to rest (**restraining force**)

Similarly, it might also be wise to discern between pushing and pulling forces used to manoeuvre or change the direction of travel of an object while in motion, as these forces may differ significantly from sustained forces and can have marked consequence on the biomechanical load and type of injury sustained. As pointed out by Rodgers et al. (1986), manoeuvring operations often take place in restricted space where the object being handled has to be turned, or placed into a particular location with a certain degree of precision. In these instances, the forces which a person can exert are often considerably less than in unrestricted situations, as the operator is unable to position his or her body weight behind the centre of gravity of the load. Thus, it is considered appropriate to include a further definition:

(5) The maximum dynamic force that can be exerted to change the direction or motion of an object (**manoeuvring force**)

In most situations, pushing and pulling tasks will encompass a combination of each of these force components, the number and type of exertions being dependent on the task. For example, in moving a trolley loaded with components, an initial force will be required to set the trolley in motion and a sustained force will be required to keep the trolley moving. During the operation, it may be necessary to manoeuvre around objects or position the trolley within the workstation, and inevitably the trolley will need to be brought to rest.

It is also important to bear in mind that during the application of pushing and pulling forces, several muscular actions may be involved. For example, whilst concentric muscle actions may be the primary mechanism for generating the force, isometric force exertions may also be present to stabilise certain body parts, such as the arms, so that the applied force can be transmitted directly to the object being moved. Furthermore, manual pushing and pulling forces can be generated in a variety of different ways (e.g. a person may apply the force using their back or shoulder) and the type of application may vary considerably, from pushing a button on a machine to pulling a loaded pallet truck.

3.2.2 Direction of Force Application

When setting design limits, some authors have elected to define pushing and pulling according to the direction of the force application. Typically, these are referenced with respect to the three principal planes of motion:

(1) Horizontal pushing and pulling, perpendicular to the shoulders (horizontal forces away from and towards the body)

(2) Horizontal pushing and pulling, parallel to the shoulders (transverse or lateral forces applied horizontally)

(3) Vertical pushing and pulling

3.2.3 Units of Measurement

The correct unit of measurement for expressing force is Newtons (N), although many authors have elected to express force according to a unit of mass, such as kg (or kgf - kg of force), which is more easily understood. A 1 kg pushing or pulling force is equivalent to the force required to support 1 kg of weight against the acceleration due to gravity, i.e. 1 kg = 9.807 N.

3.3 HEALTH EFFECTS

3.3.1 Types of Injury

According to Chaffin et al. (1999), pushing and pulling may give rise to two types of hazards and the risk of injury:

(1) Overexertion of the musculoskeletal system (e.g. low back injury)

(2) Increased risk of accidents (e.g. due to slipping or tripping), which can cause injury to the musculoskeletal system

In a review of accidents associated with manual truck and trolley handling, Rodgers et al. (1986) identified three major accident types:

(1) Fingers and hands caught in, on, or between the trolley and a wall or piece of equipment

(2) Feet, heels and the lower leg being bumped by or caught under the trolley

(3) Arm, shoulder and back strains associated with slips, trips and pushing and pulling of trucks. With powered trucks, the risks of strain injuries were considerably reduced, although hand and foot injuries will still be common.

3.3.2 Epidemiological Studies

Summarising many epidemiological studies (Snook et al. 1978; NIOSH 1981; Clemmer et al. 1991; Garg and Moore 1992;) Hoozemans et al. (1998) reported 9 – 20% of low back injuries or claims to be associated with pushing and pulling. Most reported studies, however, are now at least a decade old and with greater introduction of mechanical aids, there is a continual need to update the epidemiological evidence. Establishing any causal relationship requires further longitudinal study. Conclusive evidence relating pushing and pulling to other musculoskeletal complaints is still lacking (Hoozemans et al. 1998).

The contribution of slipping, tripping and falling to low back injury is variable in the literature, ranging from 7% (Snook et al., 1978) to 47% (Manning, 1983). However, an epidemiological link between pushing and pulling and slipping, tripping and falling is not well documented. In one study though, Manning et al. (1983) reported that 13% of slipping accidents that resulted in low back pain were associated with pushing and pulling.

3.3.3 Analysis of Pushing and Pulling Accidents Recorded on HSE's RIDDOR Accident Database

To establish the extent and aetiology of accidents associated with manual handling operations involving the pushing and pulling of loads, a detailed survey was carried out of HSE's RIDDOR accident database. Information extracted from the database comprised of all HSE investigated manual handling accidents reportable under government regulations (RIDDOR 1985 and 1995 - Reporting of Injuries, Diseases and Dangerous Occurrences Regulations) over a 13-year period (1986-1999).

A full report of the analysis has already been documented (Boocock, 2003), the main findings of which are presented below:

(1) Pushing or pulling was involved in 11% of manual handling related RIDDOR accidents investigated by HSE

(2) It was estimated that 77 major and 609 minor manual handling accidents associated with pushing and pulling were reported each year

(3) The most frequently reported site of injury was the back (44%), while the upper limbs (shoulder, arm, wrist and hand) accounted for 28.6% of injuries

(4) Where the activity at the time of the accident could be determined, pulling was involved in 12% more accidents than pushing

(5) The action of pushing or pulling (e.g. 'the force required to move the trolley resulted in the back injury') was considered to cause 69% of accidents. Indirect causation was considered to occur for 29% of reported accidents, and typically involved being struck by an object as a result of the pushing or pulling action. Figure 1 classifies the causes of pushing and pulling activities into 5 categories. The similar frequency distribution among categories supports the notion that an ergonomics approach to pushing and pulling assessment is crucial to assess the wide range of risk factors in the workplace.

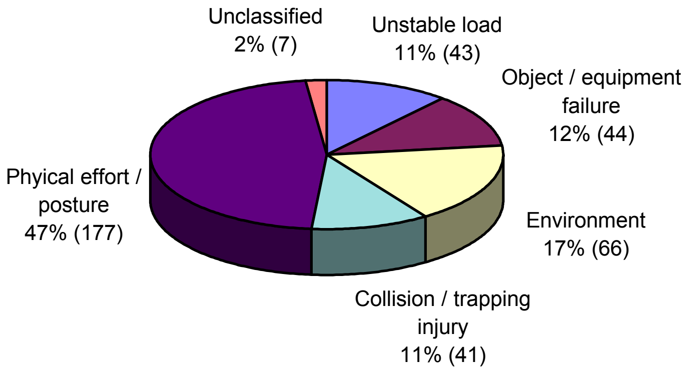


Figure 1. Classification of the causes of pushing and pulling accidents.

(6) The majority of accidents (61%) involved pushing or pulling objects that were not supported on wheels, such as furniture, bales of wool, etc. Wheeled objects and trolleys were involved in 35% of pushing and pulling accidents, although it was often difficult to ascertain the exact purpose and type of the trolley.

(7) Where the primary cause of accidents was considered to stem from environmental factors, 70% were due to the object or load catching against or becoming trapped on some part of the workplace.

(8) There were some limitations in reviewing the RIDDOR statistics. Minor workplace accidents were under-represented, and there was often insufficient detail to determine the precise cause of the accident. These factors might result in an under-reporting of slips, trips and falls during pushing and pulling activities.

3.4 GUIDANCE IN LEGISLATION

3.4.1 The Manual Handling Operations Regulations 1992

UK regulations and guidance on manual handling at work are contained within L23 (HSE, 1998). These regulations implement European Directive 90/269/EEC on the manual handling of loads, which came into force on 1st January 1993.

3.4.1.1 Making an assessment: Regulation 4(1)(b)(i)

Regulation 4(1)(b)(i) of the MHOR 1992 requires employers to make a suitable and sufficient assessment of manual handling tasks having due regard for factors and questions in Schedule 1 of the Regulations (i.e. the task, the loads, the working environment and individual capability). In response to the question '*Does the task involve excessive pushing or pulling of the load*?' guidance (L23) states that the risk of injury is increased if pushing and pulling is carried out with the hands much below knuckle height or above shoulder height. The risk of injury is said to increase in circumstances where the grip between the foot and floor is poor as a result of the condition of the floor, footwear or both. Thus, a more general factor, but equally important to pushing and pulling, is the work environment, with the assessment addressing the questions: '*Are there uneven, slippery or unstable floors?*' and '*Are there variations in level of floors or* *work surfaces?'*. Guidance proposes that uneven, slippery or unstable floors hinder smooth movement and can create additional unpredictability stresses, while the presence of steps, steep slopes, etc increases the risk of injury by adding complexity of movement.

3.4.1.2 Reducing the Risk: Regulation 4(1)(b)(ii)

In reducing the risk of injury, L23 emphasises the importance of *'using the body more efficiently'.* One way of achieving this is said to involve the replacement of lifting activities with ***controlled*** pushing or pulling tasks. However, as the guidance makes clear, ***uncontrolled*** sliding or rolling of heavy loads may introduce fresh risks of injury. The guidance identifies that for both pushing and pulling, a secure footing should be ensured and the hands applied to the load at a height between waist and shoulder height, wherever possible. One option suggested, if safety conditions allow, is said to involve the handler positioning themselves with their back against the load and exerting a pushing force with their strong leg muscles.

3.4.1.3 Risk Assessment Filter

As a guide to carrying out a risk assessment, L23 provides a set of numerical guideline figures based on published scientific literature and practical experience of assessing risks from manual handling. As the guidance is keen to point out, these figures are 'pragmatic, tried and tested; they are not based on any precise scientific formulae'. For the pushing and pulling of loads, guideline figures refer only to forces applied by the hands between knuckle and waist height. When ***starting or stopping the load***, ***a force of about 25 kg for men and about 16 kg for women*** are proposed as guideline figures. This decreases to ***about 10 kg for men and about 7 kg for women when keeping the load in motion***. L23 states that the intention of the guideline figures is to set out an approximate boundary within which the load is unlikely to create a risk of injury sufficient to warrant a detailed risk assessment. The guidelines are said to provide a reasonable level of protection for 95% of the working men and women; however, it notes that there is no threshold value below which manual handling operations may be regarded as 'safe'. No limit is proposed for the distance over which the load should be pushed or pulled, with mention only that adequate opportunities should be provided for the handler to rest and recover.

3.4.2 ISO, CEN and British Standards

Whereas L23 adopts a risk filter approach for assessing pre-existing tasks, the typical 'Standards approach' is to specify maximum recommended limits for design.

3.4.2.1 Pushing and Pulling Capability Standards

BS EN 1005-3:2002, Safety of machinery – Human physical performance – Part 3: Recommended force limits for machinery operation

BS EN 1005-3:2002 specifies recommended force limits for actions during the construction, transport, commissioning, use, decommissioning, disposal and dismantling of machinery. It is applicable to machinery for professional use by healthy adult workers with normal capability, as well as to machinery for domestic use that may be operated by the whole population, including youths and older people. The approach involves 3 steps:

(1) The maximal isometric force generating capacity is determined for the relevant actions within the intended user population.

Force limits for professional workers correspond to the 15th percentile values for the adult working population, while limits for domestic use correspond to the 1st percentile values for the same population. Table 1 displays the maximal isometric forces for whole body work in a standard posture by the general European working population in its current mix of age and gender. However, alternative methods of force calculation are provided should the intended user population differ from the general European working population or should the target population be unknown.

Table 1: Maximal isometric forces by the general European working population for whole body work in a standing posture (CEN, 2002).

Activity	Professional Use	Domestic Use
Pushing	200 N (20.4 kg)	119 N (12.1 kg)
Pulling	145 N (14.8 kg)	96 N (9.8 kg)

(2) The maximal force generating capacity is reduced according to the circumstances under which the force is to be generated (velocity, frequency and duration of action).

The extent of force reduction is specified with a set of multipliers. If the action implies an evident motion, the velocity multiplier is reduced from 1.0 to 0.8. The duration multiplier is 1.0 for durations less than 1 hour, 0.8 for durations of 1 – 2 hours and 0.5 for durations of 2 – 8 hours. The frequency multiplier, described in Table 2, depends both on the action time (duration of each action) and the frequency at which the action occurs.

Table 2: Frequency multipliers for reduction in force generating capacity (CEN, 2002).

Action Time (minutes)	Frequency of Actions			
	≤ 0.2 / min	> 0.2 – 2 / min	> 2 – 20 / min	> 20 / min
≤ 0.05	1.0	0.8	0.5	0.3
> 0.05	0.6	0.4	0.2	N/A

(3) The reduced force capability, representing the very limit of force exertion possible, is evaluated with risk multipliers to determine the risk zone associated with action forces during machinery use.

By referring to the risk zone, the manufacturer may evaluate the intended design and obtain quantitative guidance in formulating instructions for machinery use (CEN, 2002). Table 3 describes the 3 risk zones.

Table 3: Risk zone descriptions and corresponding risk multipliers (CEN, 2002).

Risk Zone	Description	Risk Multiplier
Recommended	The risk of disease or injury is negligible and no intervention is needed.	≤ 0.5
Not recommended	The risk of disease or injury cannot be neglected and the risk must be further analysed with consideration for working posture, acceleration and movement precision, vibration, man-machine interface, personal protective equipment and the external environment. The analysis may consider a risk multiplier of 0.7 to be acceptable, or it may conclude that machinery use is associated with risk and therefore, redesign or other measures will be required.	$> 0.5 – 0.7$
To be avoided	The risk of disease or injury is obvious and cannot be accepted. Intervention to lower the risk is necessary.	> 0.7

As a type B standard (group safety standard), BS EN 1005-3:2002 deals with human force limitations across a range of machinery. However, the provisions of this standard can be supplemented or modified by type C standards, which give detailed safety requirements for a specific piece of machinery.

ISO 11228-2:2003, Manual handling and force limits – Part 2: Pushing and pulling

As a working draft, ISO/WD 11228-2:2003 is yet to be referred to as an International Standard. As the document is subject to change without notice, its details shall not be reported. However, a number of features deserve mention, as reviewed on 07/07/2003. In particular, ISO/WD 11228-2:2003 builds upon BS EN 1005-3:2002 by providing two methods of pushing and pulling risk assessment.

In Method 1, a pushing and pulling general assessment checklist is completed. The results of the checklist are considered in conjunction with appropriate psychophysical data (Snook and Ciriello, 1991; Appendix C) to determine an overall risk of injury. For example, if the initial or sustained forces required are not capable by 90% of the population, the risk is rated RED and measures are required to reduce the risk. However, if actual forces are capable by more than 90% of the population, but there are still a predominant number of risk factors identified by the checklist, the risk is rated RED as well. Alternative measures reducing the risk in factors such as the working environment, load characteristics and work organisation are required or Method 2 is implemented.

Method 2, as with BS EN 1005-2:2002, determines force limits according to basic muscular strength limits adjusted according to the intended population and task characteristics (distance and frequency of the push/pull task). Additionally, ISO/WD 11228-2:2003 also attempts to determine force limits based upon compressive strength characteristics of the lumbar spine. The minimum force from either the muscular strength limit or the skeletal strength limit is then selected and risk multipliers are applied to determine the risk zones.

ISO/WD 11228-2:2003 also differs from other pushing and pulling documents by suggesting that the overall organisation of the work performed by an operator may modify the risk of injury. It identifies the following principles to reduce the risk of injury due to work organisations hazards:

(1) The composition, frequency and duration of the task should allow adequate physiological recovery time for the worker

(2) The workers should have some degree of autonomy in how they can organise their work

It is suggested that job enrichment, job enlargement and job rotation may have a key role to play in providing recovery, variety and maintaining levels of production output, as long as the tasks involve the use of different muscle groups. Additional tasks performed by the operator may also need to be evaluated. In addition, to reduce the pushing or pulling distance, storage areas should be positioned close to production areas.

(3) Operators should be trained in how to safely perform each task and how to recognise hazardous workplaces, tasks and equipment conditions

(4) Operators should be aware of the necessary procedures and communication channels through which to report and correct such hazards

(5) Equipment and facilities must be properly maintained for safe usage and defective or damaged equipment must be removed from use immediately

(6) The equipment purchase process should be based upon clear task requirements and thus should select equipment suitable for the specific workplace and task conditions

Finally, an approach for measuring pushing and pulling forces is suggested.

3.4.2.2 Work Environment Standards

Hazards of the working environment are identified in both pushing and pulling force limitation standards. BS EN 1005-3:2003 refers to extreme temperatures, humidity and lighting conditions. ISO/WD 11228-2:2203 makes additional reference to the maintenance of surfaces over which an object is pushed or pulled as well as slopes, ramps and steps, which increase the physical effort of the task. However, when assessing pushing and pulling risks, it is often found that aspects of the working environment were previously specified without adopting an ergonomics approach. Although some building and equipment specifications are compatible with standards for human physical performance, others, typically type C standards, are not. A sample of standards that impact the work environment is provided below:

BS EN ISO 14122-1:2001, Safety of machinery – Permanent means of access to machinery: Choice of a fixed means of access between two levels

BS EN ISO 14122-1:2001 is primarily aimed at the prevention of persons falling and of excessive physical effort. Whenever possible, the preferred means of access to machinery is directly from ground level or from a floor. If not possible, when selecting either a lift or ramp as a means of access between two levels, it recommends that a lift may be best in cases of: frequent access of several persons; long vertical distances and heavy loads to transport. It recommends a ramp when there is a short vertical distance and where it is necessary to transport wheeled vehicles (forklift trucks, manually moved carts, etc.).

Different angles of ramp are recommended depending on use:

(1) Maximum angle 3° – for hand carts or other manually transported wheeled vehicles

(2) Maximum angle 7° – for motor vehicles (e.g. forklift truck)

(3) Maximum angle 20° – for walking, although preferably not more than 10°

The ramp surface is recommended to have a very good resistance against slipping, particularly in the case of ramps 10° – 20°.

PD 6523:1989, Information on access to and movement within and around buildings and on certain facilities for disabled people.

In the context of access for disabled people, this published document reports that studies all show that a ramp slope greater than 1:12 (4.8°) is not appropriate unless it is very short. However, it notes conflicts in the data, particularly for the preferred gradient, which varies between 1:14 (4.1°) and 1:20 (2.9°).

BS 6190-2:1989, Tail lifts, mobile lifts and ramps associated with vehicles – Part 2: Code of practice for passenger lifts and ramps

Some of the hazards to persons during normal use of a ramp are said to include:

(1) Falling off the edge of the ramp

(2) Rolling down the ramp at an uncontrolled rate

(3) Tipping over when going down a steep ramp

No mention is made to the hazard of physical overexertion. Ramps for use with and without an attendant walking on the ramp are recommended to have a gradient no steeper than 1:12 (4.8°). This contrasts *BS EN 1789:2000, Medical vehicles and their equipment – Road Ambulances*, which recommends a maximum loading angle of 16°.

Discrepancy among International, European and British standards, particularly in the context of pushing and pulling between two levels within a building or into a vehicle, may reflect a lack of evidence-based research. In particular, little reference is made which relates aspects of the work environment, particularly steep ramps, to changes in human physical performance.

3.5 GUIDANCE FROM OTHER SOURCES

3.5.1 General Guidance on Pushing and Pulling

3.5.1.1 Horizontal pushing and pulling, perpendicular to the shoulders

According to Chaffin et al. (1999), shoe-floor traction, muscle strength, and low-back compression (and shear) force tolerance provide the biomechanical basis for some of the pushing and pulling recommendations, although there is no general consensus as to which one is more important. Furthermore, the dominant factors may depend to large extent upon the particular pushing or pulling situation.

Rodgers et al. (1986) list the following variables as being important factors governing the ability to exert horizontal push-pull forces:

(1) Body weight

(2) Height of force application

(3) Distance of force application from the body, or the amount of trunk flexion or extension

(4) Frictional coefficient of the floor

(5) Frictional coefficient of the shoe

(6) Duration of force application or the distance moved

(7) Availability of a structure against which the feet or back can push or prevent slippage

Konz (1999) proposes a number of general guidelines for horizontal pushing and pulling when the motion is perpendicular to the shoulders. These include:

(1) Force capability goes down as the force is exerted more often

(2) Two hands are better than one

(3) In general, females are weaker than males, especially in pulling

(4) Push at waist height rather than shoulder or knee level (two vertical handles on a cart, rather than one horizontal handle, allows all sizes of people to use optimum posture)

(5) Pull at knee level rather than waist or shoulder level. If a two-wheeled cart must be pulled over curbs or steps (as in retail delivery of beverages), larger diameter wheels (larger lever arm) are better.

3.5.1.2 Horizontal pushing and pulling, parallel to the shoulders

When horizontal pushing takes place parallel to the shoulders, Konz (1999) states that force capability is 50% of the pushing or pulling capability perpendicular to the shoulders. For horizontal transfer tasks, it is recommended that frictional contacts (e.g. pallets on rails, boxes on polished metal surfaces) be replaced by rolling contacts (e.g. roller track, wheels).

3.5.1.3 Limiting factors when pushing and pulling

When using strength measures to assess the potential for overexertion during handling tasks it is important to identify the weakest muscle groups used in the task (Rodgers et al., 1986), as these tend to fatigue quicker and are stressed to a higher percentage of their maximum capability. For a majority of handling tasks, the ‘weakest link’ or limiting muscle groups are considered to be those associated with grip and shoulder movements (Rodgers et al., 1986).

Likewise, Konz (1999) considers arm and shoulder capability (not the lower back) to be the limiting factor for pushing and pulling exertions when:

(1) Activity is repetitive (local muscle fatigue)

(2) Posture is poor

(3) Pushing with the arms fully extended (arm strength is greatest at ½ reach distance, drops at ¾ reach distance and is lowest at reach distance)

(4) Pushing or pulling with one arm

(5) Pushing or pulling above the shoulder or below the hip

(6) Kneeling (reduces capability by about 20% compared to standing)

(7) Seated (reduces capability by about 40% compared to standing)

Furthermore, a reduced ability to exert pushing and pulling forces stems from a lack of vertical surfaces against which to brace the body and a slippery foot-floor interface.

3.5.1.4 Control measures - NIOSH recommendations

The National Institute of Occupational Safety and Health (NIOSH, 1997), USA, as part of an ergonomics 'toolbox' for workplace evaluations of musculoskeletal disorders, have proposed a number of design principles for pushing and pulling tasks. A hierarchy of 4 design principles are considered important for reducing the risks associated with pushing and pulling:

(1) Eliminate the need to push or pull

(2) Reduce the force required to push or pull

(3) Reduce the distance of the push or pull

(4) Optimise the technique of the push or pull

Possible solutions for addressing these 4 factors are detailed in Table 4.

Table 4. Design principles and control measures for reducing the risks associated with pushing and pulling (adapted from NIOSH, 1997)

Design Principles for Pushing / Pulling Tasks	Possible Control Measures for Reducing the Risks
Eliminate the need to push or pull using mechanical aids, where applicable	• Powered conveyors • Powered trucks • Lift tables • Slides or chutes
Reduce the force required to push or pull	• Reduce size and/or weight of load • Use four-wheeled trucks or dollies • Use non-powered conveyors • Ensure wheels and castors on hand-trucks or dollies have: 1) Periodic lubrication of bearings 2) Adequate maintenance 3) Proper sizing (provide larger diameter wheels & castors) • Maintain the floors to eliminate holes and bumps • Use surface treatment of floors to reduce friction
Reduce the distance of the push or pull	• Move receiving, storage, production, or shipping areas closer to work production areas • Improve the production process to eliminate unnecessary materials handling steps.
Optimise the technique of the push or pull	• Provide variable-height handles so that both short and tall employees can maintain an elbow bend of 80 to 100 degrees • Replace a pull with a push wherever possible • Use ramps with a slope of less than 1:10 (9°)

3.5.2 Recommended Design Limits for Pushing and Pulling

Recommended guidelines for acceptable pushing and pulling force limits have been proposed by a number authors based on a variety of different methodological approaches. Principally, they are based around experimental studies of psychophysical maximum acceptable forces, strength measures (dynamic and static) and measurements of Intra Abdominal Pressure (IAP). The intention here is to present data from sources that are primarily intended as guidelines for use by practitioners.

3.5.2.1 Psychophysical Design Limits

Snook (1978) produced a series of tables for horizontal pushing and pulling based on the psychophysical methodology of perceived Maximum Acceptable Forces (MAF). These tables were later updated, following additional experimental studies, in a summary paper by Snook and Ciriello (1991). The method employed by Snook and co-workers involved the use of a treadmill powered by subjects as they pushed (2 handed) against a stationary bar. A load cell on the stationary bar measured the horizontal force exerted. Subjects controlled the resistance of the treadmill belt by varying the amount of electric current flowing into a magnetic brake geared to the rear of the treadmill. The authors considered this method of measuring push-pull forces to be realistic of working task situations, in so far as being dynamic and carried out over a given horizontal distance. An issue not raised in the work of Snook and Ciriello (1991) is the degree of traction provided by the foot-to-floor surface of the treadmill, although in a paper by Kroemer (1974) he regarded this as high (coefficient of friction approximately 0.9).

The design limit tables, reproduced in Tables 14 and 15 of Appendix C, provide MAF of initial push and pull forces for 90% of the male and female industrial population, for a range of frequencies (one push/pull every 6s, 12-15s, 22-25s, 35s, 1 min, 2 min, 5min, 30min, 8hr), distances of travel (2.1m, 7.6m, 15.2m, 30.5m, 45.7m and 61m) and handle heights (male - 64cm, 95cm, 144cm; female - 57cm, 89cm, 135cm). MAF that are less than the L23 pushing and pulling guidelines filter are shaded RED. This is particularly the case for more frequent tasks, greater distances, and high and low hand heights. This illustrates that the L23 pushing and pulling guidelines may not provide a reasonable level of protection to 90% of the working population for many conditions. Ultimately, this may reduce the number of pushing and pulling operations that are assessed in detail.

Mital et al. (1997), in their guide to manual materials handling, adjusted Snook and Ciriello (1991) data such that physiological design criteria were not violated; the violation criteria being 1000 ml/min and 700 ml/min of oxygen consumption for males and females, respectively, when performed continuously for 8 hours (NIOSH, 1981; as reported by Snook and Ciriello, 1991). It should be noted that they did not consider biomechanical design criterion to be a limiting factor in pushing and pulling. Comparisons between Mital et al. (1997) and Snook and Ciriello (1991) force guidelines show that physiological criteria were only violated for sustained forces, and typically for frequencies less than 2 pushes or pulls per minute. Mital et al.'s (1997) tables of sustained forces are reproduced in Tables 16 and 17 of Appendix C.

3.5.2.2 IAP Design Limits

The Materials Handling Research Unit of the University of Surrey (MHRU) produced a guide on acceptable force limits for pushing and pulling based on measurements of IAP from some 700 British male subjects (Davis and Stubbs, 1980). IAP measurements involve measuring changes of pressure within the abdominal cavity using a pressure pill that the participant swallows. Changes in pressure are said to provide an indirect measure of forces on the lower back. The force limits proposed by MHRU were arrived at on the basis that IAP measurements should not exceed 90 mmHg in workers whose height and weight coincide with 5th percentile limits of the British population. If the resulting force limits are not exceeded, then they claim that 'any male worker should be able to apply them without undue risk of back injury'.

Data on recommended force limits are presented in the form of force 'contour' maps for males of different age ranges (≤ 40, 41-50 and 51-60) and a range of activities, including one handed horizontal pushing (forwards) when standing with different hand/arm positions (lateral to the sagittal plane and 45 degrees above and below transverse plane). Also included are limits for two-handed pushing and pulling when standing and kneeling (on one knee) with the arms horizontal and fully extended. They emphasise that the recommended limits assume that the worker can perform the particular activity in free space, and that it is not performed more than once per minute. For tasks frequencies greater than this, they recommend a 30% reduction to the recommended force limit.

Mital et al. (1997) also provide recommended force limits based on IAP design criterion for one-handed (stronger hand) pushing and pulling when standing (presumably using MHRU data). The recommended force limits are summarised in Table 5. They point out that these values are for an arms position that is neither fully extended nor completely flexed; a shoulder-grip distance equal to half the arm length being more realistic. Nothing is stipulated regarding their definition of what constitutes frequent or infrequent tasks.

Table 5. Recommended maximum force that can be exerted with one hand (stronger hand) whilst in the standing position (Mital et al., 1997)

	Push force		Pull force (kg)	
	Infrequent	**Frequent**	**Infrequent**	**Frequent**
Males	157 N (16 kg)	108 N (11 kg)	147 N (15 kg)	98 N (10 kg)
Females	108 N (11 kg)	74 N (7.5 kg)	98 N (10 kg)	69 N (7 kg)

3.5.2.3 Strength Measure Design Limits

Mital and Kumar (1998a, 1998b) in a review article of human muscle strength intended to provide guidelines for practitioners, provides a number of strength databases that they regard as suitable for use in design. They refer to these as 'the prominent sources of information taken from the literature'.

Pushing and pulling strengths are presented for:

(1) One-handed isokinetic (constant body segment velocity) pull strengths at various speeds of exertion (0.3 to 0.75 m/s) and arm positions in the vertical plane (-30 to 240 degrees)

(2) Two-handed pulling and pushing strengths in the isometric (the body segment involved remains stationary) and isokinetic modes at low, medium and high heights, and at angles (0, 30 and 60 degrees) lateral to the sagittal plane.

These are reproduced in Tables 18 – 20 of Appendix C. It is worth noting the comments of Mital and Kumar (1998) regarding static versus dynamic strength which state:

> 'Since there is no effective limb-object-muscle movement in the case of static strengths, these strengths cannot account for the effect of inertial forces. This leads to underestimating musculoskeletal joint loading during the performance of a dynamic task. For this reason alone, the isometric strength exertion capability on individuals should not be used to assess their capability to perform dynamic tasks. Furthermore, since most industrial processes require a force application through a range of motion in a continuous activity, the design of tasks based on static strength in a fixed posture has little relevance.'

Despite these potential misgivings, Mital et al. (1997), elected to reproduce Kroemer's (1969) static strength measures for a series of unusual pushing tasks involving braced and unbraced body positions. These entailed subjects pushing against a wall mounted force plate in postures where the force was applied via the palms of the hands, preferred shoulder or the person's back. Bracing of the body was achieved using the hands, back or feet pressed up against a floor mounted footrest or a solid wall. Recommended isometric push forces, based on maximal volitional isometric strength capabilities for 90% of the male population, are presented in Tables 21 and 22 of Appendix C.

Mital et al. (1997) also reproduce the findings of Kroemer's (1974) later work where some of the previous postures (Kroemer, 1969) were repeated, but with differing degrees of floor traction (coefficient of friction was approximately 0.3, 0.6 or 1). Again, a table of recommended isometric push forces is presented (Table 23, Appendix C). To summarise, Kroemer (1974) also presents 'minimum' pushing and pulling forces for different force applications and working postures and conditions (Table 6). These are forces that 95% of healthy males should be able to exert intermittently and for short periods of time under common working conditions.

Table 6: Push & pull forces that 95% of healthy male adults should be able to exert intermittently under common working conditions (Kroemer, 1974), reproduced by Mital et al. (1997)

Force	Method of Application	Condition (μ: coefficient of friction)
108 N (11 kg) push or pull	Both hands, or one shoulder, or back	Low traction ($0.2 \leq \mu \leq 0.3$)
196 N (20 kg) push or pull	Both hands, or one shoulder, or back	Medium traction ($\mu \sim 0.6$)
245 N (25 kg) push	One hand	Braced against a vertical wall 50 – 175 cm from and parallel to the push panel.
294 N (30 kg) push or pull	Both hands, or one shoulder, or back	High traction ($\mu \geq 0.9$)
500 N (51 kg) push or pull	Both hands, or one shoulder, or back	Braced against a vertical wall 50 – 175 cm from and parallel to the panel; or Anchoring the feet on a perfectly non-slip ground (i.e. a footrest)
736 N (75 kg) push	The back	Braced against a vertical wall 60 – 110 cm from and parallel to the push panel; or Anchoring the feet on a perfectly non-slip ground (i.e. a footrest)

3.5.2.4 Combined methodology design limits

Rodgers et al. (1986) provide recommended pushing and pulling guidelines, which are said to be based on a combination of three different methodological approaches. These are presented according to overall posture or task requirement and the principal direction of force exertion. Also included as part of these design limits are hand force limits, as these are seen as important limiting factors in pushing and pulling capabilities. The guidelines are based on 'strength data from industrial workers or military personnel performing tasks that bear some resemblance to handling jobs'. The values given represent upper limits for design so that 'the large majority of the potential work force can do the task without excessive fatigue' (Rodgers et al., 1986). The authors go on to emphasise that because people can usually alter posture or methods of applying force in the large variety of handling tasks seen in industry, these guideline figures are more appropriate for the design of new jobs rather than being applied to existing ones.

Horizontal pushing and pulling, perpendicular to the shoulders

Table 7 provides the upper force limits for horizontal pushing-pulling when the direction of movement is perpendicular to the shoulders (Rodgers et al., 1986). These forces represent the upper limits of force exertion and, as such, they should be reduced if the time of force application exceeds 3 to 5 s and if the force is applied:

(1) Above shoulder or below waist height when standing or kneeling

(2) Above shoulder or below chest height when seated

Table 7: Recommended upper force limits for horizontal pushing and pulling tasks (adapted from Rodgers et al., 1986)

Posture / Task Requirement	Upper Force Limit	Examples of Activities
Standing		
a) Whole body involved	226 N (23 kg)	• Truck and trolley handling. • Moving equipment on wheels or castors. • Sliding rolls on shafts.
b) Primarily arm and shoulder muscles, arms fully extended	108 N (11 kg)	• Leaning over an obstacle to move an object • Pushing an object at or above shoulder height
Kneeling	186 N (19 kg)	• Removing or replacing a component from equipment, as in maintenance work. • Handling in confined work areas, such as tunnels or large conduits.
Seated	127 N (13 kg)	• Operating a vertical lever, such as a floor shift on heavy equipment. • Moving trays or a product on and off conveyors.

A limiting factor in overhead work stems from the arms being in a biomechanical disadvantageous position from which to exert a force. For example, in moving items along an overhead conveyor, the upper force limit reduces to 54 N (5.5 kg) (Kroemer, 1974, cited by Rodgers et al., 1986). For force exertions below the lower point, a critical factor is the space available to take up a posture where the large muscles of the legs and truck can be used. Considerably higher force can be exerted if the feet are supported against an immovable structure and the leg muscles can be employed (e.g. standing push: 742 N (75.6 kg) (Kroemer, 1970); and seated pull with extended arms and knees extended at 150 degrees: 630 N (64.2 kg) (Caldwell, 1964)).

Finally, as a guide to approximate limits required to accommodate 90% of workers performing occasional pushing and pulling activities, Chaffin et al. (1999) reviewed the work of several authors to produce a summary table of horizontally applied force limits (Table 8). As Chaffin et al. (1999) make clear, these recommendations only apply when the person:

(1) Can apply the force at about waist level (91 – 114 cm) and adopt a free posture

(2) Exerts the indicated peak forces occasionally for a short period of time (less than 6 s)

(3) Has a coefficient of friction of at least 0.5 at the feet

Table 8: Approximate limits (N) required to accommodate 90% of workers performing occasional pushing and pulling activities in good postures and surfaces of varied traction (Chaffin et al, 1999)

Source & Criteria Applied	Age of Population	# of subjects	Pushing		Pulling	
			m	f	m	f
Davis & Stubbs (1978) • Abdominal pressure limit of $12kN/m^2$	20 – 60		235		392	
Lee (1982) • Required μ = 0.5 • L5/S1 compression force < 3400N	NA	Model value	200		200	
Kroemer & Robinson (1971) • Static strengths capable of being exceeded by 95% of male subjects • μ = 0.6	18 – 25	28	200			
Snook & Ciriello (1991) • Psychological peak forces capable of being exceeded by 90% of males and females	30 (average)	119	340	220	320	230
Ayoub & McDaniel (1974) • Static strength of 50% of subjects on high-traction surface	19 – 23	46	360	230	400	290

As a determinant of push-pull capabilities, Chaffin et al. (1999) emphasises the importance of foot-to-floor traction. They suggest that, collectively, research shows that healthy young males have push-pull static strength capabilities of only approximately 200 N (20 kg) if the static coefficient of friction (COF) is about 0.3. When COF is greater than 0.6, the mean push or pull strength capability is said to increase to approximately 300 N (31 kg) for the same group. Further increases can be achieved by bracing the foot against a fixed object. When pushing or pulling heavy trolleys or carts, the required COF between shoe soles and floor may be greater than 0.8, and muscle strength may not be the limiting factor governing hand forces, but rather the high traction requirements.

Horizontal pushing and pulling, parallel to the shoulders

In situations where the handler is prevented from obtaining a position behind the object to be moved, due to workplace restriction (e.g. piping, ventilation ducts, etc), the handler may first need to move the object across the body using only the shoulder, arm and or upper body. In these situations, the use of the weaker shoulder muscles reduces force capabilities, with recommended upper force limits falling to approximately 68 N (7 kg) at full arm extension (Rodgers et al., 1986). Maximum horizontal pushing and pulling forces in front of the body should be reduced by up to 50 - 70% when applied in a transverse direction at the same elbow angle, as might be expected when operating lever controls (Hunsicker, 1957, cited by Rodgers et al., 1986).

Vertical pushing and pulling

Recommended upper force limits for tasks involving vertical pushing or pulling while standing are presented in Table 9 (Rodgers et al., 1986)

Table 9: Recommended upper force limits for vertical pushing and pulling in standing tasks (adapted from Rodgers et al., 1986)

Posture / Task Requirements	Upper Force Limit	Examples of Activities
Pull down (above head height)	540 N (55 kg)	• Activating a control; hook grip, such as a safety shower handle or manual control
	200 N (20 kg)	• Operating a chain hoist; power grip, <5 cm diameter grip surface.
Pull down (shoulder level)	315 N (32 kg)	• Activating a control; hook grip • Threading up operations, as in paper manufacturing and stringing cable
Pull up: **(25 cm above the floor)** **(elbow height)** **(shoulder height)**	315 N (32 kg) 148 N (15 kg) 75 N (7.6 kg)	• Lifting an object with one hand • Raising a lid / access port cover, palm up
Push down (elbow height)	287 N (29 kg)	• Wrapping, packing • Sealing cases
Push up (shoulder height)	202 N (21 kg)	• Raising a corner or end of an object, like a pipe or beam. Lifting an object to a high shelf

In each of the activities identified in Table 9, grip strength is not considered to be a limiting factor. Situations that are considered to give rise to the largest force exertions are those when the person pulls down from above the head or pulls up from 25 cm above the floor, as body weight can be used in the former, and leg and truck muscles in the latter.

During seated operations, maximum forces are less than those in Table 9; for downward pulls they are about 85% of standing forces (Rodgers et al., 1986). Factors considered important to the amount of force that can be developed is elbow height with respect to work height, as well as hand and forearm orientation (palms up or down; elbows out or in). In operations where frequent vertical force exertions exceed 45 N (4.6 kg), it is suggested that the workstation should either be of a standing or sit-stand design (Rodgers et al., 1986).

Forces developed by the hand

As in the case of tasks limited to upper body movements, recommended guidelines for pushing and pulling forces should be adjusted according to hand, finger and wrist involvement, often dictated by the presence or absence of handles. Rodgers et al. (1986) provide the following recommendations for hand forces:

(1) Pinch grip handling forces should not exceed 45 N (4.6 kg) and should be below 30 N (3.1 kg) in repetitive work

(2) Power grip forces greater than 225 N (23 kg) should not be a regular part of handling jobs

(3) Forces should be kept to below 40 N (4.1 kg) where finger strength is required as part of the task, as in the case of extricating a part, or pulling on an object. Where

the wrist can play a part in the force exertion, a force of 144 N (14.7 kg) is acceptable.

3.5.3 Object Characteristics - Design Considerations for the Use of Trolleys

Characteristics of the object being moved can have a significant bearing on the ease of the handling operation. It is, therefore, important to consider design aspects of the object as a means of reducing the risk. As is common to many industrial pushing and pulling tasks, the object being moved will often entail a trolley, or some piece of equipment supported on wheels. Consequently, a number of recommendations for the design and use of trolleys have been proposed.

Rodgers et al. (1986) provide recommendations for the design and selection of manual and powered operated trucks and trolleys. In the selection of a truck or trolley, a number of factors are considered important:

(1) Expected load

(2) Frequency of use

(3) The duration of continuous use (closely related to the distance of travel)

(4) Characteristics of the work area (e.g. aisle width, floor type and presence of other powered vehicles

(5) Floor surface material

(6) Load bearing characteristics

Table 10 provides recommended guidelines for the selection of hand and powered operated trucks and trolleys based on some of these factors.

Table 7: Recommended limits for the selection of hand and powered trucks and carts (Rodgers et al., 1986)

Type of Truck or Cart	Max. Load (kg)	Max. Transport Distance (m)	Max. Frequency of use/8 hrs	Min. Aisle Width (m)	Type of Transfer to / from truck*
2-wheeled hand cart	114	16	200	1	Ma, P
3-wheeled hand cart	227	16	200	1	Ma, P
4-wheeled hand cart	227	33	200	1.3	Ma, P
Hand pallet truck	682	33	200	1.3	Me, UL
Electric pallet truck	2,273	82	400	1.3	Me, UL
Electric handjack lift truck	2,273	33	400	1.3	Me, UL
Power low lift truck	2,273	328	400	2	Me, P, UL
Electric handstacking truck	682	82	400	1.3	Me, UL
Power fork truck	2,273	164	400	2	Me, UL

* Ma = Manual; Me = Mechanical, P = Parts, UL = Unit load (e.g. pallets)

Rodgers et al. (1986) sought to summarise the above recommendations as follows:

(1) Two, three, and four-wheeled hand trolleys generally should not be loaded with more than **227 kg** of materials. Hand pallet trucks can handle heavier loads. The load rating of a powered truck and of the floor in the area of interest must be considered when determining the weight limits for powered vehicles.

(2) Truck and trolley tasks occurring less than 200 times a day are suitable for manual operations. At higher frequencies powered trucks are recommended

(3) If materials are frequently transported more than 33 m, use of a powered truck should be considered

(4) Powered lift trucks need aisles at least 2 m wide for manoeuvring. Electric trucks generally need at least 1.3 m of aisle width.

In recognising the hazards and risks associated with the pushing and pulling of trolleys, the Australian National Occupational Health and Safety Commission (NOHSC) published a short guidance document entitled 'Moving Trolleys: Reducing Manual Handling Injuries When Moving Trolleys' (NOHSC, 1999). This was intended to provide information on the causes of trolley strain injuries and workplace solutions for reducing the risk of injury; a summary of which is provided in Table 11.

Table 11: Strain injuries associated with the movement of trolleys and possible solutions to reduce the risks of injury (adapted from NOHSC, 1999)

Reasons for Strain Injuries	Examples of Workplace Solutions
• Trolleys are difficult to manoeuvre • Trolley wheels are poorly maintained • Trolley and their loads are too heavy when other risk factors, such as the number of times a trolley is moved or the workplace layout, are taken into account • Surfaces over which trolleys are pushed are uneven or mismatched • Trolleys are moved over large distances or up steep slopes • Trolleys are difficult to grip due to absence of, or poor location of handles • The person pushing the trolley is unable to see over the load	• Replacement of trolleys with automatic conveyors • Mechanisation of the method to move the trolley, e.g. use of a trolley towing device • Ensure trolley wheel size and type are suitable for the job • Reduce the weight of the trolley and the load being carried • Push rather than pull, as this is considered safer • Provide trolley brakes • Provide an appropriate handle design • Locate trolley handles at a height which suits the worker • Restrict the maximum stacking heights of trolleys to improve visibility, weight and posture for users • Ensure regular pre-planned maintenance of trolleys • Provide low gradient ramps • Provide automatically opening doors

In addition to these general guidelines, more detailed recommendations have been produced regarding specific trolley design characteristics, such as, castor diameter, tyre width and profile, tyre composition, the type of wheel bearing, etc, and prepared by Rodgers et al. (1986) and Lawson et al. (1994). These recommendations are summarised in Table 24 of Appendix D.

Finally, using biomechanical modelling techniques and data from the literature, Chaffin et al. (1999) produced a simple set of qualitative guidelines for pushing a trolley:

(1) Push / pull force at about waist level

(2) Vertical and horizontal handles present on the trolley

(3) Large wheels (easy pivot); hard rubber or plastic tyres

(4) Less than 4% grade surface

(5) Clean, dry slightly rough floor

(6) Soft sole shoes with good grip

3.6 PREDICTIVE MODELS OF PUSHING AND PULLING CAPABILITIES

In comparison to the mathematical models used to predict lifting capacity, very few models have been developed to predict human pushing and pulling strength. Those that have are, like lifting tasks, based upon biomechanical, physiological, or psychophysical criteria, or a combination of these approaches.

Models limited to a single design criteria (e.g. Mital, 1983; Garg, 1978) have principally been developed according to stepwise linear regression modelling techniques in order to predict individual capacities. As such, these regression models are data-set dependent (i.e. dependent on the sample population and sample size) and apply only within the range of independent variables included in the model. The combined modelling approach described by Shoaf et al. (1997) differs in that it incorporates a multiplicative approach of independent variables (a series of multipliers), each of which are used to adjust population based pushing and pulling capacity. The models are summarised in Table 12 and described in greater detail in Appendix E.

Table 9: Summary of predictive models for pushing and pulling capability

Source	Model type	Task	Primary database	Gender / population	Dependent variables	Independent variables
Shoaf et al. (1997)	Combined (physiological, psychophysical, biomechanical)			• Acceptable for specified % of population	• Pushing capacity (kg) • Pulling capacity (kg)	• Vertical height of hands • Distance travelled • Frequency • Age group • Body weight
Mital A. (1983)	Psychophysical (Snook's data, 1978)			• Acceptable to 90 % of male and female populations	• Pushing capacity (kg) • Pulling capacity (kg)	• Horizontal distance (m) • Vertical height of hands (cm) • Frequency
Garg et al. (1978)	Physiological	• 2 handed push/pull (standing) at bench (81.28 cm) and chin height (1.524 cm high)	• Six male subjects aged 18 to 22 yrs		• Net metabolic rate (Kcal / push)	• Horizontal movement of work piece • Average push/pull force applied by hands (kg) • Body weight (kg) • Gender

3.7 CONCLUSIONS OF LITERATURE REVIEW

Conclusions from the literature review are as follows:

(1) There was ample evidence available in the literature to produce both an assessment checklist for pushing and pulling as well as general criteria guidance for the selection of trolleys and wheeled equipment

(2) The analysis of pushing and pulling accidents from HSE's RIDDOR database has shown pushing and pulling accidents to be extremely varied in cause and nature. Injuries commonly involve slips and falls, and trappings of the fingers and hands and are not confined to overexertion of the musculoskeletal system. This supports a broad ergonomics approach to pushing and pulling risk assessment.

(3) The L23 guideline figures for pushing and pulling often exceed psychophysical data of maximum acceptable force limits for 90% of the working population. Differences between the L23 guideline figures and psychophysical data are more evident for initial forces, more frequent exertions, greater distances and high or low hand heights.

(4) Differences in methodology, sample characteristics and acceptable force criteria have led to conflicting data on pushing and pulling capabilities. Thus, it is difficult to compare the L23 guidelines to a general consensus on pushing and pulling capability. However, it appears as though the L23 guidelines approximately reflect 90% capability, but under ideal conditions, for example: occasional two handed

whole body pushing or pulling; for short durations; with good floor surface traction; and hands at an optimal height. This may not be the most appropriate level at which to present a baseline filter value to 'protect' 90% of the working population. The benefit of an assessment checklist for pushing and pulling should be to identify and control workplace factors and hazards that may reduce the capability of workers or add to the overall risk of injury. If the L23 guidelines were below the capability of 90% of the working population, the pushing and pulling assessment would be used more often to identify and address the broad range of potential risk factors.

(5) Recent models predicting pushing and pulling capability have emerged in the literature (such as Shoaf et al., 1997) and are now being incorporated into European and International Standards.

(6) There are gaps in the literature, particularly with respect to:

(i) The influence of slopes on the capabilities of men and women to generate pushing and pulling forces

(ii) Dynamic pushing and pulling capabilities of people when performing more specific working tasks

(iii) Databases relating compressive and shear forces on the lumbar spine to actual workplace postures and activities involving pushing and pulling.

4 DEVELOPMENT OF THE PUSHING AND PULLING ASSESSMENT CHECKLIST

4.1 SELECTION OF RISK FACTORS

From the review of contemporary literature and other guidance, a pushing and pulling assessment checklist of risk factors and questions to consider was developed. The purpose of this section is to briefly explain the reasoning behind the selection of risk factors for the assessment checklist. Further detail and justification can be found embedded throughout the literature review and the appendices of this report.

Particular attention was paid to mimicking the existing manual handling assessment checklist format provided in L23 (1998) and including those factors and questions from Schedule 1 that were also relevant to pushing and pulling operations. However, the review of HSE's RIDDOR accident database showed a wide range of injury causes when pushing and pulling, and a fairly even distribution of occurrence among the categories. This, combined with the complexity of some pushing and pulling operations, suggested that many additional factors were required on the pushing and pulling assessment checklist.

4.1.1 The Task

Does the task involve high initial forces to get the load moving?

Higher force requirements increase fatigue and contribute to overexertion accidents such as muscle strains of the shoulders, arms and back (Rodgers et al. 1986; Hoozemans et al., 1998). High forces also limit the number of people who are capable of performing the task (Rodgers et al., 1986; Snook and Ciriello, 1991).

Does the task involve high forces to keep the load in motion?

Higher force requirements increase fatigue and contribute to overexertion accidents such as muscle strains of the shoulders, arms and back (Rodgers et al. 1986; Hoozemans et al., 1998). High forces also limit the number of people who are capable of performing the task (Rodgers et al., 1986; Snook and Ciriello, 1991).

Does the task involve sudden movements to start, stop or manoeuvre the load?

Sudden movements involve high accelerations to start, stop and manoeuvre the load (Rodgers et al., 1986). These accelerations imply large tissue forces and an increased risk of injury (CEN, 2002). If the handler is not prepared for a sudden movement, unpredictable stresses can be imposed on the body, creating a risk of injury and loss of control of the load (HSE, 1998). The risk is compounded if the handler's posture is unstable (HSE, 1998).

Does the task involve twisting/manoeuvring of the load in position or around obstacles?

Manoeuvring operations often take place in restricted space where the object being handled has to be turned, or placed into a particular location with a certain degree of precision. In these instances, the forces which a person can exert are often considerably less than in unrestricted situations, as the operator is unable to position his or her body weight behind the centre of gravity of the load (Rodgers et al., 1986).

Does the task involve one handed operations?

The amount of force that can be generated with one hand is thought to be only 50 – 60% of that which can be generated with two hands (Chaffin et al., 1999). People may not have the capability to lean as far forward or backward as when pushing or pulling with two hands and so shoulder and arm muscle strength becomes the limiting factor (Chaffin et al., 1999; Mital et al., 1997). One handed operations may also induce poor posture such as trunk twisting.

Does the task involve the hands below the waist or above the shoulder height?

Pushing and pulling capability is generally reduced when the hands are much below waist height or above shoulder height (Snook and Ciriello, 1991). As a result, the risk of injury is increased if pushing and pulling is carried out with the hands much below waist height or above shoulder height (Lee et al., 1991; HSE, 1998).

Does the task involve movement at high speed?

It is more difficult to control loads moving at speeds faster than a walking pace (Rodgers et al., 1986) and the risk of injury is increased (Lee et al., 1991). The movement of loads at high speeds may involve high accelerations to start, maintain, and stop the motion as well as change the direction of the moving load (Rodgers et al., 1986). These high accelerations imply large tissue forces and an increased risk of injury (CEN, 2002).

Does the task involve movement over long distances?

Further distances require longer periods of force application. If physical stresses are prolonged then fatigue will occur (HSE, 1998). This will reduce the amount of force that can be sustained, along with the number of people who are capable of performing the task (Rodgers et al., 1998; Snook and Ciriello, 1991).

Does the task involve repetitive pushing or pulling?

Repetitive pushing and pulling increases the frequency of initial forces and should be avoided. Increasing the frequency of pushing or pulling induces muscular fatigue and reduces the amount of force that can be generated, along with the number of people who are capable of performing the task (Snook and Ciriello, 1991; CEN 2002).

4.1.2 The Load or Object to be Moved

Does the load or object lack good handholds?

If the load is difficult to grasp, its handling will demand extra grip strength, which is tiring and may involve an increased risk of releasing the load (HSE, 1998). If there are no suitable handles protruding from the object, fingers are more likely to become trapped (Roebuck and Norton, 2002). The handler's ankles are also more likely to be hit by a trolley without protruding handles (Lawson et al., 1994).

Is the load or object unstable or unpredictable?

Load instability can increase the risk of injury and equipment damage (Lawson et al., 1994). If the load is unstable, for example because it lacks rigidity or has contents that are liable to shift, the instability may impose sudden additional stresses for which the handler is not prepared

(HSE, 1998). If the centre of gravity of the load is high, there is an increased risk of it overturning, for example, when the wheels of a high-loaded trolley hit an obstacle on the floor (Roebuck and Norton, 2002).

Is the load or object a restriction to visibility?

A high load or fully laden trolley can reduce the handler's visibility and increase the risk of the object hitting another person or obstacle. A load that restricts visibility may also cause the handler to lean sideways or twist to see past the load, placing additional stress on the handler's back (Lawson et al., 1994).

If on wheels, are the wheels unsuitable for the type of load?

Factors such as the number, diameter, size and composition of the wheels all influence the ease with which trolleys are pushed or pulled (Lawson et al., 1994; Roebuck and Norton, 2002). If the diameter of the wheels is too small for the type of load, forces required by the operator to move the trolley will be greater (Al-Eisawi et al., 1999). In general, larger wheels are required to support heavier loads; however, the impact of these factors on steering ability must also be considered.

If on wheels, are the wheels difficult to steer?

To steer effectively, the number, arrangement, diameter and composition of the wheels must all be suited to the surface characteristics and the nature of the steering task (Lawson et al., 1994). Wheels that are difficult to steer will increase the force required by the operator to manoeuvre the trolley.

If on wheels, are the wheels easily damaged or defective?

Wheels that are easily damaged will not function effectively for as long (Lawson et al. 1994). Unless maintained, they will become unsuitable for the type of load, difficult to steer and increase the risk of injury (Roebuck and Norton, 2002).

If on wheels, are the wheels without brakes or difficult to stop?

Brakes can reduce the amount of restraining force required by the operator to decelerate or stop the trolley and control the trolley down a slope (Rodgers et al., 1986). Brakes should be applied to trolleys when they are loaded and unloaded (Lawson et al, 1994; Roebuck and Norton, 2002; Rodgers et al., 1986) as a sudden movement can impose unpredictable stresses on the body and increase the risk of injury (HSE, 1998).

If on wheels, are the wheels with brakes, but ineffective?

The method of applying the brakes must suit the tasks for which the trolley is used or the brakes may be ineffective. For example, brakes on swivel castors that do not lock forward and directional (swivel) motion will be ineffective during loading and unloading of the trolley (Lawson et al., 1994). Poorly maintained castors and brakes will become progressively more difficult to use and eventually ineffective (Lawson et al., 1994).

4.1.3 The Working Environment

Are there constraints on body posture / positioning?

If the working environment hinders the adoption of a good posture the risk of injury from manual handling will be increased (HSE, 1998). For example, restricted headroom will induce a stooping posture while other obstructions may increase the need for twisting or leaning (HSE, 1998). If the handler is prevented from obtaining a position behind the object to be moved, due to workplace restrictions, the handler may first need to move the object across the body using only the weaker shoulder and arm muscles with reduced force capability (Rodgers et al., 1986).

Are there confined spaces / narrow doorways?

11% of all push-pull accidents reported to RIDDOR were deemed to be caused by a collision or trapping (Boocock, 2003). Confined spaces increase the risk of collisions with people or objects and the additional manoeuvring required results in more frequent twisting and force exertion by the handler (Lawson et al., 1994). Pushing and pulling a trolley while holding a door open results in twisted postures and one handed pushing and pulling (Lawson et al., 1994). Trolleys must be able to fit conveniently through doorways to provide safety to handlers' limbs and to reduce damage to door jambs (Lawson et al., 1994).

Are there rutted / damaged / slippery floors?

In addition to increasing the likelihood of slips, trips and falls, uneven or slippery floors hinder smooth movement and create additional unpredictability (HSE, 1998). Ridges, gaps or holes can increase the force required to move trolleys by large amounts and result in strain injuries (Lawson et al., 1994; NOHSC, 1999; Roebuck and Norton, 2002). A slippery floor will reduce pushing and pulling capability (Chaffin et al., 1999; Konz, 1999).

Are there ramps / slopes / uneven surfaces?

Ramps increase pushing and pulling forces and increase the risk of 'runaway' trolleys (Lawson et al., 1994; NOHSC, 1999, Roebuck and Norton, 2002). Moving trolleys across slopes can increase the risk of trolleys overturning sideways (Roebuck and Norton, 2002). Steering is also difficult if trolleys have no fixed castors (Lawson et al., 1994).

Are there trapping or tripping hazards?

A high number of finger trapping accidents associated with pushing and pulling objects are reported (Roebuck and Norton, 2002; Rodgers et al., 1986). In cases where the primary cause of pushing and pulling accidents stemmed from environmental factors, the RIDDOR database showed that 70% were due to the object catching against or becoming trapped by some part of the workplace (Boocock, 2003).

Are there poor lighting conditions?

Poor lighting conditions can create a serious risk of injury to the handler and others. Dimness or glare may hinder visibility and increase the risk of a collision between the object being pushed or pulled and other obstacles or people. Contrast between areas of bright light and deep shadow can aggravate tripping hazards and hinder the accurate judgement of height and distance (HSE, 1998).

Are there hot / cold / humid conditions?

High temperatures or humidity can cause rapid fatigue, and perspiration of the hands may reduce grip (HSE, 1998). Work at low temperatures may impair dexterity (HSE, 1998) and icy, slippery floor surfaces may develop.

Are there strong air movements?

Sudden air movements, whether from a ventilation system or wind, can make large loads difficult to manage safely (HSE, 1998) and cause the load to become unstable.

4.1.4 Individual Capability

Does the job require unusual capabilities?

The ability to carry out manual handling operations in safety varies between individuals (HSE, 1998). In general, the pushing and pulling capability of women, as a group, is less than that of men (HSE, 1998; Snook and Ciriello, 1991) although there is considerable overlap. An individual's capability varies with age. The risk of injury from manual handling may be somewhat higher for employees in their teens or in their 50s or 60s, who are more likely to be working closer to their maximum capability (HSE, 1998). Employers must make reasonable adjustments to the workplace or employment arrangements so that a disabled person is not at a disadvantage or an increased risk of injury (HSE, 1998).

Does the job hazard those with a health problem?

An individual's state of health may significantly increase the risk of injury from manual handling if allowances are not made for the health problem (HSE, 1998).

Does the job hazard those who are pregnant?

Manual handling has significant implications for the health of the pregnant worker (and foetus), particularly if combined with long periods of standing and/or walking. Hormonal changes during pregnancy can affect the ligaments and joint laxity, thereby increasing the risk of injury during manual handling tasks (HSE, 1998). As pregnancy progresses, it becomes more difficult to achieve and maintain good postures and this reduces capability (HSE, 1998).

Does the job call for special information / training?

The risk of injury from a manual handling task will be increased where a worker does not have the information or training necessary for its safe performance. For example, ignorance of any unusual characteristics of the loads, mechanical aids (trolleys) or systems of work safety may lead to injury (HSE, 1998). In particular, safety training may be needed for the proper use of trolleys with respect to travel routes, congested areas, lifts, ramps, doors, floor surfaces, and conditions of loading and unloading (Lawson et al., 1994).

4.1.5 Other Factors - Equipment

Is movement or posture hindered by clothing or personal protective equipment?

Gloves and other protective clothing may hinder movement, impair dexterity and reduce grip (HSE 1998).

Is there an absence of the correct/suitable PPE being worn?

Suitable PPE should consider, among many things, the risks of the workplace and the parts of the body. PPE is more likely to be worn if the demands of the job are considered, such as the physical effort required to do the job, the methods of work, the duration of PPE usage, visibility requirements and communication requirements (HSE, 1992). Differences in the physical dimensions of workers may require more than one type or size of PPE (HSE, 1992). There may be an absence of suitable PPE if an effective system of maintenance and replacement is not established (HSE, 1992).

Are trolleys / carts / floor surfaces poorly maintained / cleaned / repaired?

Poorly maintained trolleys get progressively more difficult to use (Lawson et al., 1994). Broken trolleys become dangerous (Lawson et al., 1994). Floor surfaces that are not maintained will become heavily etched, cracked and covered with materials, making handling difficult and increasing the risk of a slip, trip or fall (Rodgers et al., 1986).

Is there a lack of a regular maintenance procedure for the equipment?

Trolleys, other equipment and maintenance records should be marked with the date of the last and next service. A timely and systematic maintenance procedure will reduce the likelihood of broken and inefficient trolleys.

4.1.6 Other factors – work organisation

Is there a general awareness of operating / maintenance procedures?

All involved parties should be aware of safe operating and maintenance procedures so as to reduce the risk of injury as well as damage to equipment. In particular, employees should be aware of the proper use of trolleys with respect to travel routes, congested areas, lifts, ramps, doors, floor surfaces, and conditions of loading and unloading (Lawson et al., 1994). Employees should possess an awareness of maintenance to be able to identify and remove problem trolleys from use until they have been serviced (Lawson et al., 1994).

Do workers feel that there is poor communication between management and employees (e.g. not involved in risk assessments or when purchasing equipment)?

The views of employees can be particularly valuable in identifying manual handling problems and practical solutions to them. Management should consult employees to ensure they will be provided with the correct equipment, which they can then use safely and efficiently (Lawson et al., 1994).

Are there sudden changes in workload, or seasonal changes in volume without mechanisms for dealing with the change?

To cope with sudden rises in workload, employees may need access to additional colleague assistance, or alternative equipment and work practices to cope with the change in exposure. For example, the risk of injury may increase if there is not enough equipment to store and move the loads, the increased volume restricts the workspace or more repetitive pushing and pulling is required.

Do workers feel they have been given insufficient training and information in order to carry out the task successfully?

The risk of injury from a manual handling task will be increased where a worker does not have the information or training necessary for its safe performance. For example, ignorance of any unusual characteristics of the loads, mechanical aids (trolleys) or systems of work safety may lead to injury (HSE, 1998). In particular, safety training may be needed for the proper use of trolleys with respect to travel routes, congested areas, lifts, ramps, doors, floor surfaces, and conditions of loading and unloading (Lawson et al., 1994).

4.2 SITE VISITS

A series of site visits were undertaken to a range of premises within the industrial, retail and health care sectors in order to identify any practical problems with the pushing and pulling assessment checklist.

4.2.1 Methodology

The following practical approach was adopted when developing the assessment checklist for pushing and pulling:

(1) A structured task analysis was completed for a variety of pushing and pulling tasks. Under the guidance of a checklist, the task analysis addressed factors of:

- (i) The task (frequency, distance, pushing or pulling)
- (ii) The load (dimensions, weight, handle characteristics, forces required)
- (iii) The trolley or wheeled equipment (wheel arrangement and characteristics, load capacity, unloaded weight, loading heights)
- (iv) Safety, maintenance and work organisation

(2) User trials involving completion of the pushing and pulling assessment checklist for actual pushing and pulling tasks. 8 companies within the food industry participated.

4.2.2 Main Findings of the Task Analyses and Pushing and Pulling Assessment Checklists

4.2.2.1 The Task

86% of tasks involved a combination of pushing and pulling, although in such circumstances, the tasks mainly involved pushing. The pushing and pulling forces required had previously only been measured in 30% of assessments. Initial forces were reported to range from 7.5 kg – 50 kg (average 32 kg). Sustained forces were reported to range from 4 kg – 25 kg (average 18 kg). Frequent reasons cited for not measuring the forces were that: it was not thought to be required; it was difficult to measure the possible variation that occurred; and the necessary equipment was not available.

The frequency and distance of the pushing and pulling tasks varied extensively. The reported frequency of pushing and pulling ranged from 1 push or pull every 1.7 minutes to 1 push or pull every 4 hours. Likewise, the reported distance of the push or pull task ranged from 2 – 500 metres, although typical distances were 20 – 50 metres. This emphasises the full spectrum of tasks that the pushing and pulling assessment checklist must encompass. It also highlights the difficulty in establishing a single pushing and pulling filter guideline, as handler capabilities over 2 metres will be extremely different compared to those over 500 metres.

Figure 4 shows the frequency of reported risk levels for each *task*-related factor of the pushing and pulling assessment checklist. The spread of reported risk levels suggest that all task related factors of the checklist seemed relevant to the assessment. A number of factors were frequently deemed high-risk, the most frequent of which were the initial and sustained forces; sudden movements to start, stop and manoeuvre the load; and twisting/manoeuvring of the load into position.

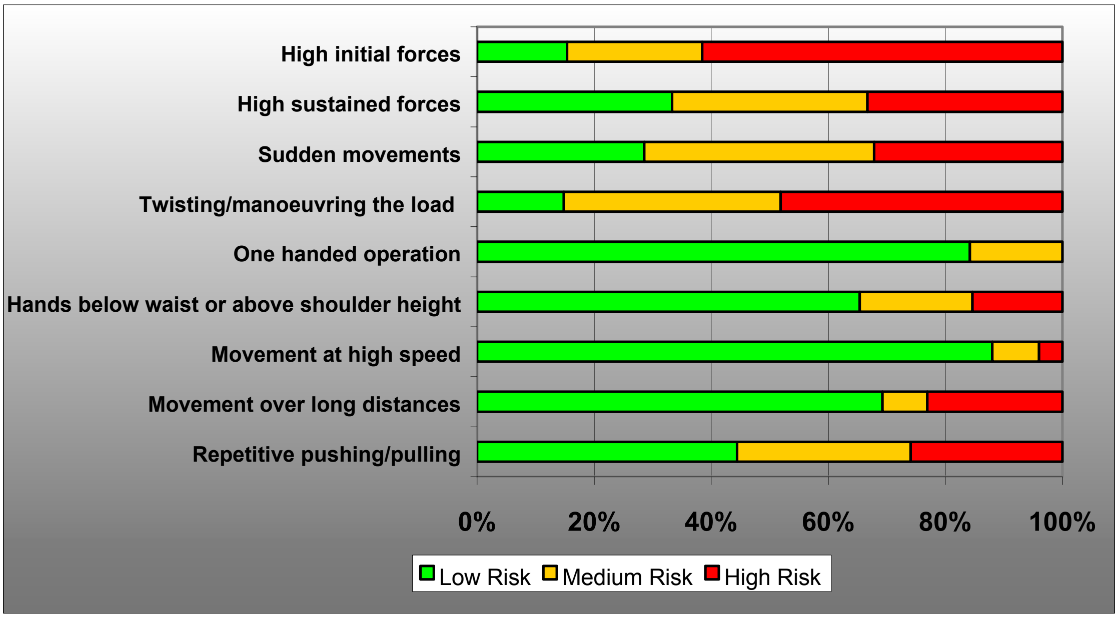


Figure 4: Risk levels reported for each *task* related factor of the pushing and pulling assessment checklist

4.2.2.2 *The Load*

From the task analyses, the loads represented a variety of trolleys, wheeled bins and racks of various dimensions that were difficult to summarise. Likewise the weight of the loads varied from 25 kg to 800 kg, although loads of 200 – 300 kg were typical. Handles were present on 52% of the loads, and in 83% of these cases the handles were orientated horizontally.

Figure 5 shows the frequency of reported risk levels for each *load*-related factor of the pushing and pulling assessment checklist. The weight of the load was reported to be high-risk for approximately 70% of the assessments. For the checklist evaluation, users may have purposely selected heavy pushing and pulling loads, believing them to be higher risk. However, aspects of the work environment and wheeled equipment may have an even greater impact on pushing and pulling forces than the weight of the load. All other risk factors of the load seemed relevant with medium or high levels of risk reported on approximately 40% of assessments.

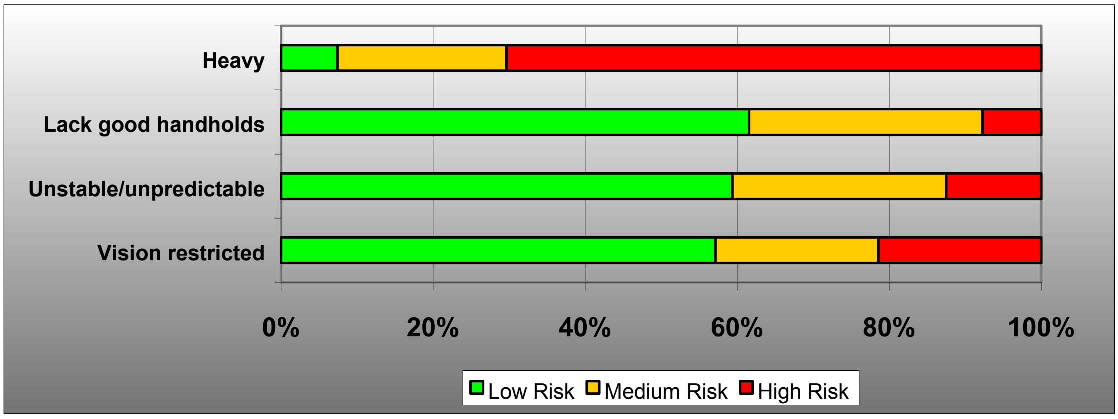


Figure 5: Risk levels reported for each *load* related factor of the pushing and pulling assessment checklist

For the pushing and pulling task analyses performed, all of the loads possessed wheels. 52% of the trolleys possessed a combination of fixed and swivel castors. The most common wheel diameters were 10 – 15 cm, reported for 74% of the task analyses. However, only one trolley (4%) possessed brakes.

Figure 6 shows the frequency of reported risk levels for each factor of the wheeled equipment included in the pushing and pulling assessment checklist. The results suggest some inconsistency in the findings of the assessments. When assessing the suitability of the wheeled equipment for the load and work environment, levels of low risk were reported for approximately 80% of the assessments. However, more frequent medium and high-risk findings for other factors indicate that the wheels were often difficult to steer, without brakes and easily damaged – perhaps not as suitable as originally assessed.

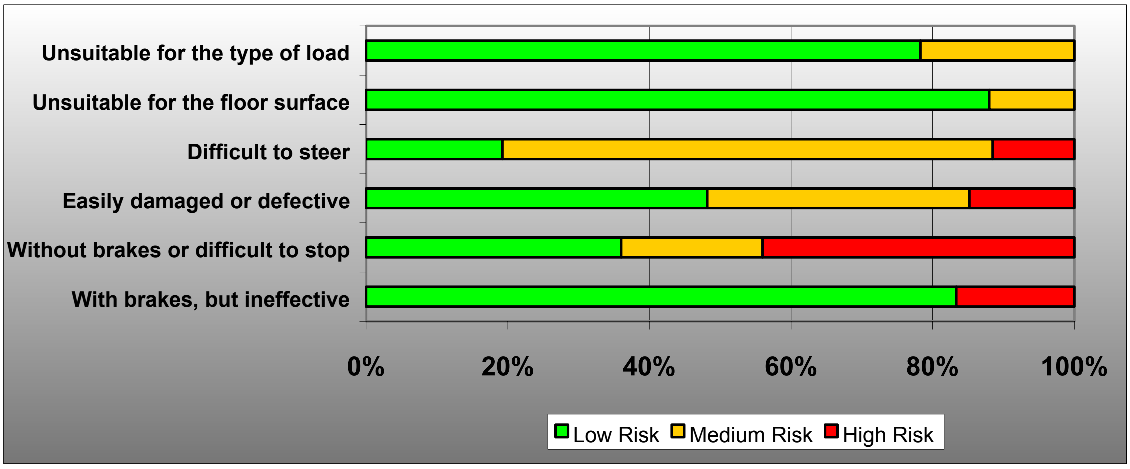


Figure 6: Risk levels reported for each *wheel* related factor of the pushing and pulling assessment checklist

4.2.2.3 Work Environment

Figure 7 shows the frequency of reported risk levels for work environment factors of the pushing and pulling assessment checklist. The frequent reporting of medium and high levels of risk confirmed the relevance of work environment factors to pushing and pulling tasks.

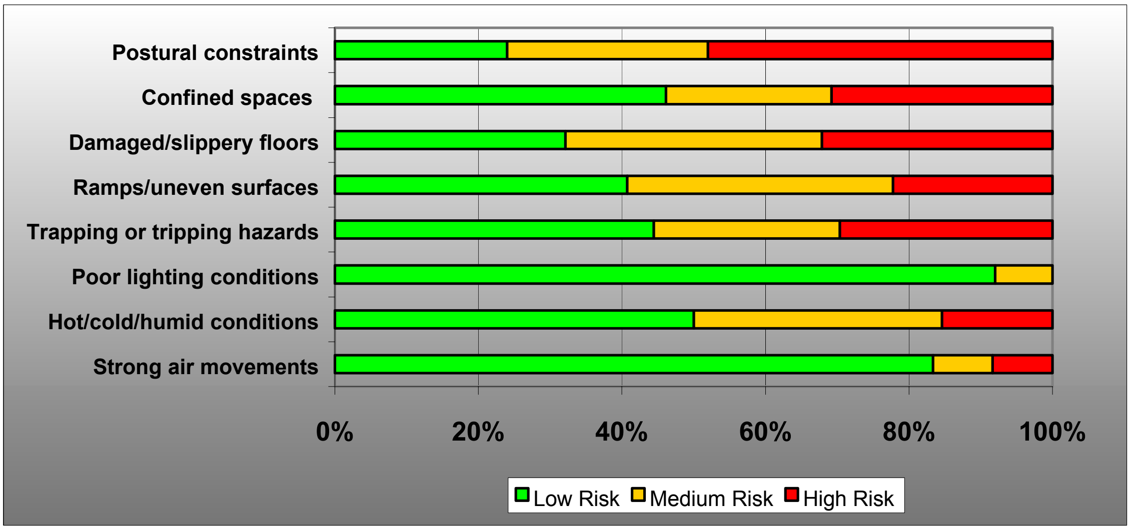


Figure 7: Risk levels reported for each *work environment* factor of the pushing and pulling assessment checklist

4.2.2.4 Individual Capability

Figure 8 shows the frequency of reported risk levels for factors of individual capability included in the pushing and pulling assessment checklist. Medium and high levels of risk were frequently reported in the consideration of individual factors that impact pushing and pulling capability.

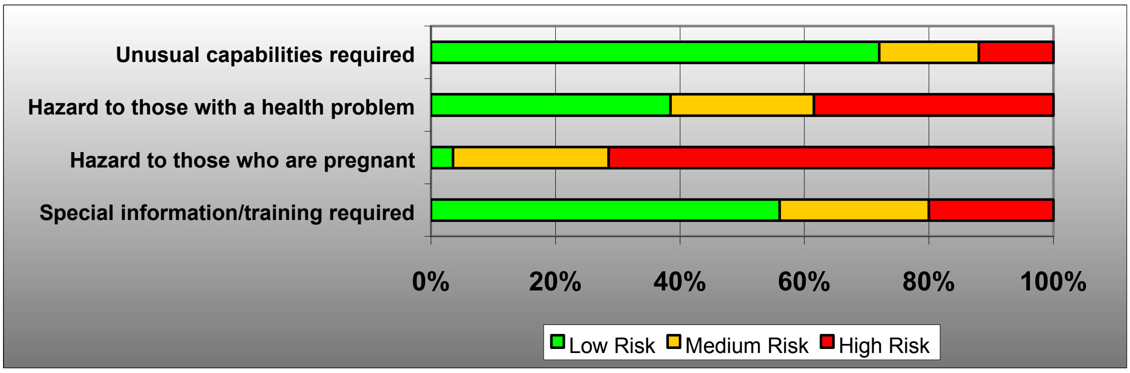


Figure 8: Risk levels reported for each factor for *individual capability* included in the pushing and pulling assessment checklist

4.2.2.5 Work Organisation

59% of the pushing and pulling tasks were supported with a maintenance programme. However, the programmes often did not involve regular checks, but rather relied on problems being reported. The most common maintenance problems reported were worn, damaged or stiff wheels and the exposure of sharp edges on equipment.

Figure 9 shows how users reported the extent to which work organisation factors were already considered in the work place.

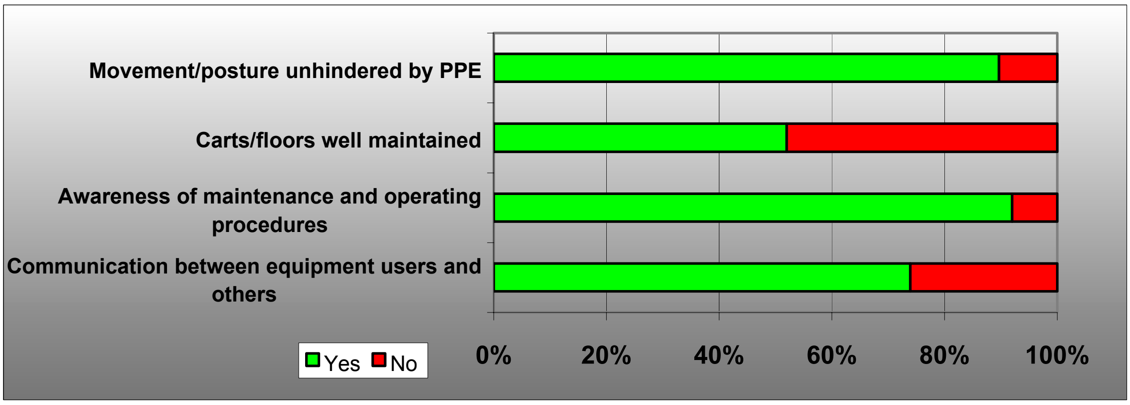


Figure 9: The extent to which users reported that work organisation risk factors were considered in the workplace

Slight inconsistency was shown with approximately 50% of assessments finding that carts and floors were not well maintained, yet less than 10% indicating that there was a lack of awareness of maintenance and operating procedures. It is possible that responses to work organisation risk factors may reflect the performance of the actual user of the checklist, for example, a health and safety manager, who may have responsibility for disseminating maintenance and operational procedures amongst the workforce. This emphasises the necessity to involve the workforce when completing the pushing and pulling assessment checklist.

4.2.2.6 Overall Pushing and Pulling Assessment Checklist Findings

Following completion of the pushing and pulling assessment checklist, only 38% of users actually determined an overall level of risk for the task. The majority (60%) of these rated the pushing or pulling task to be associated with a medium level of risk (Figure 10).

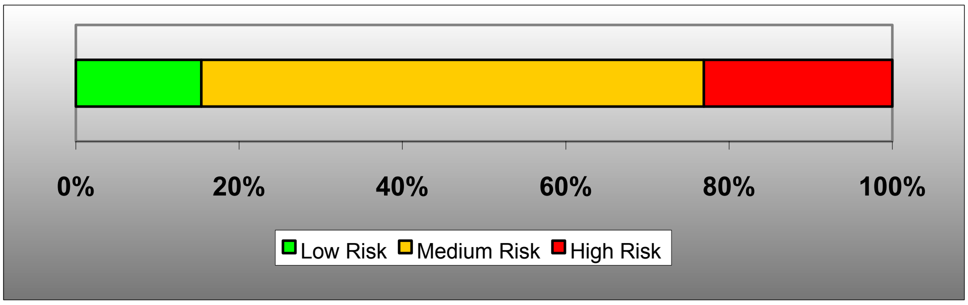


Figure 10: Frequency of reported overall risk levels for each pushing and pulling task assessed

Due to the variety of pushing and pulling tasks analysed, it was difficult to generalise many of the specific remedial measures. However, using a fairly flexible system of classification, the most frequent remedial actions suggested from the pushing and pulling assessment checklist were summarised (Table 13).

Table 13: Approximate frequencies of remedial actions suggested from use of the pushing and pulling assessment checklist

Remedial Action Suggested	Frequency of Suggestion
Revising / improving manual handling training to include pushing and pulling training	71 %
Developing / improving a safe system of work for pushing and pulling, including a procedure for staff to report problems	60 %
Inspecting / cleaning / repairing floor surface conditions	46 %
Developing a regular maintenance procedure	43 %
Ensuring a sufficient amount of suitable PPE is provided	43 %
Improving the stability of the load (i.e. strapping the load down or not stacking as high)	32 %
Introducing or increasing the use of automation / mechanical aids	29 %
Reviewing the location and access to storage areas	25 %
Improving the design / purchase of equipment	18 %
Reviewing the weight of the load	7 %

Despite the emphasis on pushing and pulling forces in the assessment checklist and the lack of force measurement revealed in the task analyses, the future measurement of pushing and pulling force was only mentioned once as a future action in the assessment checklists.

The most frequently suggested remedial actions were not necessarily those of greatest priority. Remedial actions that commonly rated first or second were:

(1) Introducing or increasing the use of automation and mechanical aids

(2) Reviewing the location and access to storage areas

(3) Improving the stability of the load

(4) Performing regular maintenance checks

4.2.3 Conclusions of the Site Visits

The conclusions from the site visits were as follows:

(1) The pushing and pulling checklist must accommodate an extensive variety of pushing and pulling tasks in the workplace, for example, with distances varying between 2 – 500 metres.

(2) The pushing and pulling assessment checklist guided users to recognise factors previously unconsidered. Whereas it appeared as though assessors had previously placed great importance on the weight of the load, the assessment checklist also emphasises other factors, for example, of the work environment and wheeled equipment. The broad range of remedial actions identified through use of the checklist suggests that the checklist does foster an ergonomics approach to pushing and pulling assessment. In addition, higher-order solutions, such as an introduction or increase in the use of automation, were commonly identified as high priority actions.

(3) Slight inconsistencies among the findings of the work organisation factors reinforce the necessity of worker involvement when completing the pushing and pulling assessment checklist. Whereas the risk factors of the task and work environment may be apparent through direct observation, users of the assessment checklist may not recognise the risks related to work organisation unless they consult those who know the job intimately. Worker involvement may need to be prescribed directly through the wording of the work organisation questions.

(4) Despite the checklist's emphasis on the pushing and pulling forces required to start, stop and sustain motion, a measurement of pushing and pulling forces was seldom performed, nor was it mentioned in the assessment checklists as a future action to be taken. Users may require further information on how and why they should measure pushing and pulling forces.

(5) Few users determined an overall level of risk for the pushing and pulling assessment. This may be due to the placement of this question on the front page of the assessment form. After filling in the assessment checklist and remedial actions, described on pages 2 – 5 of the form, it is perhaps unexpected that further completion is required on page 1.

5 USABILITY TESTING OF THE PUSHING AND PULLING ASSESSMENT CHECKLIST AND CRITERIA GUIDANCE FOR THE SELECTION OF TROLLEYS / WHEELED EQUIPMENT

21 employees from 8 companies of the Northern Foods Federation completed an evaluation questionnaire for the pushing and pulling assessment checklist and the criteria guidance for the selection of trolleys / wheeled equipment. Evaluations are based upon the findings of 29 pushing and pulling assessments, which were carried out by these employees.

The evaluation questionnaire addressed:

(1) Ease of use

(2) Usefulness of the pushing and pulling assessment checklist and the benefit received in addition to the original manual handling operations assessment checklist

(3) Usefulness of the guidance document for the selection of trolleys and wheeled equipment

(4) Suggestions for improving the quality, content and layout of the pushing and pulling assessment checklist and the guidance document for the selection of trolleys and wheeled equipment

5.1 USABILITY OF THE PUSHING AND PULLING ASSESSMENT CHECKLIST

5.1.1 Additional Benefit of the Pushing and Pulling Assessment Checklist

For the pushing and pulling checklist evaluation, only 52% of respondents reported that they had previously carried out a manual handling assessment for the particular pushing or pulling task. This reinforces the urgent need a pushing and pulling assessment checklist to complement the existing manual handling assessment checklist. Where a manual handling assessment was previously completed, 91% of respondents reported that the pushing and pulling assessment checklist had benefited their original assessment.

5.1.2 Usefulness of the Pushing and Pulling Assessment Checklist

Figure 11 displays the ratings on the usefulness of the pushing and pulling assessment checklist to identify, plan and prioritise suitable remedial actions. It should be noted that users also possessed a copy of the criteria guidance for the selection of trolleys / wheeled equipment when completing their pushing and pulling assessments. In general, the usefulness of the pushing and pulling checklist was rated quite favourably for identifying, planning and prioritising suitable remedial actions. To quote one user: "*I was able to see that the risks that appeared in the high column were the ones to action first*". This is encouraging as it demonstrates that users were able to focus their findings from their pushing and pulling assessments.

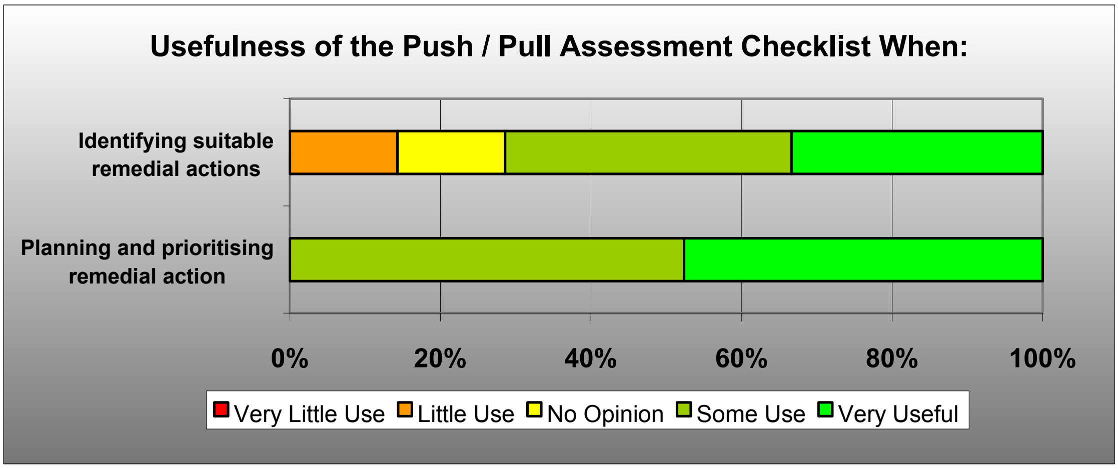


Figure 11: Ratings of usefulness when identifying, planning and prioritising suitable remedial actions with the pushing and pulling assessment checklist

Figure 12 shows the perceived ease in which users completed the checklist.

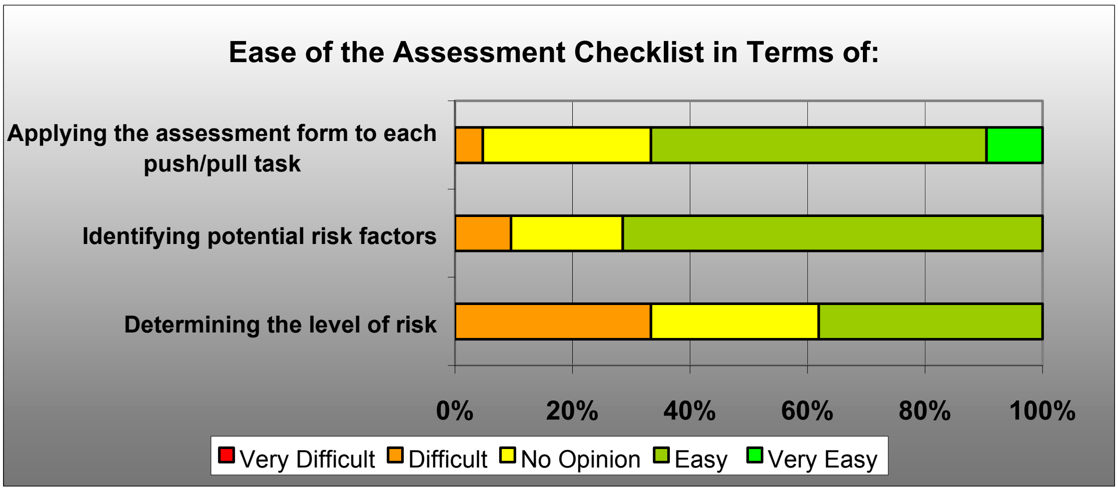


Figure 12: Perceived ease of completing the pushing and pulling assessment checklist

The ease of applying the assessment checklist to pushing and pulling tasks and identifying the potential risk factors was rated favourably by about 70% of respondents. However, the ease of determining the level of risk was only rated favourably by 40% of respondents. Qualitative feedback suggested that some of the poorer ratings reflect the complexities of assessing pushing and pulling operations:

(1) Some users did not know how to measure force. This is recognised to be a challenge when performing pushing and pulling assessments with insufficient knowledge and measuring equipment. The competency required to assess a pushing or pulling operation may be greater than that required to assess a lifting or carrying operation.

(2) Some users predicted that the subjective opinions of the assessor might influence the outcomes of the assessment. This is complicated further by pushing and pulling tasks as the level of risk depends critically on matching the equipment (e.g. trolley characteristics) to the particular work environment. There are fewer comprehensive rules to follow when assessing pushing and

pulling operations, compared to lifting operations. Thus, respondents reported that more training would be required for assessors to help them determine the level of risk.

Nonetheless, as Figure 11 shows, these problems did not seem to impact heavily upon the outcomes of the pushing and pulling risk assessments – a prioritised plan of remedial actions.

Suggestions to improve the content, quality and layout of the pushing and pulling assessment checklist were sought. Most users considered the current assessment checklist to be good. A few suggestions for improvement were mentioned and included:

- Providing further guidance to determine the low, medium and high levels of risk for each risk factor;
- Providing guidance on how to calculate forces; and
- Increasing the space available in which to write.

It should be recognised that many pushing and pulling injuries occur when the object is not supported by wheels (Boocock, 2003). However, the usability of the pushing and pulling assessment checklist for this purpose was not evaluated in this usability study.

5.2 USABILITY OF THE CRITERIA GUIDANCE FOR THE SELECTION OF TROLLEYS / WHEELED EQUIPMENT

All pushing and pulling assessments undertaken for the evaluation involved the use of trolleys, which was possibly encouraged by the provision of the criteria guidance for the selection of trolleys / wheeled equipment. Almost 80% of users viewed this document favourably with respect to assisting the pushing and pulling assessment checklists (Figure 13). Users mentioned that it "*helped identify some issues that [they] were not aware of*" such as correct handle heights, alternative types of trolleys and the provision of brakes. 'Poor' responses seemed to reflect the lack of guidance on how to measure force, as well as disappointment that wheeled equipment had been purchased prior to receiving the guidance.

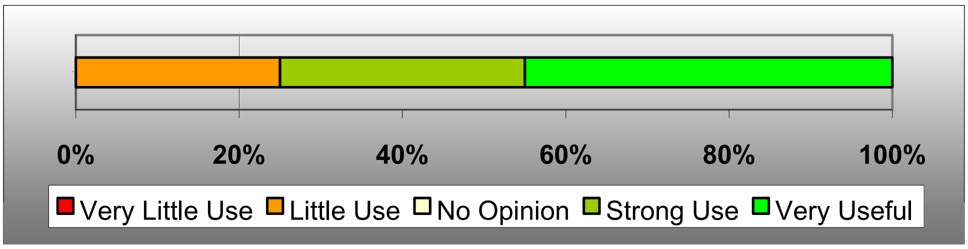


Figure 13: Ratings of the usefulness of the trolley guidance to assist with the pushing and pulling assessment checklist

Suggestions to improve the content, quality and layout of the criteria guidance for the selection of trolleys / wheeled equipment were sought and included:

- Reviewing the necessity of all content offered
- Providing a worked example of how to determine the initial and sustained forces for trolley motion

- Providing diagrams
- Maintaining consistency among units of measurement

6 CONCLUSIONS AND RECOMMENDATIONS

(1) Following a literature review and industry consultation, a pushing and pulling assessment checklist was designed for inclusion into HSE guidance on the Manual Handling Operations Regulations 1992 (L23; HSE, 1998). The checklist considers factors of the pushing/pulling task, the load, (including equipment such as trolleys), the working environment, individual capability, and work organisation. The inclusion of these factors was justified with evidence in the scientific literature, and a review of HSE's RIDDOR database, as well as practical experience and feedback obtained through site visits.

(2) Feedback on the usability of the pushing and pulling assessment checklist was obtained from 21 users. Assessment of pushing and pulling operations were rarely performed prior to this evaluation. However, in cases where an assessment was carried out previously, 91% of respondents felt this pushing and pulling assessment checklist benefited their original assessment. Respondents rated the pushing and pulling assessment checklist extremely favourably with respect to its usefulness as a tool to identify, plan and prioritise remedial actions. Some changes to the assessment checklist were made though as a result of the quantitative and qualitative feedback received.

(3) The ease of using the checklist to determine a precise level of risk for each risk factor was not rated as favourably. Qualitative feedback suggested that this was because many users did not know how to measure pushing or pulling force. Results from the task analyses showed that only 30% of previous assessments had involved pushing and pulling force measurement. Further information may be required on how and why pushing and pulling forces must be measured or how to become sufficiently competent in assessing pushing and pulling tasks.

(4) Some users predicted that, as with any risk assessment, the subjective opinions of the assessor might influence the outcomes of the assessment. This is complicated further with pushing and pulling tasks, as the level of risk depends critically on matching the equipment (e.g. trolley characteristics) to the particular task and work environment. It should be recognised that the competency required to assess a pushing or pulling operation may be greater than that required to assess a lifting or carrying operation.

(5) Despite some barriers encountered when measuring pushing and pulling forces, the pushing and pulling assessment checklist guided users to recognise factors previously unconsidered. The broad range of remedial actions identified through use of the checklist suggests that the checklist does foster adoption of an ergonomics approach to pushing and pulling risk assessment. In addition, higher-order solutions, such as an introduction or increase in the use of automation, were commonly identified as high priority remedial actions.

(6) A literature review was also used to formulate some criteria guidance for the selection of trolleys and wheeled equipment. The guidance document informs users of the implications to handling operations with respect to design features such as: the type of trolley; trolley dimensions; loading factors; handle characteristics; wheel and castor characteristics; conditions of the work environment; and trolley maintenance. The guidance document is intended to help users make more informed purchases based upon good design principles and knowledge of the various options available.

Approximately 75% of users rated this criteria guidance for the selection of trolleys and wheeled equipment favourably.

(7) The L23 guideline figures for pushing and pulling often exceed psychophysical data of maximum acceptable force limits for 90% of the working population (Appendix C). Differences between the L23 guideline figures and psychophysical data are more evident for initial forces, more frequent push/pull exertions, greater push/pull distances and high or low hand heights.

(8) Differences in methodology, sample characteristics and acceptable force criteria have led to conflicting data on pushing and pulling capabilities. Thus, it is difficult to compare the L23 pushing and pulling guidelines to a general consensus on pushing and pulling capabilities. The L23 guidelines exceed the maximal isometric forces suggested by BS EN 1005-2:2002 to accommodate the general European working population. Reviewing other literature, it appears as though the L23 guidelines approximately reflect 90% capability, but under ideal conditions, for example: occasional two-handed whole body pushing or pulling; for short durations; with good floor surface traction; and hands at an optimal height.

(9) As a result of consultation between HSL and HSE, the L23 pushing and pulling risk filter guidelines for starting and stopping a load were reduced to 20 kg for men and 15 kg for women. These guidelines assume that the distance of the push or pull is no more than about 20 metres. The reduction in the risk filter values provide a greater level of protection to the UK workforce and encourage the use of a detailed pushing and pulling risk assessment in many more instances where it would be beneficial.

(10) Analysis of HSE's RIDDOR database revealed that 11% of manual handling injuries between 1986 – 1999 were related to pushing and pulling. In addition, the analysis revealed a wide range of pushing and pulling risk factors, involving not only physical overexertion, but also limb trapping, slipping and falling, equipment breakages, and conditions of the work environment. The wide range of risk factors supports the notion that an ergonomics approach to risk assessment is crucial for assessing pushing and pulling risks. The L23 guidance, currently under revision, will advise that where critical risk factors such as uneven floors, confined spaces, kerbs and trapping hazards are present, a detailed pushing and pulling risk assessment should be undertaken.

(11) The literature review revealed a lack of information on pushing and pulling up ramps with various slopes. Current HSE guidance on the influence of slopes on pushing and pulling forces is provided in the criteria guidance for the selection of trolleys and wheeled equipment, and previous research reports (Roebuck and Norton, 2002). However, this guidance is based upon static mathematical models that do not consider implications of the dynamic nature of the task, slip potential, human behaviour and perception, and changes in muscle activity, posture, and performance capability. Such data on pushing and pulling up ramps have been collected in an extensive laboratory study, the results and analysis of which must be reported in a subsequent document.

7 APPENDICES

7.1 APPENDIX A – PUSHING AND PULLING ASSESSMENT CHECKLIST

Pushing and Pulling of Loads: Assessment Checklist

Section A - Preliminary:

*Circle as appropriate

Task name: Task description: Load weight: Frequency of operation: Push/pull distances:	Is an assessment needed? (i.e. is there a potential risk for injury, and are the factors beyond the limits of the guidelines?) Yes/No*

If 'Yes' continue. If 'No' the assessment need go no further.

Operations covered by this assessment (detailed description): Locations: Personnel involved: Date of assessment:	Diagrams (other information including existing control measures):

Section B - See over for detailed analysis

Section C - Overall assessment of the risk of injury? Low / Medium / High*

Section D - Remedial action to be taken:

Remedial steps that should be taken, in order of priority:	Person responsible	Date remedial steps completed
1	1	1
2	2	2
3	3	3
4	4	4
5	5	5
6	6	6
7	7	7
8	8	8
Date by which action should be taken:		
Date for reassessment:		
Assessor’s name: Signature:		

TAKE ACTION.... AND CHECK THAT IT HAS THE DESIRED EFFECT

Section B: Pushing and pulling - More detailed assessment, where necessary

<table>
<tr><th rowspan="2">Questions to consider:</th><th colspan="3">If yes, tick appropriate level of risk</th><th rowspan="2">Problems occurring from the task
(Make rough notes in this column in preparation for the possible remedial action to be taken)</th><th rowspan="2">Possible remedial action
(Possible changes to be made to system/task, load, workplace/space, environment. Communication that is needed)</th></tr>
<tr><th>Low</th><th>Med</th><th>High</th></tr>
<tr><td>The tasks - do they involve
• high initial forces to get the load moving?
• high forces to keep the load in motion?
• sudden movements to start, stop or manoeuvre the load?
• twisting/manoeuvring of the load into position or around obstacles?
• one handed operations?
• the hands below the waist or above shoulder height?
• movement at high speed?
• movement over long distances?
• repetitive pushing/pulling?</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>The load or object to be moved –
• does it lack good handholds?
• is the load unstable/unpredictable?
• is vision over/around the load restricted?

If on wheels/castors – are they
• unsuitable for the type of load?
• unsuitable for the floor surface/work environment?
• difficult to steer?
• easily damaged or defective?
• without brakes or difficult to stop?
• with brakes, but the brakes are poor/ ineffective?</td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Section B: Pushing and pulling - More detailed assessment, where necessary

Questions to consider:	If yes, tick appropriate level of risk			Problems occurring from the task (Make rough notes in this column in preparation for the possible remedial action to be taken)	Possible remedial action (Possible changes to be made to system/task, load, workplace/space, environment. Communication that is needed)
	Low	Med	High		
The working environment - are there • constraints on body posture/positioning? • confined spaces/narrow doorways? • rutted/damaged/slippery floors? • ramps/slopes/uneven surfaces? • trapping or tripping hazards? • poor lighting conditions? • hot/cold/humid conditions? • strong air movements?					
Individual capability - does the job • require unusual capabilities? • hazard those with a health problem? • hazard those who are pregnant? • call for special information/training?					

Section B: Pushing and pulling - More detailed assessment, where necessary

Questions to consider:	Yes / No	Problems occurring from the task (Make rough notes in this column in preparation for the possible remedial action to be taken)	Possible remedial action (Possible changes to be made to system/task, load, workplace/space, environment. Communication that is needed)
Other factors to consider:			
Equipment			
• is movement or posture hindered by clothing or personal protective equipment?	Yes / No		
• is there an absence of the correct/suitable PPE being worn?	Yes / No		
• are trolleys/carts/floor surfaces poorly maintained/cleaned/repaired?	Yes / No		
• is there a lack of general awareness about operating/maintenance procedures?	Yes / No		
Work organisation			
• do workers feel that there has been a lack of consideration given to the planning and scheduling of tasks/rest breaks?	Yes / No		
• do workers feel that there is poor communication between management and employees (e.g. not involved in risk assessment or when purchasing equipment)?	Yes / No		
• are there sudden changes in workload, or seasonal changes in volume without mechanisms for dealing with the change?	Yes / No		
• do workers feel they have been given insufficient training and information in order to carry out the task successfully?	Yes / No		

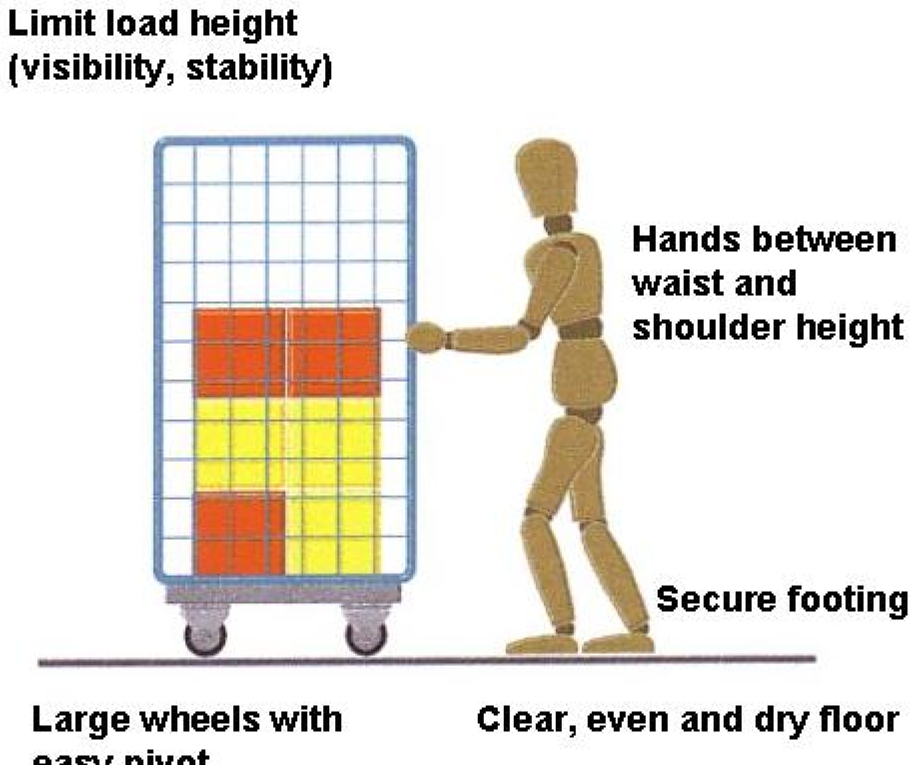
Now please complete section C

7.2 APPENDIX B – CRITERIA GUIDANCE ON THE SELECTION OF TROLLEYS / WHEELED EQUIPMENT

(Adapted from Chaffin et al., 1999; Lawson, 1994; NIOSH, 1997; and Rodgers et al., 1986)

CRITERIA GUIDANCE FOR THE SELECTION OF

TROLLEYS / WHEELED EQUIPMENT



GOOD PRACTICE MEASURES

- **Avoid / reduce the need for pushing / pulling by using mechanical aids**
  - ✓ Conveyors (powered or non-powered)
  - ✓ Powered trucks
  - ✓ Lift tables
  - ✓ Slides or chutes
- **Reduce the force required to push / pull**
  - ✓ Reduce the weight of the trolley and/or load
  - ✓ Provide suitable handles positioned between waist and shoulder height
  - ✓ Provide trolleys with suitable wheels / castors (e.g. proper sizing, composition) and ensure that they are regularly lubricated and adequately maintained according to manufacturer's specifications
  - ✓ Provide even, but slightly rough, and unbroken floor surfaces which are clean and dry
  - ✓ Provide soft sole shoes with good grip
- **Reduce the distance of the push / pull**
  - ✓ Reposition receiving and storage areas closer to production areas
  - ✓ Improve production process to eliminate unnecessary materials handling
- **Optimise handling techniques when pushing / pulling**
  - ✓ Provide variable handle heights which are at a suitable distance apart
  - ✓ Ensure low gradient ramps / slopes
  - ✓ Restrict maximum stacking heights to improve visibility, weight and body posture
  - ✓ Provide automatic opening doors

Task for which the trolley is used		
Principal design features		**Impact on handling operation**
Trolley types	**Two-wheeled trolleys**	Two wheeled trolleys are versatile and suitable for tall items that must be picked up and set down at floor level. They can be used on uneven ground and over kerbs and for delivery work where the trolley is lifted to and from a vehicle. As the load must be supported, they are not suitable for long distances on smooth floors; a platform trolley might be more appropriate.
	Low-platform trolleys	Low-platform trolleys are stable and suitable for luggage and large items. The low platform means that a large volume of stock can be carried without the overall height becoming excessive. Care needs to be taken, however, to avoid awkward bending / stooping when handling items to and from the trolley.
	High-platform trolleys	The top shelf of a high platform trolley keeps items at a more convenient height for manual handling. Lower levels provide extra capacity but should not be used for heavy or awkward items.
	Box-sided trolleys	A box-sided trolley or tub on wheels is often used for linen and loose items that are not easily stacked on a shelf. One disadvantage is the need to bend over the sides of the trolley to remove items. Drop-down sides or spring assisted false bottoms should be used to aid access.

Task for which the trolley is used		
Principal design features		**Impact on handling operation**
Handling factors	**Speed of movement**	A trolley should be moved at walking pace to ensure that it is under control at all times and that it can be stopped almost immediately. A walking pace of 3.2 to 4 km/hr (covering a distance of approximately 60 m in one minute) is reasonable; for heavier loads the speed should be reduced.
	Height of shelves	The weight of products placed on shelves will determine the optimum height. Shelves and load platforms should be arranged to minimise manual handling risk while transferring items to and from the trolley. Ideally, the handling of items should be carried out without stooping or twisting, and with the hands between mid-thigh and waist height . The preferred height for trolley shelves should be between 510 mm and 1140 mm above floor. Handling heights less than 360 mm and greater than 1300 mm should be avoided. A trolley with a platform approximately 800 mm high is suitable for handling heavy objects. A low platform, approximately 250 mm high, is better for handling items which have handles on the top, such as a suitcase. Smooth shelves without a lip allow objects to be slid to and from the trolley easily, making large objects easier to handle.
	Access to shelves	Obstructions or barriers that result in awkward postures when handling items on shelves (e.g. deep shelves and small clearances between shelves) should be avoided. In some cases, a drop-down or fold back side permits easier loading and unloading.

Task for which the trolley is used		
Principal design features		**Impact on handling operation**
Trolley dimensions	**Overall dimensions**	Trolley dimensions will be determined primarily by practical considerations, but the overall dimensions should be limited to a size that, when full, can be pushed without exceeding the recommended pushing forces. Trolleys longer than 1.3 m or wider than 1 m cannot easily be turned in many product-area aisles.
	Overall height	The operator should be able to see over the top of a trolley without restrictions to their visibility. Restricted forward vision often results in the operator adopting twisted postures to see around the sides of the trolley. A maximum laden height of 1300 mm is recommended. If the trolley must be taller than this, the sides should be open or have mesh areas so that the handler can see through it. An alternative might be designing the trolley for pulling.
	Overall width	The overall width of the trolley should be at least 80 mm smaller than the narrowest doorway the trolley will pass through. To ensure stability, however, the distance between the axles of castors when both swivel castors are pointing inwards should be at least $2/3^{rds}$ of the trolley width and $1/6^{th}$ of the trolley height or, if the trolleys are used on slopes up to 6 degrees, $1/5^{th}$ of the trolley height.
	Overall length	For ease of steering, the length of a trolley should generally be between 1.5 and 2.0 times its width.

Task for which the trolley is used		
Principal design features		**Impact on handling operation**
Load supported or carried by the trolley	**Force**	The recommended push/pull force when starting and stopping a load (i.e. initial force) is about 20 kg (200 N) for men and about 15 kg (150 N) for women. For keeping the load in motion (i.e. sustained force), the recommended forces fall to about 10 kg (100 N) for men and about 7 kg (70 N) for women. The recommended upper limit of horizontal force required for an emergency stop within 1 m is 36 kg (360 N). When these limits are exceeded, powered equipment should be considered.
	Load	Trolleys that are loaded to more than 500 kg and are operated in heavily populated work areas, or up and down ramps should be provided with audio and / or visual warning signals. They should also have a braking system to help prevent collisions.
	Starting resistance	A heavy trolley that has moulded rubber wheels has a starting resistance of approximately 196 N per 1000 kg total weight. The longer a trolley is stationary between operations and the heavier the load, the more potential there is for the wheels to 'flatten'. This increases starting resistance.

Task for which the trolley is used		
Principal design features		**Impact on handling operation**
Handle grips and location	**Handle design**	Handle type will be determined by trolley dimensions and handling requirements. Handles may be orientated vertically or horizontally and for one- or two-handed operations. Adequate clearance for the gloved hand is needed where the handle is part of the trolley structure (e.g. vertical support), or attached to it. Handles should be gripped so that the hands are in from the sides of the trolley to prevent trapping or collision injuries. They should also protrude at least 200 mm from the back edge of the trolley to provide room for a normal walking stride without the shins contacting the bottom edge of the trolley. If a trolley is pulled rather than pushed (e.g. a pallet truck), the handle should be an adjustable T-bar. In addition, handles should extend far enough out to prevent the operator from being struck on the heels when walking in front of the trolley.
	Handle placement	The width and length of the trolley and the distance between the handles will determine its manoeuvrability in tight spaces. Handles should be placed so that they straddle the load's centre of gravity, but at a height that permits comfortable posture as well as good biomechanical advantage.
	Handle height	The optimum height for a handle for pushing and pulling is between 910 mm and 1120 mm above the ground, depending upon operators stature. In general, the handle should be a little below elbow height. A middle height of 950 mm is a good compromise for most people. The higher the centre of gravity of the loaded trolley, the higher the handle should be. Handles lower than 910 mm are not recommended because they cause taller persons to stoop.

Task for which the trolley is used		
Principal design features		**Impact on handling operation**
Handle grips and location	**Vertical bars**	Vertical handles, instead of a horizontal bar, allow users to find their own most convenient height. They should be about 450 mm apart to ensure good control of the trolley. They are most satisfactory for narrow trolleys, usually less than 510 mm wide. Vertical corner posts of a trolley's frame should not be used as handles because they expose the worker's hands to trapping / collision injuries.
	Horizontal bars	Horizontal bar handles assist the handler in manoeuvring a trolley in confined spaces. They permit the handler to vary hand location to fit the task and accommodate a person's size and strength.
	Swivel castors	Trolleys with swivel castors should have handles at both ends to maximise manoeuvrability in confined spaces.

Task for which the trolley is used		
Principal design features		**Impact on handling operation**
Wheels and castors	**Diameter**	Larger wheels have lower rolling resistance than smaller wheels and are less affected by gaps, ridges and irregularities in floor surfaces. A minimum diameter of 200 mm is recommended for all trolleys that have a laden weight over 200 kg or that are used outdoors. For other trolleys, a minimum diameter of 125 mm is recommended. However, smaller wheels may be acceptable for light trolleys that are moved only short distances on smooth floors.
	Composition	Hard materials (e.g. cast iron and nylon) have the lowest rolling resistance on hard smooth surfaces, such as concrete, and are suitable in some industrial applications. However, hard wheels are more difficult to start when faced with an obstruction (e.g. debris on the floor) or gap in the floor. They also have a tendency to generate a lot of noise. Softer materials tend to even out the peak forces and may feel easier to push, even if the rolling resistance is higher on a smooth surface. Shock absorbing materials, such as rubber or polyurethane, may be required for rougher floors and outdoor surfaces. Non-marking rubber or polyurethane may be required to protect some floors. Pneumatic tyres roll easily over bumps and unpaved surfaces and may be preferred for some outdoor applications. However, they have a higher rolling resistance on smooth surfaces and need regular checking to maintain correct inflation pressure. Some softer tyre materials may have high friction on some floor surfaces and make it hard for the wheels to swivel into alignment when the trolley is started.

Task for which the trolley is used		
Principal design features		**Impact on handling operation**
Wheels and castors	**Width and tyre profile**	Narrower wheels and rounded tyre profiles roll and swivel more easily on hard surfaces. Wider treads may be necessary on soft carpets or where there are gaps that could catch a narrow wheel (e.g. slots in drainage grates or gaps between a lift and floor), but this increases the force required to move the trolley and makes cornering more difficult. A combination of a wide soft tyre with a solid central rim may be more suitable when moving between different floor surfaces, such as carpets and concrete floors. The width of the wheel will be dictated to some extent by the load rating required.
	Wheel bearings	Sealed precision ball bearings provide the lowest rolling resistance and should be used for manually moved trolleys that are used frequently or over reasonable distances. Pre-lubrication and effective sealing ensure that the low rolling resistance is maintained without the need for further lubrication. Roller bearings are more commonly available for industrial castors but require periodic lubrication to maintain low rolling resistance. Plain metal bearings are acceptable on trolleys moved infrequently and over short distances, but the rolling resistance is higher than ball or roller bearings and increases markedly if not regularly lubricated. Plastic (usually nylon or acetal) plain bearings are acceptable for light loads and do not require lubrication. Thread guards should be used to reduce the likelihood of bearings becoming clogged when used in environments where the floor is often contaminated with waste materials. They also assist in keeping dust and debris out of unsealed bearings. For this reason, they require less frequent maintenance.

Task for which the trolley is used		
Principal design features		**Impact on handling operation**
	Brakes	Brakes on at least two wheels are important if the trolley has to be loaded / unloaded on sloping surfaces or where it is important to stop movement while transferring large items. Castors are available which prevent swivelling of the castor as well as rotation of the wheel.

Task for which the trolley is used		
Principal design features		**Impact on handling operation**
Wheels and castors	**Wheel arrangements**	Four swivelling wheels offer greater manoeuvrability and is the most suitable arrangement for trolleys moved over short distances in congested or confined spaces on level floors. They are not well suited to long distances because they require more effort to steer them. On sloped surfaces the trolley may tend to drift sideways and require twisting effort to maintain straight travel. Two swivel, two fixed wheels are best suited to long distance pushing and use on sloped or uneven surfaces. The swivel wheels should be at the handle end of the trolley (rear) to reduce forces required to manoeuvre it. Four swivel, two fixed centre wheels is best for long trolleys. The trolley pivots about its centre wheels making it easy to steer around corners in passageways. But it is not easily manoeuvred into a corner or parked against a wall. Some trolleys may possess a single swivel wheel at either end, which is acceptable for relatively narrow trolleys that are uniformly loaded.
	Maintenance	Good bearings and regular maintenance reduces the push / pull force required. Tread wear should be monitored, as well as corrosion and other changes that might bind the wheels and increase the force required to move the trolley.

Task for which the trolley is used		
Principal design features		**Impact on handling operation**
Working environment	**Ramps and Slopes**	Ramps or slopes with more than a 2% gradient are difficult for manually handling trolleys because there is a tendency for the trolleys to roll downhill adding to the force needed to control them. In addition, ramps often lead to doors or openings which the handler must negotiate while at the same time controlling the trolley. When handling trolleys on a ramp, the operator should always be upgrade of the trolley, pulling it up the ramp or restraining it from above as they go down the ramp. Trolleys in excess of 227 kg that are used regularly over ramps or slopes should be powered. Trolleys used regularly on ramps or slopes should be fitted with a braking system. Foot or hand brakes can be used to lock the trolley in position or to restrain its motion. These should not require high forces to operate or have to be held continuously for more than 30 seconds. Foot brakes may be useful for restraining heavier loads. However, they should not protrude much beyond the body of the trolley so as not to strike the handler when being moved. Sustained force limits should not be exceeded when moving loaded trolleys up/down slopes. An increase in slope angle of 1 degree results in an approximate 1.75 increase in the push force (kg) per 100 kg of laden trolley weight.

Task for which the trolley is used		
Principal design features		**Impact on handling operation**
Working environment	**Surface characteristics**	Floors that are heavily rutted, cracked, with depressions or drains, or have caked materials on and in them, make trolley handling difficult. The coefficient of friction between the trolley wheels and floor can increase threefold when turning and manoeuvring (e.g. between a concrete and stone pavement), thereby requiring more physical effort from the operator. Large-wheel trolleys can overcome some of these handling problems on uneven surfaces, but they may not be practical in areas where aisle space is limited. Powered trucks are generally preferable if the floor or other surface irregularities cannot be remedied. Peak forces due to irregular floor surfaces or short ramps should not exceed initial force limits. For different floor surfaces, sustained forces should not exceed the recommended limit for the most resistant floor surface (the force required to push a trolley on carpet is typically 30% to 50% higher than on a smooth hard surface).

Increased push force (per 100 kg of trolley weight) according to different slope angles

Slope gradient (Degrees)	Push force (kg) increase per 100 kg of laden trolley weight
1	2
2	3.5
3	5
4	7
5	9
6	10.5
7	12
8	14
9	16
10	17.5

7.3 APPENDIX C – REPRODUCTION OF TABLES OF RECOMMENDED FORCE LIMITS FOR PUSHING AND PULLING

Table 14: Maximal acceptable forces of initial push (kg) for 90% the working male and female population, as recommended by Snook and Ciriello (1991)

Hand Height (cm)		Frequency of Push (One push every…)																	
		6 sec		12 – 15 sec		22 – 25 sec		35 sec		1 min		2 min		5 min		30 min		8 hour	
m	f	m	f	m	f	m	f	m	f	m	f	m	f	m	f	m	f	m	f
2.1 metre push																			
144cm	135cm	20	14	22	15					25	17	25	18	26	20	26	21	31	22
95cm	89cm	21	14	24	15					26	17	26	18	28	20	28	21	34	22
64cm	57cm	19	11	22	12					24	14	24	14	25	16	26	17	31	18
7.6 metre push																			
144cm	135cm			14	15	16	16			21	16	21	16	22	18	22	19	26	20
95cm	89cm			16	14	18	15			23	16	23	17	25	19	25	19	30	21
64cm	57cm			13	11	14	12			20	14	20	14	21	16	21	16	26	17
15.2 metre push																			
144cm	135cm					16	12	18	14	19	14	19	14	20	15	21	16	25	17
95cm	89cm					18	11	21	13	22	14	22	14	23	16	24	16	28	17
64cm	57cm					15	9	17	11	19	12	19	12	20	13	20	14	24	15
30.5 metre push																			
144cm	135cm									15	12	16	13	19	14	19	15	24	17
95cm	89cm									17	12	19	14	22	15	22	16	27	18
64cm	57cm									14	11	16	12	19	12	19	13	23	15
45.7 metre push																			
144cm	135cm									13	12	14	13	16	14	16	15	20	17
95cm	89cm									14	12	16	14	19	15	19	16	23	18
64cm	57cm									12	11	14	12	16	12	16	13	20	15
60.1 metre push																			
144cm	135cm											12	12	14	13	14	14	18	15
95cm	89cm											14	12	16	13	16	14	20	16
64cm	57cm											12	10	14	11	14	12	17	13

Table 15: Maximal acceptable forces of initial pull (kg) for 90% the working male and female population, as recommended by Snook and Ciriello (1991)

Hand Height (cm)		Frequency of Pull (One pull every…)																	
		6 sec		12 – 15 sec		22 – 25 sec		35 sec		1 min		2 min		5 min		30 min		8 hour	
m	f	m	f	m	f	m	f	m	f	m	f	m	f	m	f	m	f	m	f
2.1 metre push																			
144cm	135cm	14	13	16	16					18	17	18	18	19	20	19	21	23	22
95cm	89cm	19	14	22	16					25	18	25	19	27	21	27	22	32	23
64cm	57cm	22	15	25	17					28	19	28	20	30	22	30	23	36	24
7.6 metre push																			
144cm	135cm			11	13	13	14			16	16	16	16	17	18	18	19	21	20
95cm	89cm			15	14	18	15			23	16	23	17	24	19	24	20	29	21
64cm	57cm			18	15	20	16			26	17	26	18	27	20	28	21	33	22
15.2 metre push																			
144cm	135cm					13	10	15	12	15	13	15	14	16	15	17	16	20	17
95cm	89cm					18	10	20	12	21	14	21	14	23	16	23	17	28	18
64cm	57cm					20	11	23	13	24	15	24	15	26	17	26	18	31	19
30.5 metre push																			
144cm	135cm									12	12	13	13	15	14	15	15	19	17
95cm	89cm									16	13	18	14	21	15	21	16	26	18
64cm	57cm									18	13	21	14	24	15	24	17	30	19
45.7 metre push																			
144cm	135cm									10	12	11	13	13	14	13	15	16	17
95cm	89cm									14	13	16	14	18	15	18	16	23	18
64cm	57cm									16	13	18	14	21	15	21	17	26	19
60.1 metre push																			
144cm	135cm											10	12	11	13	11	14	14	15
95cm	89cm											13	12	16	13	16	14	19	16
64cm	57cm											15	13	18	14	18	15	22	17

Table 16: Maximal acceptable forces of sustained push (kg) for 90% the working male and female population, as recommended by Snook and Ciriello (1991) and revised by Mital et al. (1997)

Hand Height (cm)		Frequency of Push (One push every…)																	
		6 sec		12 – 15 sec		22 – 25 sec		35 sec		1 min		2 min		5 min		30 min		8 hour	
m	f	m	f	m	f	m	f	m	f	m	f	m	f	m	f	m	f	m	f
2.1 metre push																			
144cm	135cm	10	6	13	8					15	10	16	10	18	11	18	12	22	14
95cm	89cm	10	6	13	7					16	9	17	9	19	10	19	11	23	13
64cm	57cm	10	5	13	6					16	8	16	8	18	9	19	9	23	12
7.6 metre push																			
144cm	135cm			6	5	9	7			13	7	13	7	15	8	16	9	18	11
95cm	89cm			6	5	10	7			13	8	13	8	15	9	15	9	18	11
64cm	57cm			6	5	10	7			12	7	13	7	14	8	15	9	18	11
15.2 metre push																			
144cm	135cm					6	4			11	4	12	6	13	7	14	7	16	9
95cm	89cm					6	4			11	4	12	7	13	7	13	8	16	10
64cm	57cm					6	4			11	4	11	6	12	7	13	7	15	9
30.5 metre push																			
144cm	135cm									6	4			12	6	13	6	16	8
95cm	89cm									6	4			12	6	13	7	16	9
64cm	57cm									6	4			11	6	13	6	15	8
45.7 metre push																			
144cm	135cm									5	4			10	5	11	6	13	8
95cm	89cm									5	4			9	6	11	6	13	8
64cm	57cm									5	4			9	5	11	6	13	7
60.1 metre push																			
144cm	135cm											7	3	8	4	9	4	11	6
95cm	89cm											7	3	8	4	9	5	11	6
64cm	57cm											7	3	8	4	9	4	10	6

Table 17: Maximal acceptable forces of sustained pull (kg) for 90% the working male and female population, as recommended by Snook and Ciriello (1991) and revised by Mital et al. (1997)

Hand Height (cm)		**Frequency of Pull (One pull every…)**																	
		6 sec		**12 – 15 sec**		**22 – 25 sec**		**35 sec**		**1 min**		**2 min**		**5 min**		**30 min**		**8 hour**	
m	f	m	f	m	f	m	f	m	f	m	f	m	f	m	f	m	f	m	f
2.1 metre push																			
144cm	135cm	8	5	10	8					12	10	13	10	15	11	15	12	18	15
95cm	89cm	10	5	13	8					16	10	17	10	19	11	20	12	24	14
64cm	57cm	11	4	14	8					17	9	18	9	20	10	21	11	25	13
7.6 metre push																			
144cm	135cm			6	6	8	8			10	9	11	9	12	10	12	11	15	13
95cm	89cm			6	6	10	8			13	9	14	9	16	10	16	10	19	13
64cm	57cm			7	5	11	7			14	8	15	8	17	9	17	10	20	12
15.2 metre push																			
144cm	135cm					6	4			9	6	9	8	10	8	11	9	13	11
95cm	89cm					7	4			12	6	12	7	14	8	14	9	17	11
64cm	57cm					7	4			12	6	13	7	15	7	15	8	18	10
30.5 metre push																			
144cm	135cm									7	5	8	7	9	7	11	8	13	10
95cm	89cm									7	5	10	7	12	7	14	7	17	10
64cm	57cm									7	5	11	6	13	6	15	7	18	9
45.7 metre push																			
144cm	135cm									5	5	7	6	8	7	9	7	10	9
95cm	89cm									6	4	9	6	10	6	12	7	14	9
64cm	57cm									6	4	9	6	11	6	12	6	15	8
60.1 metre push																			
144cm	135cm											6	4	6	5	7	5	9	7
95cm	89cm											7	4	9	5	10	5	12	7
64cm	57cm											8	3	9	5	10	5	12	6

Table 18: One handed isokinetic pull strengths (N) in the vertical plane, with the preferred arm, reproduced by Mital and Kumar (1998)

Variable	Males		Females	
	Mean	SD	Mean	SD
Speed of exertion (m/s)				
0.30	322	250	61	65
0.35	303	236	60	73
0.48	274	219	51	68
0.58	242	197	49	63
0.75	225	192	48	63
Angle of arm (deg)				
-30° (arm up and hyper-extended; pull down)	173	159	24	6
0° (arm up; pull down)	400	265	59	47
30° (pull down)	269	200	43	23
60° (pull down)	220	186	36	21
90° (horizontal pull)	160	165	33	20
120° (pull up)	380	186	30	13
150° (pull up)	370	252	26	10
180° (arm vertical; pull up)	460	273	194	107
210° (arm hyper-extended; pull up)	230	152	50	74
240° (arm hyper-extended; pull up)	190	195	22	10

Table 19: Two handed pushing and pulling strength (N) of males in isometric and isokinetic modes at low, medium and high hand heights, reproduced by Mital and Kumar (1998)

Height	Peak Forces (N)						Average Forces (N)					
	Sagittal		30° lateral		60° lateral		Sagittal		30° lateral		60° lateral	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Isometric Pushing												
Low	363	92	335	74	281	59	258	73	233	55	199	47
Medium	395	123	358	93	295	60	266	85	249	65	202	46
High	320	44	274	68	229	62	216	74	191	48	156	39
Isokinetic Pushing												
Low	338	96	300	92	253	66	72	43	54	11	47	10
Medium	339	85	306	76	281	60	60	11	56	9	52	8
High	327	115	301	104	263	54	58	15	54	13	49	7
Isometric Pulling												
Low	423	135	364	71	311	67	292	102	253	47	217	48
Medium	537	133	432	64	338	65	387	94	300	50	237	50
High	469	73	428	131	324	139	320	47	277	88	224	107
Isokinetic Pulling												
Low	337	92	326	73	266	31	106	18	93	14	76	10
Medium	434	96	377	95	289	40	137	25	119	32	86	11
High	390	88	316	65	235	46	127	30	98	16	75	13

Table 20: Two handed pushing and pulling strength (N) of females in isometric and isokinetic modes at low, medium and high hand heights, reproduced by Mital and Kumar (1998)

Height	Peak Forces (N)						Average Forces (N)					
	Sagittal		30° lateral		60° lateral		Sagittal		30° lateral		60° lateral	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Isometric Pushing												
Low	275	72	260	74	239	71	204	60	192	60	169	47
Medium	288	72	271	47	227	37	207	52	189	41	158	27
High	224	42	196	38	186	52	167	34	140	30	134	30
Isokinetic Pushing												
Low	171	40	197	40	160	41	44	20	42	7	36	7
Medium	270	56	246	47	197	40	90	74	51	10	44	7
High	220	28	200	32	191	27	49	8	45	8	44	7
Isometric Pulling												
Low	306	80	303	82	247	67	219	63	220	61	176	56
Medium	385	119	328	84	281	50	275	109	230	72	204	44
High	368	72	306	92	281	107	267	59	221	75	197	78
Isokinetic Pulling												
Low	209	53	202	46	185	46	64	13	56	9	52	9
Medium	292	53	202	46	230	42	91	16	78	13	67	13
High	253	47	218	35	177	30	85	16	74	12	62	13

Table 21: Isometric push force (kg) for 90% of the male working population when braced between two walls and adopting various working postures, recommended by Kroemer (1969) and reproduced by Mital et al. (1997).

Horizontal Distance Between Walls (% of thumb-tip reach)	Postural Condition		
	Pushing with the back; squatting	Pushing - one hand (shoulder height)	Pushing - two hands (shoulder height)
50		18	41
60		21	47
70		24	65
80	98	34	79
90	95	28	60
100	103	21	33
110	123		
120	122		
130	113		

Table 22: Isometric push forces (kg) for 90% of the male working population when braced with one foot and adopting various working postures, as recommended by Kroemer (1969) and cited by Mital et al. (1997).

Height of Force Application (% of shoulder height)	Horizontal Distance Between Brace and Hands (% shoulder height)	Postural Condition		
		Pushing with two hands; one foot braced on wall	Pushing with shoulder; one foot braced against footrest	Pushing with two hands; one foot braced against footrest
50	80	44		
50	100	51		
50	120	58		
60	70		55	
60	80		64	
60	90		62	
70	60		44	
70	70		55	44
70	80	52	55	50
70	90			42
70	100	44		
70	120	65		
80	60		36	
80	70		48	40
80	80		47	40
80	90			44
90	70			32
90	80	45		34
90	90			39
90	100	43		
90	120	69		

Table 23: Isometric push forces (kg) for 90% of working males under various postures and floor surface conditions with no available braces, recommended by Kroemer (1974) and reproduced by Mital et al. (1997).

Floor Condition (μ: coefficient of friction)	Posture Condition [a]		
	Pushing with two hands; standing	Pushing with shoulder; standing	Pushing with back; squatting
Very slippery ($\mu = 0.3$)	15	15	14
Moderately slippery ($\mu = 0.6$)	22	23	24

[a] Operator selects height of force application and distance between foot and hands

7.4 APPENDIX D – SUMMARY OF SPECIFIC TROLLEY DESIGN GUIDELINES

Table 24: Summary of Trolley Design Guidelines (Lawson et al., 1994)

Recommendations	Reasons
Trolley Dimensions	
Height • Maximum trolley height of 140 cm • Arrange trolley stacking so no goods, can be stored above 1.4 metres • If the trolley is too high, allow visibility through the frame, mesh or bars at eye level • High trolleys should be moved with one user at each end for safety	• High trolleys obstruct visibility. 1.4 metres based on the 5th percentile female shoulder height (Pheasant, 1986). Operators may constrain posture to peer around trolley edges • High narrow trolleys lack sideways stability and can topple on sloped floors or if moving quickly around corners • High trolleys create higher stacking heights and have a greater volume (total load)
Length • Trolley length should be 1.5 – 2 times its width • Longer trolleys should be steered with two operators	• Long trolleys may be difficult to steer or fit into small spaces (e.g. lifts). This may increase manoeuvring forces. • Long trolleys may be difficult to tow
Width • Width trolleys are preferred <u>but</u> width should be at least: - 8 cm less than narrowest doorway for hand pushing/pulling trolley - 50 cm less than narrowest doorway for towing single trolley - 70 cm less than narrowest doorway for multiple trolleys	• Tight space between doorways and trolleys may lead to pinched fingers and trapped upper limbs • If trolley access is restricted, more lifting and carrying will occur • Wider trolleys are more stable, as long as castors are spaced far apart
Shelf Height & Design • Maximum shelf height of 140 cm • Optimal shelf height of 80 – 110 cm (knuckle to elbow height) for heavy and frequently used items • Only store light and infrequently used items on shelves lower than 60 cm and higher than 110 cm • Consider self adjusting units with bin trolleys or platform trolleys to raise loads to optimal working height • If heavy loads must be placed on the bottom shelf, recess the shelves at knee height to allow the operator to face to load when lifting • Shelf depth should not exceed 80 cm at 80 – 120 cm heights; 45 cm at heights < 80 cm; and 30 cm at 120 – 140 cm heights • Avoid small clearances between shelves • Consider guard rails during use • Shelves should be smooth and either horizontal or sloped slightly inwards	• Lifting above elbow and shoulder height places operator under greater muscle and joint strain • Taller operators will have to bend slightly to use shelves with heights of 60 – 80 cm • Shelves under 60 cm cause too much operator bending • Wide shelves may lead to awkward reaching postures when loading and unloading items • Loads should be placed on the shelf edge and slid into place. • Sloped or guarded shelves resist the load sliding off during use

<table>
<tr><th>Recommendations</th><th>Reasons</th></tr>
<tr><td colspan="2">External Features</td></tr>
<tr><td>Sides / Gates
• Consider mesh, bars or plates on sides
• Consider detachable gates rather than fixed sides
• If carrying liquids, trolley floors should contain any spills until they can be mopped out later
• Ensure it is easy to detach and refit the sides or gates and there are no sharp edges</td><td>• Mesh or bars allow improved visibility through the trolley and lighter construction
• Plates may protect against dust, spill, etc.
• Detachable gates allow access to goods for improved manual handling</td></tr>
<tr><td>Handle Design
• Fit at least one handle to a trolley
• Fit handles in from the sides of trolleys
• Trolleys with 4 swivel castors will require handles at both ends
• Handles should allow grip between 91 cm – 100 cm
• Handles may be positioned horizontally or vertically. Vertical handles should be spaced about 45 cm apart from each other
• Handle diameters should be between 2.5 and 4 cm
• Allow clearance of 12 cm to clear palm breadth and 5 cm to clear the knuckles. Allow additional clearance when wearing gloves
• Allow 20 cm clearance out from the back edge of trolleys used at low speeds, and 40 cm for trolleys used at higher speeds
• Handles should be cylindrical, smooth and have no sharp edges. Consider a replaceable insulating material on the handles</td><td>• Using trolleys without handles, or handles at the edges, risks crushing fingers
• Handles at both ends improve mobility in confined spaces
• Vertical handles allow users to find their optimal height; horizontal handles allow selection of optimal hand separation
• Small handle diameters cramp the grip while larger diameters are uncomfortable
• Sufficient hand clearance is required to grip the handle quickly and easily
• Handle clearance from the trolley required so ankles do not hit shelves when taking a good stride
• Cylindrical handles best for safe power grips
• Un-insulated handles may become hot or cold with environmental changes</td></tr>
<tr><td>Buffers
• Fit appropriate buffers, made from impact absorbing material (e.g. rubbers, polyurethane)</td><td>• Buffers reduce damage to trolleys, walls, doors and other equipment and thus reduce the amount of splinters, metal slivers and roughness that can damage people</td></tr>
<tr><td>Towing Fixtures
• Tow bars, hitches, brackets and other couplings must be designed, constructed and fitted appropriately. Couplings must be robust and secure.
• For towing, heavy duty castors or wheels must be used (20 cm minimum diameter)
• Trial all towing trolleys in their environment</td><td>• Towing causes high impact loads and trolleys and castors must be especially strong
• Trolleys that break loose at speed are an immediate and serious danger
• Castors for manual pushing/pulling are usually unsuitable for towing</td></tr>
<tr><td>Material & Structure
• Trolley weight should be about 25% of the load for which it is designed
• Consider hygiene / cleaning requirements
• Consider hot, cold, wet or chemically-exposed environments</td><td>• Frame material and structure affects trolley weight, rigidity, durability, visibility through the frame, noise, vibration, potential for cuts and scratches, and selection of castors</td></tr>
</table>

Recommendations	Reasons
Wheels and Castors	
Wheel & Castor Alignment • Castors should be positioned at all corners of the trolley • Trolleys with 4 swivel castors are best for congested / confined areas. Consider a directional lock on one of the castors • Trolleys with 2 fixed (front) and 2 swivel (rear) castors are best for longer distances, sloped paths and outdoor use • Trolleys with 4 swivel castors at corners and 2 fixed castors at centre are best for heavy loads, long trolleys and long travel distances	• Trolley corners without castor support may be unstable with heavy loads or when on slopes • Trolleys with 4 swivel castors are highly manoeuvrable and suitable for level floors and short distances. They are difficult to steer on uneven of sloped floors • Trolleys with fixed castors require more space for turning and cannot be pushed sideways into small spaces, but are easier to steer over long distances
Wheel and Castor Diameter • Minimum castor diameter of 20 cm for all trolleys with loads over 200 kg or used outdoors • Minimum diameter of 12.5 cm for all other trolleys • Smaller diameters (7.5 – 10 cm) may be acceptable for light loads and short distances on smooth floors, without obstructions.	• Larger diameter wheels reduce the forces for all trolley manoeuvring. They roll over ridges and irregular floor surfaces with greater ease and less vibration • Larger wheels are more resilient to damage
Tyre Material • Non-marking rubber or polyurethane tyres are recommended • Hard plastic materials (e.g. nylons) should only be used if all pushing and pulling is restricted to carpet and there are no obstructions • Pneumatic tyres are only recommended for the roughest surfaces (e.g. roads and gravel)	• Softer tyres absorb shocks well but require more force to move. If tyres are too soft though (i.e. flat), forces increase drastically • Nylons swivel easily on carpets but pick up gravel and leave indents on some flooring • Harder tyres are generally noisier and cannot be used across a variety of surfaces • Pneumatics have problems maintaining pressure in smaller sized wheels
Bearings • Use high quality bearings • Establish and maintain a regular greasing and maintenance programme • Use total brakes whenever the trolley is to be immobilised • Use wheel lock to lock rolling movement only	• High quality bearings reduce forces to move trolleys and help maximise the load within the force guidelines • With total braking, the wheel and head swivel is locked, giving maximum stability • Wheel lock only is not suitable if any work is to be performed on the trolley as it moves forward or backwards
Thread guards • Fit thread guards	• Thread guards prevent lint or thread from wrapping around the wheel axles and slowing rotation. They also protect the bearings from dirt and moisture
Springs • Use spring castors for transportation of heavy fragile goods or in outdoor environments	• Spring castors reduce rattle and bounce over bumps

7.5 APPENDIX E – MODELS USED TO PREDICT PUSHING AND PULLING CAPABILITIES

Table 25: Psychophysical model of push / pull capabilities (Mital, 1983)

Dependent Variable	Type of task	Gender	Model	R^2
Pushing capacity (kg)		Male	PC = 17.29 - 0.166 x HD - 11.45 x F + 0.0013 x (HD^2) + 5.60 x (F^2) + 0.001 x (1/F) + 0.047 x HD x F	0.968
		Female	PC = 10.31 - 0.133 x HD - 16.15x F - 0.154 x LN(F) + 6.17 x EXP(F) + 0.056 x HD x F	0.96
Pulling capacity (kg)		Male	PLC = 18.48 - 0.685 x F - 0.0003 x (VD^2) + 0.003 x VD x F - 0.5 x LN(F)	0.978
		Female	PLC = 15.03 - 0.394 x F - 0.0003 x (VD^2) - 0.331x LN(F)	0.945

Key
PC: Pushing capacity (kg)
PLC: Pulling capacity (kg)
HD: Horizontal distance of push (m)
VD: Vertical distance of pull (height of force application - cm)
F: Frequency of push/pull (times/min)

Table 26: Physiological model of push / pull capabilities (Garg et al., 1978)

Dependent Variable	Type of task	Model
Net metabolic rate (Kcal/push)	Pushing/pulling at bench height (0.8 m)	NMR = 0.00112 x HM x BW + 0.0115 x F + 0.00505 x F x G
	Pushing/pulling at 1.5 m height	NMR = HM x (0.086 + 0.036 x F)

Key
NMR:Net metabolic rate for the activity performed
BW: Body weight (kg)
HM: Horizontal movement of work piece (m)
F: Average pushing/pulling force applied by hands (kg)
G: Gender (male=1, female=0)
Both models are valid for a duration of less than one hour.

Table 27: Combined model of push / pull capabilities (Shoaf et al., 1997)

Dependent Variable	Type of task	Model
Pushing capacity (kg)	Generic	PC = F_B x V x T x F x AG x BW x TD
Pulling capacity (kg)	Generic	PLC = F_B x V x T x F x AG x BW x TD

Key

PC: Pushing capacity (kg)
PLC: Pulling capacity (kg)
F_B: Maximum force acceptable to a specified percentage of worker population (kg) and is also a function of type of force (initial or sustained)
V: Multiplier for vertical distance from floor to hands (cm)
T: Multiplier for travelled distance
F: Multiplier for frequency of push/pull
AG: Age group multiplier
BW: Body weight multiplier
TD: Task duration multiplier

Table 28: Base forces for pushing and pulling (Shoaf et al., 1997)

	66.5	39.6	44.2	31.5	62.5	38	44.5	30.7
	62.2	37.3	41.5	29.4	59.4	36.1	41.7	28.8
	59.5	35.9	39.7	28	57.1	34.8	39.9	27.5
	57.8	34.5	38.2	26.9	55.8	33.9	38.4	26.5
	55.7	33.9	37	25.9	54	32.7	37.1	25.6
	53.9	33	35.9	25	52.3	32	36	24.8
	52.2	32.2	34.9	24.2	51.6	31.3	34.9	24
	50.8	31.4	33.9	23.5	50.3	30.5	33.9	23.3
	49.3	30.6	32.9	22.7	49.2	29.8	33	22.7
	48	30	32	22	48	29.1	32	22
	46.5	29.4	31.1	21.3	46.9	28.4	31	21.3
	45.8	28.6	30.1	20.5	46	26.9	30	20.7
	43.9	27.9	29.1	19.8	44.8	26	29.1	20
	42.2	27	28.1	19	43.5	26.1	28	19.2
	40.4	26.3	27	18.1	42.2	25.5	26.9	18.4
	38.8	25.7	25.8	17.1	40.7	24.3	25.6	17.5
	36.3	24.2	24.3	16	38.9	23.7	24.1	16.5
	34	23	22.5	14.6	36.8	22	22.3	15.2
95	29.9	20.8	19.8	12.5	33.9	20.1	19.5	13.3

Table 29: Body weight multiplier (Shoaf et al., 1997)

Weight (kg)	Male	Female
40	0.7	1
45	0.7	1
50	0.7	1
55	0.7	1
60	0.7	1
65	0.8	1.2
70	1	1.4
75	1.2	1.68
80	1.3	1.85
85	1.41	1.98
90	1.45	2.05
95	1.45	2.05
100	1.45	2.05

Table 30: Task duration multiplier (Shoaf et al., 1997)

Duration (hr)	Multiplier
0	1
1	1
2	0.77
3	0.67
4	0.6
5	0.58
6	0.54
7	0.5
8	0.45

Table 31: Vertical height multiplier for pushing and pulling (Shoaf et al., 1997)

Height (cm)	Initial Push Male	Initial Push Female	Sustained Push Male	Sustained Push Female	Initial Pull Male	Initial Pull Female	Sustained Pull Male	Sustained Pull Female
60	-	-	-	-	1	1	1	1
65	-	-	-	-	0.983	0.993	0.993	0.995
70	-	-	-	-	0.966	0.987	0.984	0.99
75	-	-	-	-	0.947	0.981	0.974	0.985
80	-	-	-	-	0.928	0.975	0.962	0.979
85	-	-	-	-	0.908	0.969	0.949	0.973
90	0.988	0.971	0.989	0.983	0.887	0.964	0.935	0.967
95	0.996	0.984	0.995	0.992	0.865	0.958	0.919	0.96
100	1	0.993	0.999	0.998	0.842	0.953	0.901	0.953
105	0.999	0.998	1	1	0.818	0.949	0.882	0.945
110	0.993	1	0.999	0.999	0.794	0.944	0.862	0.937
115	0.982	0.998	0.996	0.994	0.768	0.94	0.84	0.929
120	0.966	0.992	0.99	0.985	0.742	0.936	0.817	0.92
125	0.945	0.982	0.983	0.973	0.715	0.932	0.792	0.911
130	0.92	0.969	0.972	0.958	0.687	0.929	0.765	0.902
135	0.889	0.952	0.96	0.939	0.658	0.926	0.738	0.892
140	0.854	0.931	0.945	0.917	0.628	0.922	0.708	0.882

Table 32: Travel distance multiplier for pushing and pulling (Shoaf et al., 1997)

Distance (m)	Initial Push Male	Initial Push Female	Sustained Push Male	Sustained Push Female	Initial Pull Male	Initial Pull Female	Sustained Pull Male	Sustained Pull Female
1	-	-	-	-	1	1	1	1
5	-	-	-	-	0.93	0.95	0.831	0.972
10	-	-	-	-	0.878	0.856	0.743	0.877
15	-	-	-	-	0.845	0.752	0.697	0.75
20	0.732	0.741	0.597	0.637	0.785	0.739	0.631	0.696
25	0.6667	0.719	0.552	0.583	0.717	0.726	0.562	0.655
30	0.614	0.71	0.511	0.537	0.657	0.713	0.514	0.625
35	0.577	0.708	0.474	0.52	0.614	0.7	0.49	0.604
40	0.548	0.713	0.44	0.534	0.577	0.687	0.466	0.587
45	0.523	0.711	0.409	0.536	0.547	0.674	0.442	0.565
50	0.499	0.695	0.383	0.504	0.524	0.657	0.418	0.532
55	0.476	0.671	0.36	0.455	0.505	0.631	0.394	0.492
60	0.455	0.638	0.341	0.338	0.491	0.6	0.37	0.446
65	0.438	0.597	0.326	0.305	0.485	0.568	0.347	0.393

Table 33: Frequency multiplier for pushing and pulling (Shoaf et al., 1997)

Frequency (times/min)	Initial Push		Sustained Push		Initial Pull		Sustained Pull	
	Male	Female	Male	Female	Male	Female	Male	Female
0.002	1	1	1	1	1	1	1	1
0.016	0.901	0.956	0.894	0.877	0.898	0.958	0.909	0.864
0.03	0.854	0.933	0.844	0.818	0.851	0.938	0.865	0.8
0.1	0.843	0.919	0.83	0.795	0.842	0.924	0.852	0.783
0.2	0.833	0.9	0.813	0.773	0.83	0.906	0.838	0.76
0.5	0.813	0.8	0.719	0.727	0.787	0.813	0.73	0.68
1	0.792	0.767	0.688	0.682	0.766	0.781	0.703	0.64
4	0.542	0.667	0.438	0.545	0.7	0.783	0.598	0.62
6	0.557	0.6	0.203	0.455	0.663	0.696	0.539	0.568

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