Operator-centric Assembly Station Design

by

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ABSTRACT

Productivity requirements in high volume manufacturing industry necessitate the widespread use of machine-based assembly stations. Although high production volumes can be achieved by a small number of workers (operators) the resulting fatigue on these operators is often overlooked in the design of the assembly station. Fatigue mitigation is then required via job rotation on the shop floor but this is both unsatisfactory and a partial solution only.

The aims of this thesis are:

- to develop an approach to the design of operator-centric assembly stations
- to evaluate this approach in real life case study applications
- to produce an evaluative tool which embodies "best practice" for use by designers enabling them to aim to avoid or mitigate musculoskeletal disorder problems for operators.

The thesis reviews current approaches to the design of ergonomic- and process-driven assembly stations using literature available in the public domain which includes guidelines, regulations, and legislative requirements for health and safety.

Also reported is work undertaken by the author, at H R Adcock Ltd, on two assembly stations which have been comprehensively re-designed in response to unacceptable health risks for the workforce, poor quality products and a low production rate. The original design and operation of the two stations will be analysed along with the techniques used for their improvement.

The core of this thesis is to demonstrate a 'best practice' design approach to the re-design and to evaluate the outcome. It became clear during the compilation of this thesis that if it were possible to incorporate some simple checking procedures which would identify all potential hazards and evaluate risks early in the design process then this would eliminate or reduce the need for costly downstream design changes.

The system developed is **RIMAN** - an acronym for **RI**sk **MAN**agement procedure.

RIMAN incorporates the following:

- Development of design criteria
- Co-operation between disciplines to facilitate the development of the design criteria
- Risk identification
- Evaluation of identified risks and assessment of how to eliminate or reduce them to an achievable level
- Utilisation of RIMAN as a recording/auditing tool and as a technical folder which would outline the regulations and standards used in the design criteria and specify the risk levels identified by risk evaluation.

RIMAN was successfully evaluated, retrospectively, against the assembly station case study already mentioned. It demonstrated how particular risks were identified and dealt with early in the design process. It is proposed that further work is undertaken on a RIMAN version 2 and that the tool be actively incorporated into the working practices of H. R. Adcock Ltd., or any company, on a live design project.

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ACRONYMS

ACOP – Approved code of practice

ANSI – American National Standards Institute

CA – Conformity assessment

CTD – Cumulative trauma disorders

CTS – Carpal tunnel syndrome

EHSR – Essential health and safety requirements

HSAWA – Health and safety at work act 1974

HSC – Health and Safety Commission

HSE – Health and Safety Executive

LOLER – Lifting operation and lifting equipment regulations 1998

MHO – Manual handling operations regulations 1992

MSD – Musculoskeletal disorders

NIOSH - National Institute of Occupational Safety and Health

OSHA - Occupational Safety and Health Administration.

PPE – Personal protection equipment

PUWER – Provisional use of work equipment regulations 1998

RSI - Repetitive strain injury

RMI - Repetitive motion injury

SME – Small-medium enterprise

SMSR – The supply of machinery (safety) regulations 1992

UECTD - Upper extremity cumulative trauma disorders

WMSD, WRMSD - Work related musculoskeletal disorders

WRULD - Work related upper limb disorder

CHAPTER 1 – INTRODUCTION

The objectives of this chapter are:

- To provide a background to the thesis
- To define the aims and objectives of the thesis

1.1 Background

H. R. Adcock Ltd, in Shepshed, Leicestershire, has numerous assembly operations. Regulations and Health & Safety in the workplace are significant and increasingly put emphasis on the need to understand man/machine relationships. Since 1998, the company has been designing and developing its own assembly machines but had little experience of operator-related injuries due to the normal operation of machinery.

Adcocks has its own very basic risk assessment procedure to identify the potential hazards of using machines and depends on one individual's ergonomic experience. The design department have found it difficult to extract useful information from these risk assessments as they lack detail and are therefore difficult to use constructively. The first part of this thesis comprises research for an appropriate and useful tool that will allow machine designers to collect useful information to quantify risks. The scope of the research includes investigation of regulations, guidelines and standards and the rules and legal requirements that an employer must follow.

Large companies would normally use a specialist in the design team, with the ergonomic experience to ensure that health, safety and the welfare of a machine's users are considered. However a small- or a medium-sized enterprise may not have the financial resources to employ or hire a specialist but must rely on its own design team to cover these risks. They would, by necessity, meet the minimum requirement of risk assessment in order to satisfy the health and safety regulations.

It is anticipated that the outcome of this work will improve the in-house capability to address musculoskeletal disorders at an early stage of assembly station design, with an objective of maintaining or improving quality and productivity. By expanding the company knowledge base and the provision of additional resources it is hoped that there should be the development of a culture of awareness of the importance of health, safety and the welfare of employees.

1.2 Aims and Objectives

The aims of this thesis are:

- To develop an approach to designing operator-centric assembly stations
- To evaluate this approach against real life case studies
- To provide an evaluative tool, embodying best practice for the design of operator-centric assembly stations.

The objectives set to meet these aims are as follows:

- To review relevant literature and current issues and topics relating to ergonomic/machine design in the manufacturing industry
- To identify "best practice" suitable for small/medium enterprise companies such as H. R. Adcock Ltd
- To demonstrate how ergonomic design is improved by "best practice"
- To develop an approach for design of operator-centric assembly stations
- To review the case studies of H. R. Adcock Ltd's existing assembly stations, their design approach to the build, and how improvements were subsequently made
- To review the approach against the case study examples
- To make proposals to H. R. Adcock Ltd of "best practice" for the design of ergonomic- and process- driven assembly stations
- To draw conclusions and recommend further work.

1.3 Report structure

Firstly, the thesis will report current approaches to the design of ergonomic- and process- driven assembly stations from literature, the Internet and various health and safety and machinery safety organisations. It also endeavours to understand how musculoskeletal disorders are caused through working with machines in an industrial setting.

It will identify "best practice" using a design approach in combination with risk assessment analysis on machinery safety, production and quality, taking ergonomics into consideration.

The thesis covers work carried out by the author on one assembly station that was replaced. The new designs tackled issues which included poor quality products, a low production rate and risks of a health and safety nature. An analysis of the assembly stations demonstrates how they were originally designed and operated and shows what has been improved. As the core of this thesis is to demonstrate a "best practice" design approach, the re-design is evaluated to show if further improvements should have been made.

An objective of this investigation is to produce a "best practice" design approach suitable for a small- and medium-sized enterprise such as Adcocks and should, therefore, combine the findings from both the case studies and relevant literature to form a proposal to H. R. Adcock Ltd.

This proposal should allow the company to integrate their in-house design with both the requirements of safe operation and optimum ergonomic activity.

CHAPTER 2 LITERATURE REVIEW

The objective of this chapter is:

- To examine the literature in the public domain and to identify current and topical issues relevant to ergonomic/machine design in manufacturing industry.

Introduction

This chapter reviews the literature concerning the human body and the relationships between man and machine.

The use of existing assembly stations allows the identification of hazards associated with people using machines. Using known engineering design tools and techniques and applying health and safety in the workplace regulations it will become evident that the integration of these two disciplines is essential to the design process.

2.1 Musculoskeletal disorders in the workplace

Musculoskeletal disorders and injuries are prevalent in the workplace as the health and safety executive statistics in 2004 show: **[1-2]**

- 235 fatal injuries to workers in 2003/04, an increase of 4% on 2002/03 figures of 226
- 30,666 major injuries to employees were reported in 2003/04, an increase of 9% on the previous year, over one-third of all reported major injuries were caused by slipping and tripping
- 129,143 over three-day injuries to employees were reported in 2003/04, an increase of 0.7% on the previous year, two-fifths were caused by handling, lifting and carrying
- An estimated 2.2 million people suffered from ill health that they thought was work-related. Around three-quarters of the cases of work-related ill health were musculoskeletal disorder (MSD), or stress
- An estimated 39 million working days in total were lost in 2003/04
- 30 million due to work-related ill-health
  - 9 million due to workplace injury
- The number of prosecutions by the HSE was up by 6% on the previous year.

There have been improvements in the production industries, especially construction and manufacturing, the rate of major injury, but *"there still a lot of work to do"* (Justin McCraken, Deputy Director of the HSE). **[1]**

At the turn of the twentieth century there were 4,753 workers per year killed in the UK, or the equivalent 92 per week. However, during 2003 the number was reduced to 226, or the equivalent of 4 deaths a week. This demonstrates a 95% improvement. However, despite this reduction, the costs to society remain huge. In addition to the 226 people killed in 2003, 3,000 died each year from asbestos-related ill-health, up to 3,000 more die each year from other work-induced cancers and between 16,000 and 42,000 people leave the workforce each year because they are no longer able to work. **[1]**

The personal tragedy and human suffering underlying these figures is clearly devastating for the individuals and their families, but the financial cost to companies and the economy is also massive. Some 40 million working days are lost each year, and the cost of health and safety failures is around 1.5 per cent of GDP (gross domestic product) every year.

This was from a keynote speech by Dr Timothy Walker CB, a Director General of the Health and Safety Executive on the 9th November 2004 outlining the emotional impact to the workforce and employers in the industry. **[1]**

Musculoskeletal disorders (MSDs) may affect the upper limbs (neck, shoulder, arms, hands, wrists and fingers), back and lower limbs (knees, hips and feet) and can result in debilitating pain, discomfort or numbness. MSDs arise in many forms and the symptoms are frequently non-specific. Some disorders classified as MSDs exhibit well-defined signs and symptoms (e.g. carpal tunnel syndrome, tenosynovitis, tennis elbow). Others are less well defined such as myalgic conditions involving pain and discomfort, numbness and tingling sensations throughout the neck, shoulders, upper limbs, lower back and lower limbs. Table 1 shows the classifications of some of the common MSDs that a doctor might diagnose for an injured employee.

Workers suffering from MSDs may experience less strength for gripping, less range of motion, loss of muscle function and inability to do everyday tasks. Common symptoms include:

- Painful joints
- Pain, tingling or numbness in hands or feet
- Pain in wrists, shoulders, forearms, knees
- Fingers or toes turning white
- Shooting or stabbing pains in arms or legs
- Back or neck pain
- Swelling or inflammation
- Stiffness
- Burning sensation

Tendon-related disorders	Nerve-related disorders	Muscle-related disorders	Circulatory/ vascular type disorders	Joint-related disorders	Bursa-related disorders
- Tendinitis - Peritendinitis - Tenosynovitis - Synovitis - Epicondylitis - De Quervain's disease - Dupuytren's contracture - Trigger Finger - *Gangloin cyst*	- Carpal Tunnel syndrome - Cubital Tunnel syndrome - Guyon Canal syndrome - Pronator teres syndrome - Radial tunnel syndrome - *Cervical syndrome* - Digital neuritis	- Tension neck syndrome - Muscle sprain and strain - Myalgia and *myositis*	- Hypothenar hammer syndrome - Raynaud's syndrome	- Osteoarthristis	- Bursitis

Table 1 Classification of some neck and upper limb musculoskeletal disorders according to pathology **[3]**

The occurrence of MSDs could be significantly reduced by interventions encompassing all of the following elements: **[3]**

- Senior management commitment
- Worker involvement
- Risk assessment
- Control measures
- Training
- Medical management.

Health and Safety Executive's key messages to the employers about MSDs are:

1. you can do things to prevent or minimise MSDs,
2. the prevention measures are cost effective
3. you cannot prevent all MSDs, so early reporting of symptoms, proper treatment and suitable rehabilitation is essential. **[1]**

2.1.1 The Human Body

When the human body has repeated biomechanical loads imposed on living tissue the biochemical response is to either strengthen the tissue or weaken it. For example, working with weights in a gym may strengthen arm muscles particularly when time is given for recovery. On the other hand prolonged over-exercise without recovery time is likely to cause damage. Although muscle tissue can recover, nerves are less able to adapt to prolonged abuse. This is evidenced by injuries such as those imposed by vibrating machines, which cause, for example, "Raynaud's phenomena - white finger syndrome" where there is loss of feeling.

Simply, where there is continued prolonged repetition of particular types of activity without a suitable recovery time, there may be a risk of tissue or nerve damage, which can manifest itself in the form of inflammation, oedema (excessive swelling of fluid) or other biochemical responses including the loss of feeling.

The significance of this in the workplace is that where operators are working, for example, two to three hours without a break, repeating the same action perhaps two thousand times every day, they may be at risk of tissue or nerve damage. **[4-8]**

The essential knowledge of ligament structure, function, injury and rehabilitation can be used in ergonomic planning. The knowledge allows the designers/ergonomists to put forward proposals and concept designs to the company, who then decide which control measures could be developed early in overall planning.

Control measures can be taken which will help prevent ligamentous injuries and aid in the recovery of workers who have already suffered a sprain. This may involve a job analysis and work place revisions in order to identify hazardous exposures and to eliminate unwarranted biomechanical stresses

associated with the job. Factors such as constrained or static postures, repetitive motions, and poor ergonomic equipment design can be found to be accountable for ligamentous injuries.

An ergonomic assessment, with the aim of minimising ligamentous overload and subsequent re-injury, must address both the high load stress and the low load repetitive mechanisms in the workplace. The key to both the prevention and treatment of ligament injuries is the minimisation of excessive forces on the joint/s in question. Prevention and treatment of ligament macro-trauma involve attention to the details of a person's job description and to the workplace in an effort to minimise the chances that the worker may suffer a sudden, forceful loading of any joint.

Although work-related injuries are commonly associated with damage to soft tissues or joints (e.g. repetitive strain injuries), the prevalence of bone fractures is still high. The primary means of preventing fractures should consist of eliminating situations that may generate high-risk mechanical environment. The workplace related mechanical environment should be adjusted to have a minimal impact on the worker.

Minimisation of forces and moments acting on bones may be accomplished by educating employees about better techniques or by using improved equipment. Secondary prevention of occupational, bone-related injuries should emphasise the enhancement of bone quantity and quality, muscular strength, and proprioception. **[4-8]**

There is a difference between injuries and disorders**[7]** that are found in the workplace.

> An ***injury***, by definition, means mechanical disruption of tissue. Consequently, it is a distressing event in which the integrity of the tissue in question is violated and its mechanical order has been perturbed. This would lead to pain in addition to inflammation and other biochemical responses, hence the difficulty in deploying these structures in any activity including occupational.
>
> A ***disorder***, by definition, means malfunctioning of an organ or an organism. In contrast to injury, a disorder can result without a mechanical perturbation of the tissues involved. Examples of disorders can be myopathies, neuropathies or several central nervous system problems resulting in improper functioning of the musculoskeletal system.

For example, an injury may result in a functional disorder that can be remedied by healing the injury, the injury in itself is not a disorder. Another difference between an injury and a disorder is that while the onset of a disorder may be gradual and mediated by a pathogen or prepathological progression, the onset of an injury is sudden and does not involve prepathogenesis. Although on the other hand, it may involve mechanical degradation of the tissue due to overuse. Subsequent to injury inflammation and pathology of healing sets in.

2.1.2 Workplace risk factors

Musculoskeletal disorders are multi-factorial in aetiology and previous studies show it is necessary to consider physical, psychological and personal aspects as risk factors. (Hales and Bernard, 1996; Bongers et al., 1993; Hagberg 1988, 1992) **[9]**

Table 2 show potential workplace activities that cause musculoskeletal disorders in their associated risk factors.

There are other non-work factors that may be taken into account to enable understanding of the complex determinants of health symptoms associated with work. **[9]**

Physical risk factors such as force, posture and repetition can be harmful to the body and can lead to people developing musculoskeletal disorders.

Psychosocial risk factors are things that may affect workers' psychological response to their work and workplace conditions (including working relationships with supervisors and colleagues).

As well as leading to *stress*, which is a hazard in its own right, psychosocial risk factors can lead to musculoskeletal disorders. For example, there can be stress-related changes in the body (such as increased muscle tension) that can make people more susceptible to musculoskeletal problems; or individuals may change their behaviour, for example, doing without rest breaks to try to cope with deadlines.

Therefore, both the physical and psychosocial factors need to be identified and controlled in order to have the greatest benefit. The best way to achieve this is by using an ergonomic approach, which looks at achieving the best "fit" between the work, the working environment and the needs and capabilities of the workers. **[2]**

As with physical risk factors, psychosocial issues are best addressed through full consultation with and the involvement of the workforce. The following control measures that can be considered to improve the working environment within the workplace: **[2]**

- reducing the monotony of tasks where appropriate
- ensuring there are reasonable work loads (neither too much or too little) deadlines and demands
- ensuring good communication and reporting of problems
- encouraging teamwork
- monitoring and control of shiftwork or overtime working
- reducing or monitoring payment systems which works on piece rate
- providing appropriate training.

Physical factors	**Personal factors**
Heavy, static, monotonous work Extreme or constrained postures Repetitive movements Unsuitable workplaces and equipment Excessive forces Exposure to vibrations Contact stresses Poor grip Bending and twisting	Gender Age Seniority Exercise habits Life style Psychosocial characteristics and capacities Unsuitable clothing
Psychosocial factors	**Non-physical factors (Environment)**
Work organisation Interpersonal relationships Short cycle tasks Poor work control Piece rate payment system Poor management Unsatisfactory training Long work hours Lack of breaks Time demands	Extreme lighting Loud noises Extreme temperatures Electrical exposures Poor visual displays Chemical exposures

Table 2. Workplace risk factors **[9]**

2.2 Legislation and guidelines

What Health and Safety law requires:

'The basis of British Health and Safety law is the Health and Safety at Work Act 1974." **[10]**

UK law requires employers to have good management and prudence that will assess risk and take sensible measures to tackle them.

2.2.1 Health and Safety at Work Act 1974

The Act **[11-16]** sets out the general responsibilities that employers have towards employees and members of the public, and employees have to themselves and to each other.

The employer has two main obligations under the Health and Safety at Work Act 1974, Section 2. The employer must:

A. ensure, SO FAR AS IS REASONABLY PRACTICABLE, the health, safety and welfare at work of all their employees;

B. conduct his undertaking in such a way as to ensure, so far as is reasonably practicable, that persons NOT in his employment who may be affected thereby are not thereby exposed to risks to their health or safety.

Put another way, paragraph A states that the employer's responsibility towards his employees applies wherever they work, not just at his workplace. The employer's health and safety procedures must cover employees who work in public places, at customers' or suppliers' sites, in people's homes, or anywhere else.

As for paragraph B, the employer's responsibility towards non-employees applies if their health or safety may be affected by how he conducts his business. The employer's health and safety procedures must cover contractors, sub-contractors, customers, suppliers and members of the public who may visit his workplace. It must also cover neighbours and people passing by his workplace or anywhere else that his employees may be working. His health and safety procedures must also cover users of any services he provides. In most cases, it must cover people who may be at risk from any products he designs or makes.

The employer should identify all the circumstances in which his employees could be at risk whilst at work, along with all the circumstances in which anyone else could be at risk as a result of anything done in his business and determine the level of resources needed to manage each risk effectively, taking account of the level of risk **[16].** Only by directing and applying a level and effectiveness of resources commensurate with the risk can the employer perform his general duties so far as is reasonably practicable.

The term "so far as is reasonably practicable" means that the degree of risk in a particular situation can be balanced against the time, trouble, cost and physical difficulty of taking measures to avoid the risk. If these resources are so disproportionate to the risk that it would be unreasonable to expect any employer to have to incur them to prevent it, the employer is not obliged to do so unless there is a specific requirement that he does.

The greater the risk, the more likely it is that it is reasonable to go to very substantial expense, trouble and invention to reduce it. Nevertheless, if the consequences and extent of a risk were small, insistence on great expense would not be considered reasonable. It is important to remember that the judgement is an objective one and the size or financial position of the employer is immaterial.

In other words, an employer does not have to take measures to avoid or reduce the risk if they are technically impossible or if the time, trouble or cost of the measures would be grossly disproportionate to the risk.

The main requirement on employers is to carry out a risk assessment.

There are three main sources **[14-33]** which enable employers to take appropriate action to provide proper safeguards for employees and the public:

1. Guidance, from HSC/E (Health and Safety Commission and the Executive)
2. Approved Codes of Practices (ACOPs), and
3. Regulations.

2.2.1.1 Guidance

HSE publishes guidance on a range of subjects. For example, 'Five steps to risk assessment' leaflet INDG163 **[34]**

The main purposes of guidance are:

- To interpret – helping people to understand what the law says – including, for example, how requirements based on EC Directives fit with those under the Health and Safety at Work Act
- To help people comply with the law
- To give technical advice.

Following guidance is not compulsory and employers are free to take other action. Nevertheless, if they do follow guidance they will normally be doing enough to comply with the law.

Health and Safety Commission (HSC)/Executive (HSE) aim to keep guidance up-to-date, because as technologies change, the risks and the measures needed to address them change too.

2.2.1.2 Approved Codes of Practice, ACOP

Approved codes of practice **[14]** offer sensible examples of good practice. They give advice on how to comply with the law by, for example, providing a guide to what is "reasonably practicable".

Approved Codes of Practice have a SPECIAL LEGAL STATUS. If employers are prosecuted for a breach of Health and Safety law and it is proved that they have not followed the relevant provisions of the Approved Codes of Practice, a court can find them at fault unless they can show that they have complied with the law in some other way.

2.2.1.3 Regulations

Regulations are defined in law, approved by Parliament. These are usually made under the Health and Safety at Work Act **[16]**, following proposals from HSC. This applies to regulations based on EC Directives as well as national ones.

The Health and Safety at Work Act is goal setting and leaves employers freedom to decide how to control risks that they identify. Guidance and ACOP provide advice to employers and employees. However, some risks are so great, or proper control measures so costly, that is would not be appropriate to allow employers discretion in deciding what to do about them. Regulations identify these risks and set out specific actions that must be taken. Often these requirements are absolute – to do something irrespective of whether or not it is reasonably practicable.

The Health and Safety at Work Act deals with general duties and contains no specific requirements on the prevention of musculoskeletal disorders. However, relevant aspects include the provision and maintenance of safe plant, machinery and systems of work and provision of information, instruction and training. **[2]**

2.3. Machinery Directives

There are two European directives that are of direct relevance to the safety of industrial machinery and equipment. **[35-36]**

1. The Machinery Directive
2. The Use of Work Equipment by Workers at Work Directive

These two Directives are directly related as the Essential Health and Safety Requirements (EHSRs) from the Machinery Directive can be used to confirm the safety of equipment in the Use of Work Equipment Directive.

2.3.1 Essential Health & Safety Requirements

(Referred to as EHSRs)

The Directive **[35-36]** gives a list of EHSRs to which machinery must comply where relevant. The purpose of this list is to ensure that the machinery is safe and is designed and constructed so that it can be used, adjusted and maintained throughout all phases of its life without putting persons at risk.

Themes covered in the EHSR's include: materials used in the construction of machinery; lighting; controls; stability; fire; noise; vibration; radiation; emission of dust, gasses etc.; maintenance; accompanying documentation (handbooks).

The directive also provides a hierarchy of measures for eliminating the risk:

(1) *Inherently Safe Design*—Where possible the design itself will prevent any hazards.

Where inherently safe design is not possible:

(2) *Additional Protection Devices*, e.g., Guards with interlocked access points, non-material barriers such as light curtains, sensing mats etc., should be used.

Any residual risk that cannot be dealt with by the above methods must be contained by: -

(3) *Personal Protective Equipment* and/or *Training.* The machine supplier must specify what is appropriate.

2.4. Relevant regulations and standards

The objective of this section is to establish the relevant regulations and standards that would apply to operator-centric assembly station design.

2.4.1 The Management of Health and Safety at Work Regulations 1992

The management regulations **[10]** include requirements for employers to:

- Assess risks
- Arrange for effective planning, organisation, control, monitoring and review of preventive and protective measures
- Appoint competent people to assist the employer in complying with health and safety law
- Co-operate and co-ordinate health and safety actions where the activities of different employers interact
- Provide appropriate health surveillance, information and training

2.4.2 The Provision and Use of Work Equipment Regulations (PUWER) 1998

The PUWER Regulations **[37-38]** were made under the Management of Health and Safety at Work Regulations (MHSWR). They were originally introduced in 1992 and placed wide-ranging responsibilities for health and safety in the workplace on employers and employees alike. Regulation 3 of the MHSWR requires every employer to assess the risks to the health and safety of people in their workplace. This means that it is the employer's responsibility to look not only at work equipment but also at the whole working environment (from the front door to the back gate).

There are 39 regulations, divided into Parts 1 to 5.

Part 1 – 'Introduction' covered by regulations 1 to 3

Part 2 – 'General' covered by regulations 4 to 24

Part 3 – 'Mobile work equipment' covered by regulations 25 to 30

Part 4 –'Power presses' covered by regulations 31 to 34

Part 5 –'Miscellaneous' covered by regulations 35 to 39

In general terms, PUWER requires that equipment provided for use at work is:

- suitable for the intended use
- safe for use, maintained in a safe condition and, in certain circumstances, inspected to ensure this remains the case
- used only by people who have received adequate information, instruction and training
- accompanied by suitable safety measures, e.g. protective devices, markings, warnings.

Appendix 1 provides detailed information on The Provision and Use of Work Equipment Regulations 1998.

2.4.3. The Supply of Machinery (Safety) Regulations 1992 (SMSR)]

These regulations **[39]** place duties upon those who supply machinery and safety components, including manufacturers, importers and others in the supply chain. They set out the essential health and safety requirements that must be met before machinery or safety components may be supplied in the UK.

There are three steps to dealing with the requirements:

1. The responsible person should ensure that machinery and safety components satisfy the relevant essential health and safety requirements of the Supply of Machinery (Safety) Regulations and that, where appropriate, relevant conformity assessment procedures have been carried out.
2. The responsible person must issue a declaration of conformity (or a declaration of incorporation) that is issued with the finished product so that it is available to the user. This will contain various details such as the manufacturer's address, the machinery type and serial number, and the harmonised European, or other standards, used in design.

3. When the first two steps have been satisfactorily completed, the responsible person or person supplying or assembling the final product should affix the CE marking if they are satisfied it is safe

Most machinery that has supplied within the EU has to satisfy the wide-ranging Essential Health and Safety Requirements (EHSRs) for the design and construction of machines, as specified in Schedule 3 of the Regulations. This also applies to imports from countries outside the EU and *in-house machinery where manufacturers put their own machinery into service.*

2.4.4. Personal Protection Equipment at Work Regulations 1992

These regulations **[40-49]** apply to all situations where personal protection equipment (PPE) is required.

PPE is defined in the Regulations as 'all equipment (including clothing affording protection against the weather) which is intended to be worn or held by a person at work and which protects him against one or more risks to his health or safety', for example, safety helmets, gloves, eye protection, high-visibility clothing, safety footwear and safety harnesses. Waterproof, weatherproof or insulated clothing is subject to the Regulations only if its use is necessary to protect employees against adverse climatic conditions that could otherwise adversely affect their health or safety.

The main requirement of the PPE at Work Regulations 1992 is that personal protective equipment is to be supplied and used at work wherever there are risks to health and safety that cannot be adequately controlled in other ways.

In the other words personal protective equipment is always the last line of defence. Wherever possible, other measures should first be taken to reduce or control the risk.

If PPE is the only effective means of controlling the risks of injury or ill health, and then employers must ensure that it is available for use at work - free of charge.

2.4.5. Relevant standards

There are three different types of standards. **[50]**

Type A standards (basic safety standards) giving basic concepts and principles for design, and general aspects that can be applied to all machinery.

Type B standards (generic safety standards) dealing with one safety aspect or one type of safeguard that can be used across a wide range of machinery.

> *B1* – particular safety aspects e.g. safety distances, surface temperature, noise)
>
> *B2* – Safeguards e.g. two-hand controls, interlocking devices, pressure sensitive devices, and guards.

Type C standards (machine safety standards) dealing with detailed safety requirements for a particular machine or groups of machines. If this standard exists it has priority over the A or B standard. Nevertheless, a C standard can make reference to a type B or type A standard. If there is no C standard for a machine, conformity can be established based on the type A or type B standard. In any case the requirements of the Machinery Directive must be met.

When a Type C standard deviates from one or more provisions dealt with by Part 2 of this standard or by a Type B standard, the Type C standard takes precedence.

Table 3 shows some of the relevant European and International standards.

2.4.6. EN 1050:1997 Safety of machinery – principles for risk assessment

EN 1050 **[53]** is essential to this thesis in developing an approach to design for operator-centric assembly stations. Risk assessment incorporated as a design tool is useful in ensuring that a machine is essentially safe.

EN 1050 outlines the fundamentals of the process of assessing the risks during the machinery's life.

The EN 1050 standard does not provide a detailed description of the methods for analysing hazards and estimating risks, although it does provide a summary of the overall process.

Standard Type	Number in Europe EN	International Number ISO/IEC	Title
Type A	EN 292-1	ISO 12100-1	Safety of machinery – Basic concepts, general principles for design
	EN 292-2	ISO 12100-2	
	EN 1050	ISO 14121	Safety of machinery – Principles for risk assessment
Type B	EN 61496-1	IEC 61496-1	Safety of machinery – Electro-sensitive protective equipment – Part 1: General requirements and tests
	prEN 61496-2	IEC 61496-1	Part 2:Particular requirement for equipment using active opto-electronic protective devices
	EN 61496-3	IEC 61496-1	Part 3: Particular requirements for equipment using opto-electronic devices responsive to diffuse reflection (AOPDDRs)
	EN 294	ISO 13852	Safety of machinery: safety distances to prevent danger zones from being reached by the upper limbs
	EN 954-1	ISO 13849-1	Safety-related parts of control systems – Part 1: General principles for design
	prEN 954-2	ISO 13849-2	Part 2: Validation
	EN 60204-1	IEC 60204-1	Electrical equipment of machines – Part 1: General requirements
	EN 1088	ISO 14119	Interlocking devices associated with guards – Principles for design and selection
	EN 574	ISO 13851	Two-hand control devices – Functional aspects, principles for design
	EN 1037	ISO 14118	Prevention of unexpected start-up
Type C	EN 692		Mechanical presses; safety
	EN 693		Hydraulic presses; safety
	EN 12622		Hydraulic press brakes; safety
	EN 775	ISO 10218	Manipulation industrial robots; safety
	EN 1010	ISO 1010	Technical safety requirements for the design and construction of printing and paper converting machines
	EN 11111	ISO 11111	Safety requirements for textile machinery

Table 3. Some examples of standards **[51-52]**

2.5 CONCLUDING COMMENT

There has been an increasing trend to introduce new regulations and guidelines that focus on the welfare of people, both in the public and the private domain and it can be argued that the UK is becoming a compensation culture, which costs millions of pounds to its industries.

It is common sense for small medium enterprises (SME's) to provide health and safety for the well-being of their employees as well as creating excellent products.

It could be considered inadvisable to have a company policy which only meets the minimum requirements for levels of health and safety and more sensible to establish higher levels which considered employees' safety as fundamental to the success of the enterprise, thus minimising loss of production arising from injury in the workplace.

Currently, SMEs in the automotive industry are driven by cost and quality considerations, principally in relation to assembly machines, accepting such risks to their human operators as MSDs. More often when problems arise in the form of, for example MSDs, only then do SMEs react to the problem.

There is a need for a pragmatic and expeditious work-based approach to dealing with ergonomics in a 'proactive' rather than 'reactive' way. It is cost effective to prevent or predict potential risks before they have occurred rather than pay compensation for injury and carry out expensive, corrective actions. Simply, this avoids the compensation, loss of production, increased absenteeism and higher staff turnover rate.

The next chapter will review specific literature relevant to ergonomic design for safety and includes risk assessment processes.

CHAPTER 3 ERGONOMIC DESIGN FOR SAFETY

The objective of this chapter is:

- To examine the specialised literature which is relevant to ergonomic design for safety and establish the groundwork to propose a way forward.

Introduction

Ergonomic design for safety demands consideration of ALL possible uses of the equipment (including misuse), both when the equipment is new and when wear may have reduced its reliability. Where similar equipment already exists, failure and damage records may be investigated, along with accident and injury records. Misjudgments by operators should not be dismissed as human error but considered as reasonable actions of the individuals at the time, where their understanding of the situation might have been adversely affected by stress or compounded by deficiency of training, overwork or social or operational difficulties. Only where no other explanation can be offered should irrationality be assumed and even then on a provisional basis pending more information.

3.1 Design for Safety

Risk assessment is crucial to safe machinery design and in Europe we are encouraged to carry out risk assessments in line with the harmonised standard EN 1050:1997 Safety of machinery – principles for risk assessment, as mentioned briefly in the previous chapter.

Machinery must be safe to use and the best way to achieve this is through good design and conscientious working practices. The regulations emphasise the need to assess the machine's risk, both at the design stage and in its application. Each type of machine has its own distinctive range of associated risks. Risk levels must be determined at the design stage, so that any necessary and electrical design improvements can be identified, so that the machine will comply with regulatory standards.

EN 1050 is an important standard to follow which emphasises that it is necessary to "assess the risks during all phases of the life of the machinery".

Risk Assessment is a management tool that allows administrators to check that health and safety policies are effective and provide records that clearly show the justification for the established arrangements.

Therefore risk assessment is a '*qualitative or quantitative evaluation of the chance that a hazard will do harm, taking into account all the significant factors that can affect the chance and extent of the harm. This should conclude whether and how such factors can be improved to eliminate or reduce that chance*'. **[53]**

Risk assessment is a systematic method, and figure 1 shows the iterative process to achieve safety.

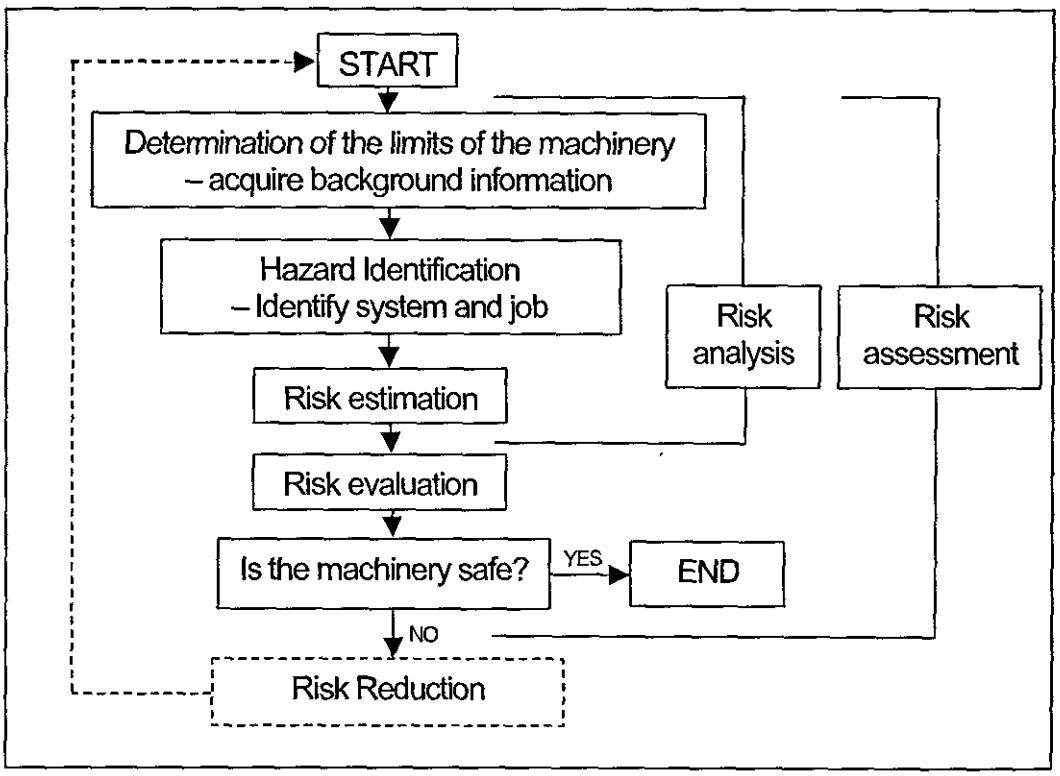


Figure 1. The iterative process to achieve safety. *Obtained from* BS EN 1050: 1997 Safety of machinery - Principles of risk assessment. **[53]**

Design for safety requires input from at designers, constructors, commissioning staff, users, maintenance people and management. They all influence the way the product is used and hence its level of safety. The "design for safety" working group should be available throughout the period of design to consider major changes to specifications or other matters which may affect the subsequent safety of the product.

Before starting an iterative process to achieve safety, a safety-working group must be formed with appropriate members such as client's representatives, the production department, machine builders and designers.

To form an effective safety-working group, the members should have a common understanding of the system's process, operations and site to ensure a general focus for discussion for individuals with differing skills.

Once this group has been established, the first stage of the design is to determine the limits of the machinery by acquiring background information.

Ergonomics and safety standardisation is one approach closely connected with International integration. In recent years the number of ergonomics and safety standards has increased rapidly. Standards are necessary to provide quality control and to support legislation and regulations used in establishing an acceptable international market (Parsons, 1994). **[54]**

Other background information such as maintenance and operations records for previous or similar systems should be used to assess the types of likely failures or errors.

Other sources of information and experience of the safety of similar systems are consultants, insurance companies and government safety inspection bodies. Research organisations of public or private laboratories, including universities, are also potential sources that can be approached.

One effective method of obtaining a comprehensive collection of information that would identify occupational hazards is through task analysis. This is a powerful and simple tool as it breaks down large tasks into their sub-systems or smaller components. This, then, is the next stage once all the background information has been acquired. Appendix 2 shows a detailed study of the methods and techniques used to analyse data to identify work-related hazards.

Following data collection, the second stage of the design process is to identify system and job hazards. The objective of this stage is to identify both the hazards to people passing through or working in close proximity to the system. These might include system or task-related hazards which, if not controlled, can lead to injury, ranging from physical discomfort and fatigue to mental stress for those working with the system. It identifies potential hazards due to technical factors, including interaction of machines with operators, and how these may be affected by personal experiences to create or aggravate a hazard.

There is a systematic procedure to identify system and job hazards:

1. Break the system into appropriate sub-systems, e.g. from component or sub-assembly schedules; give location in proposed operation site.
2. Analyse separately jobs performed during each appropriate phase of the system's life, e.g. construction, operation, maintenance and decommissioning. This is an important part of design where designers need ideas and support from the technical department, who would be involved in the construction and maintenance of an operation, and also from the production department who would train new operators to perform the tasks.
3. List all physical inputs and outputs to/from the sub-systems which, if not controlled, could give rise to hazards, e.g. water, steam or chemicals, vehicles.
4. List all tools and equipment, including protective equipment and job aids, required to perform the tasks and all neighbouring equipment that might interact to cause a hazard, e.g., piping and ducting, emergency equipment, access routes.

5. Identify and list all potential hazards, including physical and mental, using a checklist. Be specific and quantify as far as possible.
6. List all work tasks/activities for each sub-system; use task analysis procedures.
7. Having identified the work tasks and task requirements, note the presence of any environmental factors (quantify where possible) that may affect the worker's ability to perform the tasks safely, such as noise, temperature and vibrations, see Table 4.
8. Use the checklist of performance shaping factors (factors relating to the worker's environment or task which affect performance) to determine any other factors that may affect the worker's ability to carry out the required tasks safely, see Table 5.
9. Use the information from the steps above to identify and list the hazards and describe each in relation to each task.
10. Use the information collected above to identify the root causes of the hazards. Figure 2 illustrates the process whereby information collected is analysed to help identify the root causes of the hazards to assist in developing solutions.

Table 4 Environmental factors **[54]**

- Mechanical
- Electrical
- Height
- Noise
- Thermal
- Light
- Dust
- Confined space
- Radiation
- Vibration
- Distractions
- High traffic area
- Materials and substances

Note: This is not an exhaustive list of environmental factors.

Table 5 Performance shaping factors **[54]**

- Training
- Experience
- Health
- Environment
- Work hours/breaks
- Shift rotation
- Time pressures
- Feedback
- Monotonous work
- Emotional state
- Social factors
- Mental overload/underload
- Human-machine interaction

Note: This is not an exhaustive list of performance shaping factors.

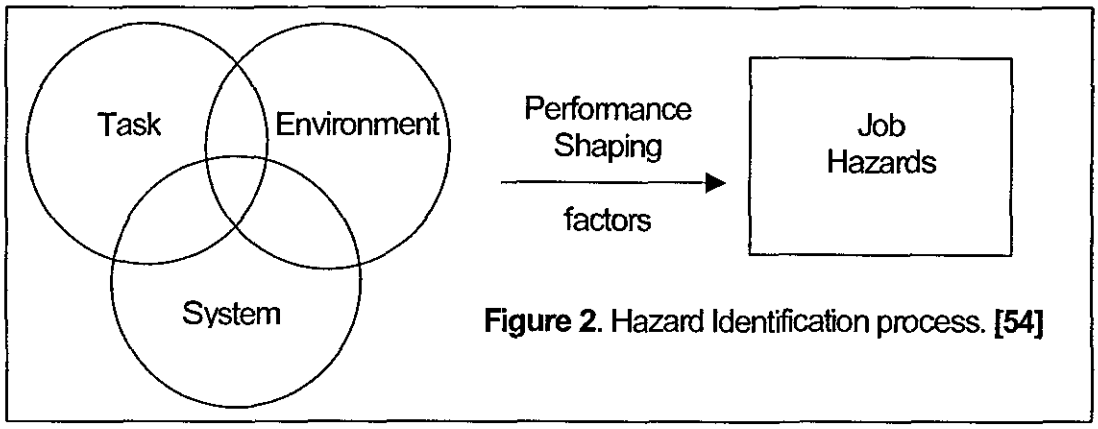


Figure 2. Hazard Identification process. **[54]**

Once both system and job hazards have been identified, the next stage for the safety working group is to implement design solutions which include assessing risks, defining technical and cost implications and, finally, selecting the most appropriate solution, taking into consideration the balance between the accepting hazards and minimising risk.

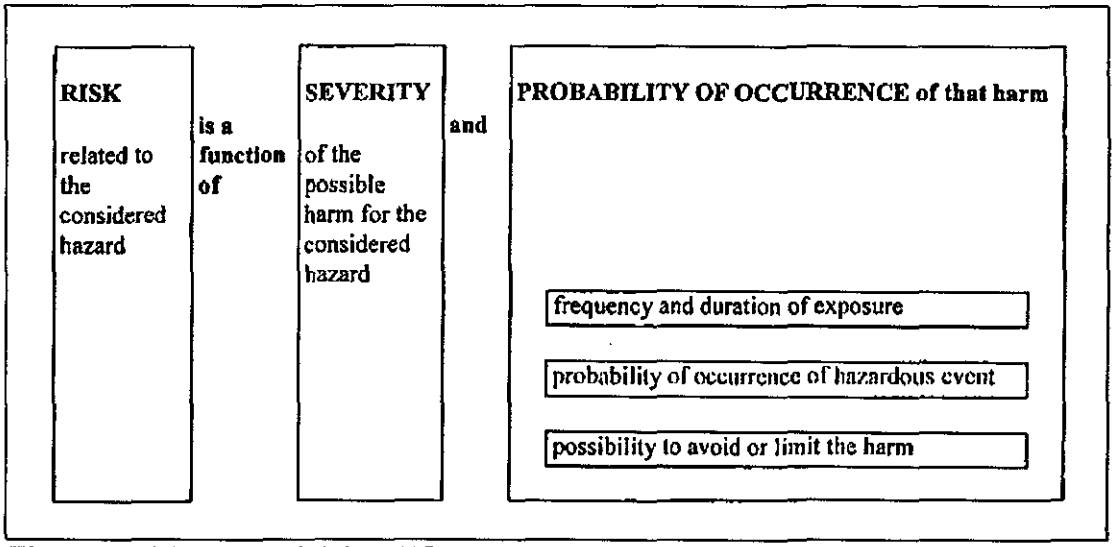


Figure 3. Element of risk. **[53]**

As part of the process of identifying design criteria the safety-working group must estimate the severity of the hazard and the likelihood of it occurring. Figure 3 shows the correlation between the two elements of risk, namely Severity and Probability.

Extracted from the BS EN 1050:1997, which the management regulations are based on, 'severity' can be estimated by taking into account the following:

a) The nature of what is to be protected:
    1. Persons
    2. Property
    3. Environment.

b) The severity of injuries or damage to health:
    1. Slight (normally reversible)
    2. Serious (normally irreversible)
    3. Death.
c) The extent of harm (for each machine);
    1. One person
    2. Several persons.

Extracted from the BS EN 1050:1997, 'probability of occurrence of harm' can be estimated by taking into account the following:

a) Frequency and duration of exposure:
    1. Need for access to the danger zone (e.g. for normal operation, maintenance or repair)
    2. Nature of access (e.g. manual feed of materials)
    3. Time spent in the danger zone
    4. Number of persons requiring access
    5. Frequency of access.
b) Probability of occurrence of a hazardous event:
    1. Reliability and other statistical data
    2. Accident history
    3. History of damage to health
    4. Risk comparison – similar machinery that is safe.
c) Possibilities of avoiding or limiting harm:
    1. Personnel who operate the machinery:
        a By skilled persons
        b By unskilled persons
        c Unmanned.
    2. The speed of onset of a hazardous event:
        a Suddenly
        b Fast
        c Slow.
    3. Awareness of risk:
        a By general information
        b By direct observation
        c Through warning signs and indicating devices.
    4. The possibility of avoiding or limiting harm by human action (e.g. reflex, agility, possibility of escape):
        a Possible
        b Possible under certain conditions
        c Impossible.
    5. Practical experience and knowledge:

a Of the machinery
b Of similar machinery
c No experience.

When embarking on risk assessment based on defined limits for the intended use of the machine, it is assumed that a hazard will eventually lead to harm if no protective measures are taken.

Various methods can be used to combine the two functions of a given level of risk. The most common method of classifying a level of risk is to use a scoring of 1 to 10, where, for example, for severity, 1 is a harmless scratch and 10 signifies death. With regard to the probability of occurrence of harm, 1 suggests it is unlikely to occur and 10 shows a constant exposure to harm. When the scores are multiplied together they give an overall estimation of risk ranging from 1 to 100. However, on its own, the score does not provide adequate information for a safety group to make design decisions, for example, to look for alternative designs or amend an existing one.

To develop design solutions which can be evaluated for costs and technical consequences it is preferable to use the following checklist in sequence:

(a) Inherently safe design to eliminate hazard.

"Protective measure which either eliminates hazards or reduces the risk associated with hazards by changing the design or operating characteristics of the machine without the use of guards or protective devices"

(b) Inherently safe design to minimize hazard

(c) Provide barriers such follows:

a. Safeguarding – "protective measure using safeguards to protect persons from the hazards which cannot reasonably be eliminated or from the risks which cannot be reduced sufficiently by inherently safe design measures"

b. Protective measures – "measures intended to achieve risk reduction, implemented by the designer or the user such as organisation, supervision, training etc.

(d) Provide 'Information for use' about residual risk

c. Residual Risk – "risk remaining after protective measures have been taken "

d. Information for use can be displayed on the machine such as warning signs, signals and warning devices or/and in the instruction handbook.

(e) Provide formal work methods.

The procedure therefore is to select design solution (a) first. If that eliminates the hazard and if there are no significant implications for the design, the next

stage is to progress down the priority list, always assuming that costs are acceptable and the technical implications are surmountable. However if there are problems with significant implications, criteria must be re-written so that risk assessment can progress. Sometimes the methods can be modified to suit local conditions but definitions and criteria should be agreed by the safety-working group and written into the group's procedure for later reference and review.

Once all the identified hazards, and new hazards detected during design alterations, are at acceptable risk level, the safety-working group has achieved its first objective and can continue to develop the machine. Risk assessment should be constantly reviewed at agreed intervals to ensure that hazards continue to be at an acceptable risk level.

3.2 Machine Design

The design of any machine usually starts with task analysis and an awareness of what went before. Moreover, an awareness of further developments may anticipate future design and this can be built into the machine. The process of design is usually an iterative one in addition to being solution led. Initially ideas are clarified, various options as to the optimum method of operation sought and consideration given to the operator's task.

If the operation is a manual one, which is repetitive and likely to cause tissue damage, other options of interaction between machine and operator may have to be considered.

A spin-off of this ergonomic consideration may lead to the further benefit of automation enabling the designer to allow for and anticipate future more-efficient developments.

There are major considerations in machine design to ensure good ergonomics. Ergonomics should be regarded as an essential part of good design, not as something separate. Essentially, ergonomics should be considered at ALL stages of the design process, especially in the early stages where it should be integrated into the brief or specification when all major design decisions are being made. Ergonomic requirements must be clearly outlined, otherwise it will be subsidiary to other design considerations.

Co-operation between members of a design team and the client's production department is vital to the success of good ergonomics in machine design. The comments of operators as the end users of the machine are particularly valuable. However, most design decisions involve compromise and, if an optimal ergonomic solution is not possible, it is essential to ensure that recommended limits of risk are not exceeded.

Ergonomic data should be applied intelligently and with caution. Care is needed to ensure that the data are applicable to the problem in hand. The origins and assumptions of a variety of data should be examined

Ergonomic specialists should be consulted if ergonomic problems are beyond the skill of the team or where a logical approach alone is insufficient and where the consequences of error are serious.

Using ergonomic information is likely to result in a better first approximation of the ultimate design. In fact, the uses of mock-ups, even simple ones, with representative users are valuable for confirming details for fit, reach and layout.

Figure 4 shows the main interactions between ergonomics and design and performance factors. There is a strong relationship between operability and safety, shown in the 4th and 5th columns. The outcome of operability and safety is dependant on the influence of the physical and visual workspace, the environment surrounding the operator and human characteristics.

	Design and performance factors										
Ergonomics factors	Functional requirements	Cost	Size[a]	Operability	Safety	Maintainability	Reliability	Manufacturability	Quality control	Marketability, acceptability	Aesthetics
General human characteristics											
Human vs. machine operation	●	●	○	●	●	●	●	●	●	●	
User population characteristics (age, sex, background, toleration)	○	○	●	○	●	●				●	○
Skills, selection, training	●	●		●	●	●		●	●	●	
Physical Workspace											
Body-size variation	○	○	●	●	●	●				●	
Reach, clearance and fit	○	○	●	●	●	●				●	
Postural comfort	○		●	●	○	○				○	
Seating design	○		○	○	○					○	
Strength: limits and variations	●			●	●	●				○	
Physical work capacity, endurance	●	○		●	●	○	○			○	
Control design	○	○	○	●	●	○	○				○
Layout of work and controls	○	○	○	●	●	●	○	○	○		○
Visual workspace, display and information											
Visual abilities and defects	○	○	○	●	●	○			●		
Visual task design	○	○	○	●	●	○	○	○	○	○	
Visual display design	○	○	○	●	●	○	○	○	○	○	○
Layout of visual tasks and displays	○	○	●	●	○	○		○			○
Control – display compatibility	○	○		●	●		○				
Passive displays (labels, symbols, instructions, manuals)	○	○		●	●	●	○				○
Auditory signals and displays (attention, processing, memory, etc.)	○	○		○	●	○	○				
Information load	●			●	●		○				
Physical Environment											
Lighting (recommended illumination, contrast, colour, glare)	○	○	○	●	●	●	○		●	○	○
Temperature (dry bulb high/low, radiant high/low, humidity, air speed)	○	○	○	●	●	●	○		○	●	
Noise (dangerous levels, masking of signals)	○	○	○	●	●	●	○		○	●	
Vibration (damaging effects, interference)	○	○	○	●	●	●	○		○	●	
Organizational											
Layout and flow of personnel, material and plant	○	●	●	●	○	○					
Rate of work (pacing, buffer stocks, shifts)	○	●		●	○	○			○	●	
Job content	○	●		○	○	○	○			○	
Inspection system/Quality system	○	●					●		●		

○ = interaction ● = strong interaction.

[a]Size refers to the size of the structure, access, workstation or components.

Figure 4. An interaction matrix between ergonomics factors and the design and performance factors. Obtained from 'A Design Manual' by Corlett and Clark **[54]**

3.3 Control measures

For the effective development of ergonomics in the workplace its application should start small, targeting those problem conditions which are clearly identified through health and safety data and job analysis information. **[4-5]** Moreover, the control actions can be directed to those conditions that appear easy to fix. Early successes can build the confidence and experience needed in later attempts to resolve problems that are more complex.

A follow-up evaluation is necessary to ensure that the controls which reduced or eliminated the ergonomic risk factors succeeded and that new risk factors were not introduced. This follow-up evaluation should use the same risk factor checklist or job analysis that was used initially. Therefore, if the hazards are not substantially reduced or eliminated, the problem-solving process is not considered to be complete.

Because some changes in work methods (and the use of different muscle groups) may actually make employees feel sore or tired for a few days, follow-up should occur no sooner than 1 or 2 weeks after implementation, with a month being the preferable timescale. Recognising this may help avoid discarding an otherwise good solution.

There are three types of controls for ergonomic hazards.

- Engineering controls – reducing or eliminating potentially hazardous conditions
- Administrative controls –Changes in working practices and management policies such as job rotation and training
- Personal equipment – Wrist supports, back belts or vibration attenuation gloves.

Engineering controls have, in theory, the greatest impact in eliminating or reducing risk factors to workers but it still requires the influence of administrative controls such as education, training and safety policies to ensure that complementary controls are in place to reduce risk factors further.

3.3.1 Engineering controls

The preferred approach to prevent and control MSDs is to have a comprehensive approach in the design of the operation and include:

- The workstation layout
- Selection and use of tools
- Work methods – to take account of the capabilities and limitations of the workforce.

There are several engineering control strategies to reduce ergonomic risk factors and include the following:

- Changing the way materials, parts and products can be transported – e.g. using mechanical assistance devices to relieve heavy load lifting/carrying tasks or using handles or slotted hand holes in packages requiring manual handling

- Modifying containers and parts presentation, such as height-adjustable material bins
- Changing the workstation layout which might include using height adjustable workbenches or locating tools and materials within short reaching distances.
- Changing the way parts, tools and materials are to be manipulated; for example, using fixtures (clamps, vice-grips, etc.) to hold work pieces. This eliminates the need for awkward hand/arm positions. Another possibility is the use of suspended tools to reduce weight and allow for easier access.
- Changing tool designs – e.g. pistol-handled grip knives can reduce the wrist bending postures often required by straight-handled knives or the use of squeeze-grip-actuated screwdrivers to replace finger-trigger-actuated screwdrivers.
- Changes in materials and fasteners e.g. lighter-weight packaging materials to reduce lifting load.
- Changing assembly process and sequence e.g. removing physical and visual obstructions when assembling components to reduce awkward postures or static exertions
- Increase level of automation to assist all of above.

Engineering controls involve altering the physical items in the workplace, including actions such as modifying the workstation, obtaining different equipment, or changing tools.

The focus of engineering controls involves identifying the underlying stressor (risk factor of awkward posture, force, repetition, etc.) and eliminating it through changing the physical environment.

Engineering controls are the preferred method of risk control because they permanently reduce or eliminate the risk.

3.3.2. Administrative controls

Administrative controls are management-dictated work practices and policies to reduce or prevent MSDs and include:

- Changes in job rules and procedures such as scheduling more rest breaks – reducing shift length or curtailing the amount of overtime and scheduling more breaks to allow for rest and recovery
- Rotating workers through jobs that are physically tiring – rotating workers through several jobs with different physical demands to reduce the stress on limbs and body regions
- Training workers to recognise ergonomic risk factors and to learn techniques for reducing the stress and strain while performing their work tasks and observing good working practices that can ease the physical demands of tasks.
- Adjusting the work pace to relieve repetitive motion risks and give workers more control of the work process.

Administrative controls can be helpful as temporary measures until engineering controls can be implemented and may be necessary when engineering controls are not technically feasible.

Administrative controls DO NOT eliminate hazards and therefore management must be assured that the practices and policies are followed. These include

- Increasing the frequency/duration of breaks.
- Assigning a second worker to assist in performing selected tasks
- Ensuring correct working techniques are followed
- Conditioning workers for the physical exertion that a task may demand
- Enlarging job responsibilities such that the same task is not repeatedly performed
- Implementing a preventive maintenance program for mechanical and power tools and equipment
- Developing a housekeeping programme
- Limiting overtime work.

A job rotation system is another administrative control but it can only provide a temporary solution to reducing MSDs.

It is important that the programme is implemented gradually at first so that it can be further refined before being implemented elsewhere.

Developing a job rotation system that is effective and can be monitored with regard to its sound operation is not a simple task. The successful implementation of such programme requires teamwork and should include input from management, supervisors and especially line employees. Line employees provide critical feedback as to the effectiveness of a job rotation programme to management and supervisors.

Final note: Job rotation does not improve the job itself.

"Job rotation should be used with caution and as a preventive measure, not as a response to symptoms." (OSHA, 1989) **[4-5]**

3.4 CONCLUDING COMMENT AND WAY FORWARD

There is some criticism in the literature regarding the use of risk assessment as laid out in the guidelines and regulations. The designer may find that the techniques used to analyse the risk levels of their assembly machines, either built or at the conceptual stage, are inadequate. Risk level estimation may provide little assistance to the designer to make positive alterations to the tasks, to improve productivity and facilitate ease of use by the operator. The Health and Safety at Work Act 1974 is flexible in allowing companies to comply in the most affordable way. However, with the introduction of new regulations and guidelines, flexibility is reduced and using simple risk assessment as a technique of compliance is becoming more difficult.

It may be useful at management level to have an overview of health and safety policy using a simple risk assessment tool which will allow them to prioritise issues of cost, quality or, indeed, corrective action and improvement.

There is potential to exploit Risk Assessment as a management tool for health, safety, cost and quality for every assembly station. Designers require both extensive and relevant information to design an assembly station "right first time" with the lowest risk level. In order to achieve this, a combination of methods and techniques to collect information is required. It may be time consuming but it can be argued that there will be overall economies by using this approach.

The next chapter will demonstrate the incorporation of relevant literature and design for safety, including best practice, into an evaluative tool – a **RI**sk **MAN**agement tool – **RIMAN**. It analyses risks by identifying the hazards that may affect the users. The users could be the operators, maintenance staff or cleaners of the machine, in all phases of machine life from machine building, commissioning the machine, through to running in production and, finally, decommissioning at the end of its life cycle. Once all the hazards are identified, a scoring system will be constructed, combining various factors of the overall risk level posed to the users or by the machine itself. The factors include: severity of injury, the level of exposure to the user, the likelihood of injury and the countermeasures already in place which allow a potential hazard to be detected or prevented from happening. The overall risk level for each hazard identified will decide whether further work is required to reduce the risk.

CHAPTER 4 BEST PRACTICE FOR A RISK MANAGEMENT PROCEDURE

The objective of this chapter:

- To incorporate "best practice" into a risk management procedure.

4.1 Introduction

There are many different methods and techniques used in the design of operator-centric assembly stations. Designers may have their own preferences regarding which methods or techniques could function as design tools in order to achieve their goals.

A comparative analysis between different methods and techniques shows there are various intangible factors. Each has its own advantages and disadvantages.

Instead of evaluating each method or technique to find the best design methodology, it would be preferable to develop an alternative management tool to facilitate design methods or techniques which will achieve the same goal. To be able to use more than one method or technique produces a stronger management tool, enabling designers to increase functionality and safety and enhance the well-being of the operator and maintenance technicians.

A risk management tool would require a combination of different risk assessment techniques from different sources, such as from a design manual with a design-by-safety approach or regulations and standard guidelines. Together with the principles of tabular methods, a risk management procedure which incorporates health & safety legislation can complement work done by other departments and enables them to use their own methods and techniques in the design of assembly stations.

RIMAN shall be the new term for **RI**sk **MAN**agement procedure in this thesis.

4.2 RIMAN

All risk assessment tools have similar approaches ranging from design manuals **[24]** to international standards **[6, 8, 20 and 23]** but the scorings are different. Some may be more suited to certain disciplines, for example the Management of Health and Safety at Work Regulations **[6]** would be more appropriate to management staff than to designers. In another instance, process Failure Mode and Effect Analysis (FMEA) tackles process failures to achieve high quality products without to the customer but does not provide any valuable information regarding which process would affect production (downtime), the well-being of the operators and the ease of maintenance, thus increasing productivity and, potentially, better quality products.

Risk assessment does not include information needed by designers to facilitate the development of the ideal assembly process that would generate the highest quality products, increase productivity and limit residual risks to the end users. In order to achieve this, the designers would need to collect very comprehensive information beforehand, with full support from all departments, in order to develop precise criteria for the construction of an assembly station. Each method and technique has its own distinctive way of collecting information.

Therefore, a management tool is required which would ensure that appropriate methods and techniques are used to their full extent. The whole process may be time consuming – but if the assembly station was designed with a large volume of effective inputs – it could, in theory, be designed right first time.

There are several stages in RIMAN, with the first three stages being focused on getting a team together and collecting data to identify potential hazards. The remaining stages are the risk assessment of all the hazards identified. The risk assessment contained within RIMAN is an expanded and improved version from three main sources:

1. The risk assessment calculator, provided freely on the Internet from a machine guarding company, based in Caerphilly, Procter Machine Guarding.
2. BS EN 1050:1997 standard – The principles of risk assessment.
3. Pilz Guide to machinery safety, 6th edition, by machine safety equipment supplier Pilz GmbH & Co.
4. The risk assessment calculator by Procter provided the initial format in the form of a spreadsheet could be used as a tool, together with a numerical scoring that was sourced from the Pilz guide. In addition to these RIMAN used countermeasures to influence the overall risk level. Engineering and administrative controls provide the countermeasures to detect or prevent a hazard developing.

The risk assessment calculator by Procter had a list of hazards obtained from the lists in annexes A and B of BS EN1050: 1997 standard. The user of the risk assessment had to work down the list of hazards to see which were appropriate. It had four factors to provide a combined score for the Hazard Risk Number for each applicable hazard. The four factors were: degree of possible harm, likelihood of occurrence, frequency of exposure and number of persons at risk. Reference tables are provided for each of the factors. The risk assessment calculator by Procter is ideal for simple mechanical machinery where most of the hazards would be identified on the lists, but to incorporate the latest technologies to the design of machinery would require further investigation for additional potential hazards that are beyond the scope of the list provided. This would require collecting data at the beginning of the exercise before identifying all potential hazards.

The following RIMAN flowcharts, namely figures 5 and 6, outline the sequential stages used to evaluate risks in designing operator-centric assembly stations.

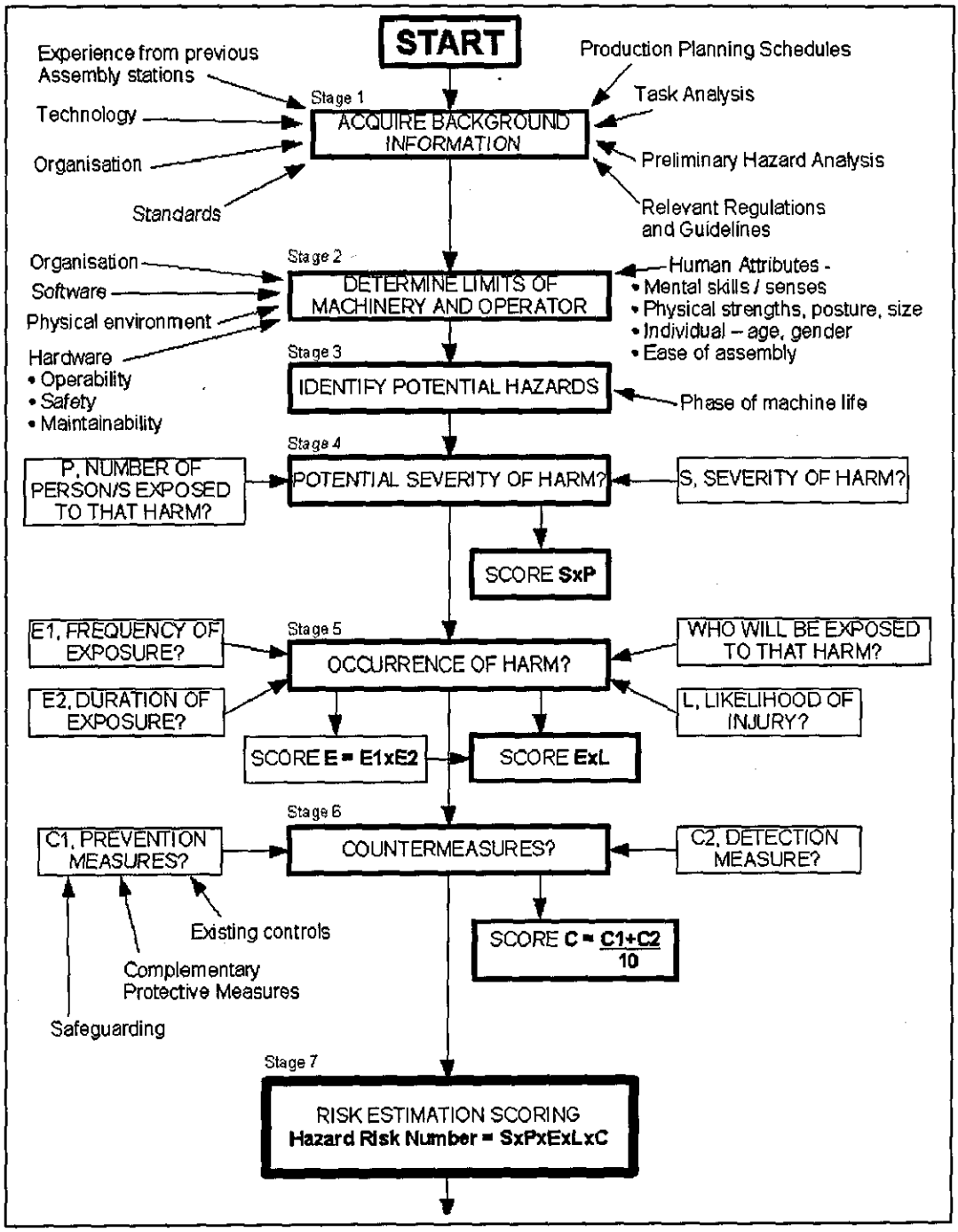


Figure 5. RIMAN flowchart 1, sequential steps to evaluate risks.

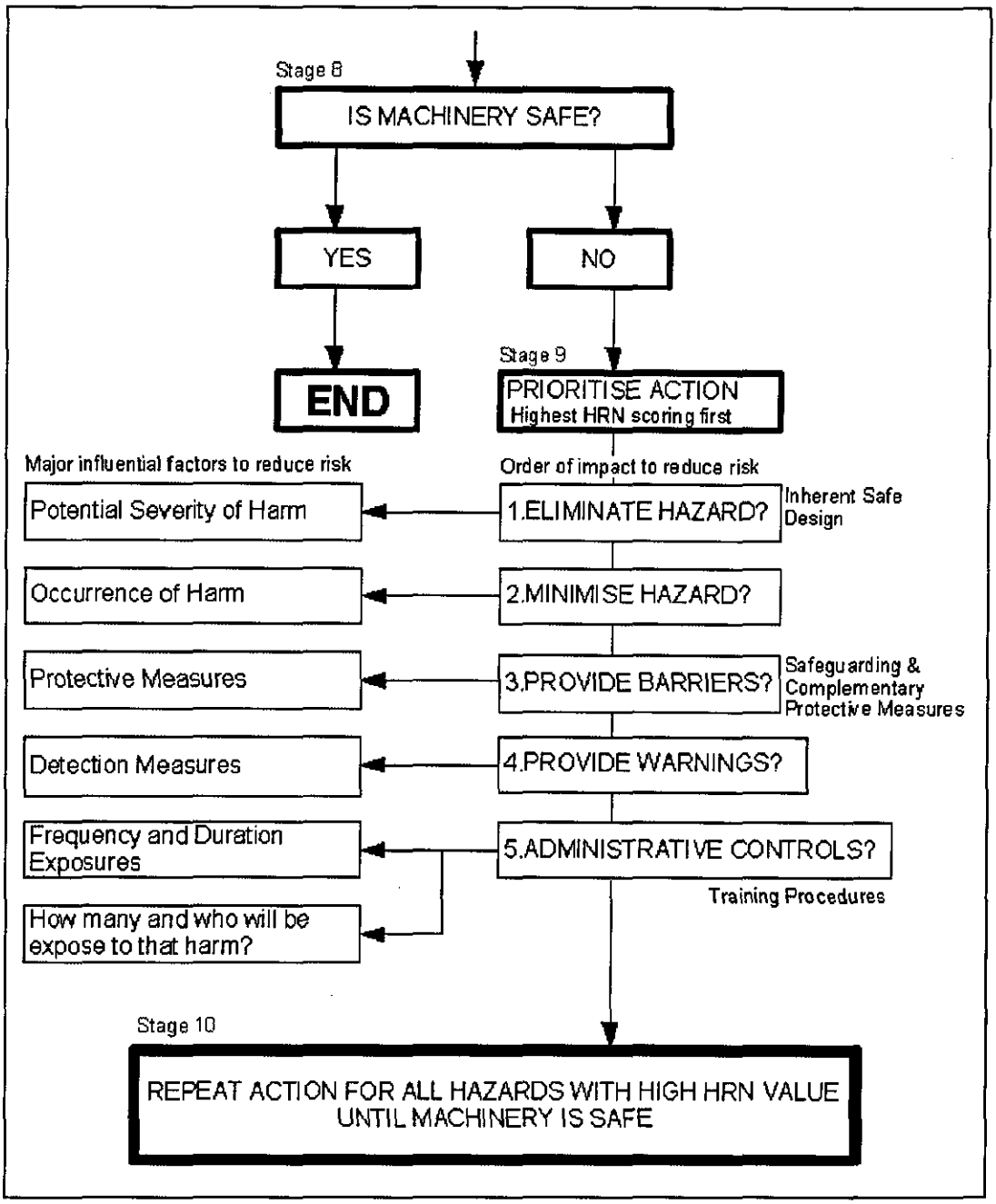


Figure 6. RIMAN flowchart 2, sequential steps to evaluate risks.

4.3 Procedure

A focus group of staff with an interest in the machine's lifecycle could use RIMAN as a tool to increase inter-departmental communications. This would provide additional information to the designer's initial design criteria.

RIMAN could be used for new design or the redesign of an existing assembly station. With redesign, RIMAN data from the original design could be used to identify the risks before a redesign is formulated.

Four sheets are used in this risk evaluation procedure:

a. Stage 4 - Potential Severity of Harm
b. Stage 5 - Occurrence of Harm
c. Stage 6 - Prevention and Detection Measures
d. Stage 7 - Risk Estimation

The above-mentioned sheets are in spreadsheet-based format as displayed on Tables 6 to 9.

Every sheet has the Hazard number, Function/Process and Potential Hazard columns to allow easy cross-referencing of the documents. The sheets must be completed sequentially. For example, sheet one, 'Potential severity of harm' must be completely filled in before collecting data for the second sheet – 'Occurrence of Harm'. The reason for this is to allow the group to focus on each sheet independently without the influence of the others. If the assessment group is allowed to scan back and forward throughout the four procedure sheets there may be a danger that the essentials of the design requirement would be compromised.

Potential Severity of Harm									
Hazard No.	Function / Process	Phase of machine life	Potential hazard	Type of hazard	Severity of Injury (S) **(assume *running for* 8 hours)**	Number of person/s exposed (P)	S	P	S*P

Table 6. Potential Severity of Harm – Stage 4 of RIMAN.

Occurrence of Harm										
Hazard No.	Function / Process	Potential hazard	Who will be exposed to that harm?	Frequency of exposure? (E1)	Duration of exposure (E2)	Likelihood of injury (L)	E1	E2	L	E1*E2*L

Table 7. Occurrence of Harm – Stage 5 of RIMAN.

Countermeasures								
Hazard No.	Function / Process	Potential hazard	Scoring so far = S*P*E*L *(if 5 or less = countermeasures are not required)*	Prevention measures (existing controls) (C1)	Detection measures (Existing training and information) (C2)	C1	C2	(C1+C2) /10

Table 8. Countermeasures – Stage 6 of RIMAN.

Risk Estimation								
Hazard No.	**Function / Process**	**Potential hazard**	**RISK HPN (S*P*E*L*C)**	**Risk Level**	**Root Cause**	**Recommended action/s**	**Responsibility & target completion date**	**New Hazard No.**

Table 9. Risk Estimation – Stage 7 of RIMAN.

The procedure should always be to evaluate the whole design, to get the essentials and then plan the necessary corrective actions to eliminate or reduce problems within a time scale and budget. Indeed with this approach several problems might be resolved by one corrective action.

Prior to using the sheets, a focus group must acquire as much background information as necessary to be familiar with the project.

4.3.1. RIMAN stage 1 - Acquire background information

Collecting information is crucial to the whole process of achieving a rigorous risk evaluation and a design right first time philosophy. If data collection is not undertaken prior to the risk evaluation process it may lead to REACTIVE corrective action after the assembly station is built and running.

Background information is gathered, primarily, using task analysis tools to achieve the objectives.

At this stage, a conceptual design for an assembly station could be non-existent. A designer will be required to find the most appropriate range and type of technologies, mechanisms and controlling devices from the market place. Thereafter s/he will assess the core function of the assembly process and determine the ergonomic requirements in detail. These may include the overall size of assembly station, availability of floor space, number and type of people involved in the build and those running the process, such as machine builders, operators and maintenance engineers. The designer may ask himself the following questions:

- What do these workers have to do, see, reach, operate and maintain?
- What are the environmental conditions that may affect both people and the assembly station?
- Where is the operator to be positioned in relation to the assembly station? Sitting down, standing up, or a choice of sitting or standing at different times?
- What type of access to the assembly station is needed for operator, maintenance engineer, materials and equipment?
- How must the controls be set for the operators and is there a need for additional controls to protect the maintenance engineer?
- What types of display are needed to give operational signals and warnings?

The designer has to ask these initial questions in order to generate detailed design criteria for the assembly station.

Task analysis tools have other attributes which will improve the overall functionality of the assembly station. For example:

- Maximising value-added tasks, such as placing components in a casing
- Minimising non-value added tasks, which are required between value-added tasks, such as setting up a machine or product in a certain way in order to process to the next stage of the sequence
- Eliminating time-wasting, unnecessary tasks, such as walking a distance to collect a part, when the same part should be within comfortable arm reach
- Standardising tasks to allow different operators to achieve the same cycle times and produce high quality products to a standard with minimal rejects.

4.3.2 RIMAN stage 2 – Determines the limits of machinery and operators

Once the focus group has acquired background information, the next step is to determine the limits of machinery and interaction with its operators as part of the overall design criteria.

Use limits:

- Phases of machine life
- The intended use of the machine
- Different operational modes and different procedures for the end users such as operators, maintenance staff, material handlers, untrained personnel and visitors
- An inappropriate use of the machine

Space limits:

- Range of movement
- Installation space requirement
- Machine-power supply interface
- Operator-machine interface
- Maintenance and access around the machine

Time limits:

- The foreseeable "life-limits" of the machine and/or of some of the components such as equipment, tools, parts that wear out, electrical components, e.g., roller bearings have limited life before they deteriorate
- Taking the above "life limits" into account for its intended use.

Environmental limits:

- Type of environment in which the machine will be installed – Outside/inside? Clean or oily? Dry or wet? Chemical exposure?
- Emissions from the machinery?

Operator limits:

- Ease of assembly
- Individual attributes – age, gender, physical size and strength, skills and senses.
- How long an operator should work on one machine each day? Organisational?

Maintenance limits:

- Ease of maintainability
- Individual attributes – physical strengths, body size and skills
- What are the tools required to maintain this machinery?
- Special requirements that are separate from an operator's? Additional skills?

Organisational limits:

- Working hours?
- Rest breaks?
- Method of manufacturing – Just In Time, batch production, single-part flow philosophies.
- Training requirements
- Budget to build the assembly machine and training end users?

Control limits:

- Ease of programmability
- Type of controls – manual, semi or automatic?
- Analogue or digital inputs/output control?

4.3.3 RIMAN stage 3 - Identify potential hazards

The information gathered and the limits of the machinery and operator will be used to identify potential hazards. Other methods and techniques can be used for identifying potential hazards, such as PFMEA, What-If analysis, Fault tree analysis and Preliminary Hazard Analysis, all of which are described in Appendix 2.

The designer must take human interaction into account during the whole life-cycle of the machine as described below:

- Construction
- Transport, assembly and installation
- Programming
- Commissioning
- Normal operation
- Fault finding
- Setting
- Process changeovers
- Cleaning
- Decommissioning, dismantling and disposal

With RIMAN, a designer may use checklists of mechanical, non-mechanical and ergonomic hazards. Tables 10, 11 and 12, assist to identify and describe the potential hazards quickly in a tabular form. There will be other unique potential hazards that are not in checklists but they should be covered in RIMAN.

Entanglement	Contact with a single rotating surface i.e. couplings, spindles, chucks, leadscrews, mandrels, bars, rotating workpieces
	Catching on projections or in *gaps i.e. fan blades, spoked pulleys, chain wheels, gear wheels, flywheels, mixer and beater arms, spiked cylinders, belt fasteners, projecting keys, set screws, cotter pins on shafts, slat conveyors*
	By catching between two parts ➢ Between counter-rotating parts *i.e. gear wheels, rolling mills, mixing rolls and calenders, material being drawn between two rolls* ➢ Between rotating and tangentially moving parts *i.e. power transmission belt and pulley, chain and chain wheel, rack and pinion, metal, paper, rope, and a reeling drum or shaft, batch-up, reel-up, conveyor belt and its driving pulley or bend pulley* ➢ Between rotating and fixed parts *i.e. spoked handwheel or flywheel and the machinery bed, screw or worm conveyors and their casing, revolving mixer and mincing mechanisms in casing having unprotected opening, Z-blade and ribbon-blade mixers, extruder scroll and barrel, the periphery of an abrasive wheel and an incorrectly adjusted work rest*
	Catching in materials in motion i.e. *in centrifuges, in tumble driers, in dough mixers*
	Swarf from machining operations
Friction and Abrasion	
Cutting	
Shear	
Stabbing and Puncture	
Impact	
Crushing	
Drawing-in	
Injury by compressed air or high pressure fluid injection *i.e. hydraulic*	

Table 10. Potential mechanical hazards checklist

Access	Slips	Fire and explosion	
	Trips	Noise and Vibration	
	Falls	Pressure and Vacuum	
	Falling objects	Temperature	High
	Moving Objects		Low
	Obstruction	Inhalation of mist, fume and dust	
	Projection	Suffocation	
Electricity (including static electricity)	Shock	Biological	Viral
	Burns		Bacterial
Ionising and non-ionising radiation Chemicals	Toxic	Handling and lifting	
	Irritant	Ionising and non-ionising radiation	
	Flammable		
	Corrosive		
	Explosive		

Table 11. Potential non-mechanical hazards checklist

Physical factors	Heavy, static, monotonous work
	Extreme or constrained postures
	Repetitive movements
	Unsuitable workplaces and equipment
	Excessive forces
	Exposure to vibrations
	Contact stresses
	Poor grip
	Bending and twisting
Non-physical factors (Environment)	Extreme lightings
	Loud noises
	Extreme temperatures
	Electrical exposures
	Poor visual displays
	Chemical exposures
Psychosocial factors	Work organisation
	Interpersonal relationships
	Short cycle tasks
	Poor work control
	Piece rate payment system
	Poor management
	Unsatisfactory training
	Long work hours
	Lack of breaks
	Time demands
Personal factors	Gender
	Age
	Seniority
	Exercise habits
	Life style
	Psychosocial characteristics and capacities
	Unsuitable clothing
Combined hazards	e.g. Excessive forces with repetitive movement

Table 12. Potential ergonomic hazards checklist

4.3.4 RIMAN stage 4 - Potential severity of harm

When all potential hazards have been identified and no further analysis is useful, then the first stage of RIMAN can begin with Sheet 1 – Potential Severity of Harm. (See Table 6).

As mentioned earlier, columns 1, 2 and 4, Hazard No., Function/Process and Potential hazard respectively are completed equally on all four evaluation sheets.

'Hazard Number', starts from 001, is numbered in series, and itemises every potential hazard identified relating to the assembly station.

'Function/Process' is a description of a function, either a specific task by and or an action from a machine.

The third column: 'Phase of machine life' helps to identify likely hazards and those that will be rare. For example, an assembly operator may be well protected by machine guarding but a maintenance engineer checking the machinery may be exposed to a minimal risk from investigating beyond the guards.

The fourth column: 'Potential Hazard' is a description of a hazard that could potentially harm a person or group of people.

The fifth column: 'Severity of injury' considers injury from minor to a worst-case scenario. It is sensible to assume the worst is unlikely to happen. It may mislead evaluation as the type of injury may never occur but allowance for it should be made on the 'Occurrence of Harm' sheet. This factor outlines to the assessment group that they may assume that the exposure for an individual is limited to 8 hours per day. Extra work time is evaluated in Occurrence of Harm sheet.

A checklist is available to quickly identify the description of the severity of an injury. (See table 13).

The sixth column: 'Number of person/s exposed to that harm' is a risk factor in its own right and presents a higher severity of injury risk level as more than one person is exposed. For example, an explosion from machinery would injure neighbouring workers in addition to the operator.

The S and P columns give a score based on the checklists. Each potential hazard that is described on the checklist has a score from 1 to 13, where 1 is defined as harmless and 15 means death. (See Table 21 for the scoring table for S, 'Severity of injury').

The last column is the combined score of S (severity of injury) and P (number of person/s exposed to that harm) and is carried forward to sheets 3 and 4.

S, SEVERITY OF INJURY

Mechanical injury	No injury
	Anything that requires first aid only
	Medical recordable
	Anything that requires resuscitation
	Scratch or bruise
	Internal bleeding
	Laceration (tearing of the flesh)
	Minor cut, temporary scarring
	Major cut, minor scarring
	Severe cut, major scarring
	Minor burn, temporary scarring
	Burns causing permanent scarring
	Injury to face or eyes (temporary blindness)
	Break of minor bone (fingers, thumb and toes) (Temporary)
	Break of major bone (arms and legs, pelvis) (Temporary)
	Dislocation of the shoulder, hip, knee or spine.
	Loss of one limb, eye, hearing (permanent)
	Loss of two limbs, eyes (permanent)
	Loss of consciousness (not prolonged)
	Prolonged unconsciousness (coma)
	Paraplegia (paralysis of the lower half of the body, from waist down)
	Quadriplegia (paralysis of all 4 limbs, from neck down)
	Minor brain haemorrhage
	Major brain haemorrhage
	Severe brain haemorrhage – lead to possible brain-death
	Fatality
Non-mechanical Injury	Lower back injury
	Skin allergy
	Viral disease
	Bacterial disease
	Deafness by noise
	Blindness by light
	De-hydration
	Electrical shock
	Electrical burn
	Chemical burns
	Suffocation
	Fall, slip, trip and objects fall from height.
	Projection
Physical/ psychological hazard	Startled
	Shock
	Slight, minor or major strain ➢ Fingers ➢ Hands ➢ Wrists ➢ Arms ➢ Shoulders ➢ Back ➢ Leg ➢ Feet ➢ Neck ➢ Eye
	Minor musculoskeletal disorder (reversible disorder)
	Major musculoskeletal disorder (Minor irreversible disorder)
	Severe musculoskeletal disorder (Major irreversible disorder)

Table 13. Checklist for description of potential severity of injuries or disorders

If at this point there is an identifiable risk which is both severe in its consequence and is likely to occur, the focus group could make an immediate decision before continuing to the next stage of RIMAN. The group would need to ensure that the potential hazard was eliminated or reduced dramatically before continuing. However, if the occurrence of that hazard is considered to be unlikely and there is no apparent easy design except one that has a high cost technological solution, the focus group must reach a decision before proceeding.

4.3.5 RIMAN Stage 5 - Occurrence of harm

Once all potential hazards are identified and the levels of severity of harm determined, stage 5 – Occurrence of harm can begin. (See table 7).

Stage 5 of RIMAN summarises a combination of three risk factors; E1 - Frequency of exposure, E2 - Duration of exposure and L - Likelihood of injury? and additionally identifies 'Who will be exposed to that harm?'

The first three columns - Hazard No., Function/Process and Potential hazard are identical to Stage 1 of RIMAN – Potential Severity of Harm.

The fourth column – 'Who will be exposed to that harm?' can be explained as follows. Each person has a different level of exposure to the risk. For example, maintenance staff may have a higher exposure to risk because of their access into the workings of the machinery, whilst an operator has restricted entry.

The identification of those at risk and the extent of the risk is crucial to the working of RIMAN and should be constantly reviewed and considered a live document.

The fifth column, E1 'Frequency of exposure' is a risk factor that takes the number of times a person will be exposed that potential hazard in an 8-hour period. For example, an operator would be exposed to a risk more frequently than a maintenance engineer. This suggests that efforts should be made to reduce that frequency. (See table 14).

The sixth column, E2 'Duration of exposure' is a risk factor similar to E1 but takes into account that the assembly station may run longer than 8 hours and be manned by a second and possibly a third shift operator. Running the process or function for more than 8 hours would thus increase the chance of exposing more people to the potential hazard. E2 has a scoring from 1 to 3, 1 being within 8 hours, 2 meaning double shift work and 3 – 24 hours. (See Table 15).

The seventh column, L 'Likelihood of injury' takes into account how likely it is that a person or persons will be injured. (See Table 16).

The remaining columns – E1, E2 and L show the scores, transferred from the relevant checklists. The last column is the product of E1, E2 and L multiplied. (See tables 23, 24 and 25).

On the 'Occurrence of harm' sheet, all three factors are combined and carried forward to sheets 3 and 4.

Once in every:	Month
	Week
	Day
	Hour
	15 minutes
	1 Minute
More than once every minute (2-6 times)	
Several times a minute (7+)	

Table 14. E1 - Frequency of Exposure checklist. Amount of exposure to a potential hazard in an 8-hour shift.

8 hours (single shiftwork)
16 hours (2 shiftwork)
24 hours (full 24/7 shiftwork)

Table 15. E2 - Duration of Exposure checklist. Length of exposure to a potential hazard per working day

Almost impossible – possible only under extreme circumstances
Highly unlikely – though conceivable
Unlikely – but could occur
Possible – but unusual
Even Chance – could happen
Probable – not surprising
Likely – only to be expected
Certain – no doubt

Table 16. L - Likelihood of Harm checklist.

4.3.6 RIMAN Stage 6 - Countermeasures

'Countermeasures' is the third stage of RIMAN. It provides information to determine if there are additional measures, such as detection equipment, personal protection equipment, constant training and awareness of the potential hazards. Ultimately they can significantly reduce the overall impact of the risk level. (See table 8).

First three columns - Hazard No., Function/Process and Potential hazard are as explained for Stage 1 of RIMAN – Potential Severity of Harm.

The fourth column shows, the scores from RIMAN stages 4 and 5. They are identified and scored as follows:

S	=	Severity of injury
P	=	Number of persons exposed to that harm
E1	=	Frequency of exposure
E2	=	Duration of exposure
L	=	Likelihood of harm

These scores are combined by multiplying:

S x P x E1 x E2 x L

The combined scoring provides the initial assessment before making any further determination of whether additional countermeasures are required.

There is a simple rule for this. If the scoring equalled five or less the risk levels for that potential hazard are acceptable and no further action or countermeasures are required.

If the scoring is six and over, then countermeasures are required but they must be those that are already in place as engineering or administrative controls. However, if the assessment is on a new design and there are no existing countermeasures in place, the total score should be doubled. This doubling of the score emphasises the need for effective design and improved administrative control. Simply, it can be a part of an improvement program in a Company's Health and Safety policy.

Columns 5 and 6 are the countermeasures:

1. PREVENTION MEASURES = C1
2. DETECTION MEASURES = C2

Countermeasures are practical and active. Instead of deciding the worst case scenarios, they aim to protect people from hazards or can include early detection of a hazard. Each countermeasure is given a scoring from 0.5 (very effective) to 10 (irrelevant).

The last column is the combined scoring of the 2 countermeasures:

C, Countermeasures = (C1+C2)/10

The combined score ranges from 0.1 to 2. This formula allows a final score to reflect a position where no countermeasures are applied. The total Hazard Risk Number (HRN) is doubled emphasising a company decision to live with a risk. A score of 1 and above would mean that there is no change to the current risk level and although countermeasures may be in place they will not reduce a risk. On the other hand, a score of less than 1 down to 0.1 is making an impact to reduce the initial risk.

There is a fine line between inherent safe design and protective measures. Inherent safe design is the major contributory factor that will eliminate or reduce a potential hazard. On the other hand protective measures only protect the operator but do not remove the hazard. Safeguarding access areas on the machine with interlocking devices at suitable effective locations would be considered inherent safe design. When the guard is open, the machine is inoperable and when it is guarded, that potential hazard would have low chance of occurring.

Using a scoring system for countermeasures puts emphasis on the importance of inherent safe design over the application of protective/detection methods.

From a design point of view, countermeasures are either *temporary* engineering and/or administrative controls, which will require reviewing, maintaining and servicing to ensure that the risk levels have not changed. For example, a technician, under pressure of work, removes the guards to gain access to make a repair and forgets to be aware of the potential hazard. It is the designers' duty to ensure, even when people forget to be aware, that there are additional engineering controls to prevent that hazard occurring when guards are removed.

A similar situation exists with administrative controls and the use of personal protection equipment. For example, safety glasses may protect the eyes but not the rest of the head and, indeed, their use may be neglected by an operator.

Tables 17a and 17b show checklists of the majority of preventative measures that could apply to machinery design.

Table 18 shows examples of controls of detection. Detection is an assessment of the ability of the design/machinery controls to identify potential hazard/s.

Design/machinery controls are methods, techniques, devices, or tests used to:

- Prevent the hazard from occurring, or reduce rate of occurrence
- Detect the hazard and lead to corrective design actions
- Detect the potential hazard.

Table 19 shows checklists of the majority of detection measures that could apply to machinery design.

Where access to the danger zone is not required during normal operation	Fixed enclosing guard
	Fixed distance guard
	Interlocking guard
	Trip device ➢ Sensitive screen or barrier – mechanical trip devices ➢ Electro-sensitive protective device i.e. light curtain, light beam ➢ Pressure sensitive mat or floor
Note. For fixed enclosing and distance guards – how much area is protected? – 100%, 75%, 50%, 25% or none at all	
Where access to the danger zone is required during normal operation	Interlocking guard
	Push-away guard
	Trip device ➢ Sensitive screen or barrier – mechanical trip devices ➢ Electro-sensitive protective device i.e. light curtain, light beam ➢ Pressure sensitive mat or floor
	Adjustable guard
	Self-adjusting guard
	Two-hand control device
	Hold-to-run control
Emergency Stop actuation	Situated next to start button
	Situated less than an arm length of normal working position
	Situated beyond arm length of normal working position
	Non-designated button e.g. machine normal stop or 'off' button
Start control	Two-hand and hold-to-run control
	Two-hand and no hold-to-run control
	Single hand and hold-to-run control
	Single hand and no hold-to-run control
	Trip device to start independently.
	Trip device/interlocking with single hand and no hold-to-run control
	Trip device/interlocking with single hand with hold-to-run control
	Trip device/interlocking with two-hand and no hold-to-run control
	Trip device/interlocking with two-hand and hold-to-run control
Noise Control	Full enclosed guard ➢ Total Noise elimination ➢ Partial noise elimination
	Partial cover guard
Fume Control	Maximum fume extraction (no fume inhalation)
	Head breathing equipment – air supplied from elsewhere
	Simple face mask
Continue next page	

Table 17.a. Prevention Measures checklist.

Seating comfort	Customised ergonomic chair
	Fully adjustable ergonomic chair
	Chair with height adjustment
	Chair with no adjustments at all
Engineering controls	Partial mechanical support – semi automated
	Full mechanical support – fully automated
Administrative controls	Training to learn techniques to reduce stress and strain while performing task ➢ Competent person – engineers, technicians, trainers. ➢ Fully trained ➢ Newly trained
	Exposure limit to potential hazard ➢ No more than 8 hours per day per person ➢ No more than 4 hours per day per person ➢ No more than 2 hours per day per person ➢ No more than 1 hour per day per person ➢ 30 minutes a day limit only per person ➢ 10 minutes a day limit only per person ➢ 1 minute a day limit only per person
Personal Protection Equipment	Full body protection
	Partial body protection e.g. Leather apron
	Helmet
	Face screen
	Safety glasses
	Ear muffers
	Ear plugs
	Safety shoe
	Gloves

Table 17.b. Prevention Measures checklist.

Design Controls	Machinery Controls
Worst case analyses	Proximity sensors
Derating	Temperature sensors
Tolerance studies	Oil pressure light
Simulation studies	Timing sensors
Design reviews	Proactive maintenance*
Safety margins	Vibration sensor

Table 18. Examples of controls of detection

**Proactive maintenance* actions are key preventive, predictive, and visual management tools to control the reliability of machinery. Preventive maintenance schedules, procedures, and in-plant resources are valid design controls to reduce the occurrence ratings of the machinery risk assessment only if they have been developed as part of the design process and are included in the machinery's user manual.

Detection by design/machinery control	**Absolute uncertainly** that machinery controls will not and/or not detect potential hazard, or there is no design or machinery control.
	Remote chance a design/machinery control will detect a potential hazard. Machinery control will provide indicator of imminent hazard.
	Low chance a design/machinery control will detect a potential hazard. Machinery control will prevent an imminent hazard (e.g. stop machine)
	Moderately chance a design/machinery will detect a potential hazard. Machinery control will prevent an imminent hazard and will isolate the cause. Machinery control may be required.
	High chance a design/machinery control will detect a potential hazard. Machinery control will prevent an imminent hazard and will isolate the cause. Machinery control may be required.
	Very high chance a design control will detect a potential hazard. Machinery control NOT necessary.
	Almost certain that a design control will detect a potential hazard. Machinery control NOT necessary.
Detection by Administrative controls	Training to recognise ergonomics risk factors ➢ Competent person – trainer, ergonomists. ➢ Fully trained person ➢ Newly trained person ➢ Unskilled
	Process awareness ➢ By Information (training or/and machinery manuals) ➢ By observation (ability to see a possible potential hazard) ➢ By warning signs and indicating lights
Detection by avoiding or limiting harm	Impossible human reflexes to avoid or limit harm
	Possible (under certain circumstance) human reflexes to limit harm
	Possible human reflexes to limit harm
	Possible human reflexes to avoid harm
	Sudden appearance of hazard
	Fast appearance of hazard
	Slow appearance of hazard

Table 19. Detection measures checklist.

Note: The main objective of a design is to make the machine robust so that machinery controls are NOT REQUIRED. The design engineer must not rely on machinery controls or control plans to overcome potential design weaknesses.

4.3.6 RIMAN Stage 7 - Risk estimation

The last sheet is a culmination of all three sheets with their scores combined as S x P x E x L x C. (See Table 9). Their scores will fall into one of these four categories of RISK LEVELS, which will help to simplify the decision process.

Four categories of RISK LEVELS	
0 – 5	Acceptable
6-50	Low, but significant
51-500	High
501+	Unacceptable

The scoring risk levels have been obtained from a couple of sources. One was from the machine guarding company, Procter Machinery Guarding, who specialise in machine guarding, light guards, floor detection mats and other safety related equipment. Their risk level scorings have been obtained both from BSI EN 1050:1997 **[53]** and Pilz Guide to Machinery Safety, 6th Edition **[51]**.

The course of action to follow from the combined scoring is as followed:

ACCEPTABLE indicates no further action is required.

LOW, BUT SIGNIFICANT indicates that action is required by analysing the existing controls. Develop contingency plans to cope with this residual risk

HIGH indicates urgent action is required. Determine what action is required to reduce these risks to an acceptable level.

UNACCEPTABLE indicates the highest priority for immediate action to reduce risk to an acceptable level. Consider withdrawing the design, process or function if the risk constitutes a "serious and imminent danger" after analysing the existing controls. Alternatively, seek professional advice to reduce the risk to an acceptable level.

4.3.6 RIMAN Stage 8, 9 and 10 – IS MACHINERY SAFE?

Root Cause analysis is the next evaluative exercise. The fourth evaluation sheet of RIMAN shows the root cause column, when risk levels are other than 'acceptable'. The designer may know what the root cause of the problem is and address it promptly. However, sometimes in complex design, a root-cause analysis or similar could be used to determine the potential root causes which could generate hazards, increase the severity of injury or the likelihood of harm. Task analysis or other information gathered at the beginning of RIMAN evaluation could be used to identify the root cause of problems.

When a root cause is identified and corrective action completed, the assessment group must determine what new potential hazards may arise with the latest design. These must be added to the list and evaluated by RIMAN.

The last three columns are used by management to allocate responsibility with target dates for action. A new hazard number is given when corrective action has been completed. In this way each new corrective action will be evaluated intensively the same way as the original potential hazards.

When managing risk, the highest risk level should be tackled first, with others being arranged in a hierarchical order and dealt with in sequence.

The process of RIMAN must be repeated for all hazards with high HRN values until machinery is deemed safe. At the end of the RIMAN procedure there will be some residual risk level and warning signs must be displayed to draw them to the attention of users.

4.4 Numerical scoring tables

Most of the scoring for risk levels was obtained from Procter Machinery Guarding's Risk assessment calculator, BSI EN 1050:1997**[53]** and Pilz Guide to Machinery Safety, 6th Edition **[51]**.

The checklists as described in tables 13 to 19 are used together with risk scoring for each description as shown in tables 20 to 26. The scores are given in relation to the level of risk imposed. For example, in Severity of Injury checklist, table 20, the range is from 0.1 for no injury and 15 for a fatality.

These numerical scores are similar to those from Procter Machinery Guarding but RIMAN has added new types of injury. For example, slight strain would be considered in the same level of severity as minor cut or burn because the injury is temporary.

For stage 5 of RIMAN – occurrence of harm - the exposure factor was split into two separate factors – duration and frequency. This was adapted from the BS EN 1050:1997 standard. This is to allow for machines that are intended to run for more than 8 hours a day.

For stage 6 of RIMAN – Countermeasures were derived from BS EN 1050:1997 under the heading 'probability of occurrence of harm'. This important factor was omitted from both Procter Machinery Guarding and Pilz Guide to Machinery Safety, 6th Edition. The numerical scoring system for the countermeasures was formulated by trying out various calculation methods to give realistic overall risk levels.

Both the two countermeasures, Detection and Prevention, give their range of scoring from 0.5 to 10, 0.5 implying sufficient controls and 10 identifying none. These two scores are added together and divided by 10. The combined countermeasures then produce risk level scores from 0.1 to 2.

A score of 0.1 from the countermeasures would effectively reduced the risk considerably, whereas a scoring of 2 would double the risk, emphasising the importance of administrative and engineering controls to preserve the integrity of the machines.

S, Severity of injury scoring table	
Description of Injury	**Scoring**
No injury	**0.1**
Scratch or bruise	
Anything that requires first aid only	**0.5**
Laceration (tearing of the flesh)	
Startled	
Shock	
Minor cut, temporary scarring	**1**
Minor burn, temporary scarring	
Slight strain	
Skin allergy	
Medical recordable	**2**
Major cut, minor scarring	
Injury to face	
Break of minor bone (fingers, thumb and toes) (Temporary)	
Minor strain	
Severe cut, major scarring	**4**
Injury to eyes (temporary blindness)	
Break of major bone (arms and legs, pelvis) (Temporary)	
Lower back injury	
De-hydration	
Major strain	
Minor musculoskeletal disorder (reversible disorder)	
Major musculoskeletal disorder (Minor irreversible disorder)	**5**
Internal bleeding	**6**
Burns causing permanent scarring	
Dislocation of the shoulder, hip, knee or spine.	
Anything that requires resuscitation	**8**
Loss of one limb, eye, hearing (permanent)	
Loss of consciousness (not prolonged)	
Severe musculoskeletal disorder (Major irreversible disorder)	
Loss of two limbs, eyes (permanent)	**10**
Paraplegia (paralysis of the lower half of the body, from waist down)	
Prolonged unconsciousness (coma)	**12**
Quadriplegia (paralysis of all 4 limbs, from neck down)	
Fatality	**15**

Table 20. Scoring table for Table 13. S - Severity of injury.

P, Number of Person/s exposed to the hazard scoring table	
Number of person/s	**Scoring**
1-2	**1**
3-7	**2**
8-15	**4**
16-50	**6**
50+	**10**

Table 21. *Scoring table for P - No of person/s exposed to the hazard.*

Exposure risk scoring was developed after experimentation on the combination of the 2 factors – frequency and duration. Frequency of exposure is a factor in its own right and is based on a single work shift of 8 hours. Duration of exposure is an additional factor to Frequency of exposure when machinery is running for more than 8 hours.

E1, Frequency of exposure scoring table	
Frequency	**Scoring**
Once a month	**0.1**
Once a week	**0.5**
Once a day (8 hours)	**1**
Once an hour	**2**
Once every 15 minutes	**3**
Once every minutes	**4**
More than once every minutes	**6**
Several times a minutes	**8**

Table 22. Scoring table for Table 14. E1 - Frequency of exposure.

E2, Duration of exposure scoring table	
Duration	**Scoring**
8 hours (single shift system)	**1**
16 hours (Double shifts system)	**2**
24 hours (3 or more shifts system)	**3**

Table 23. Scoring table for Table 15. E2 - Duration of exposure
Note. If frequency of exposure = once a month or once a week - give duration of exposure score of 1.

L, Likelihood of injury scoring table	
Likelihood	**Scoring**
Almost impossible – possible only under extreme circumstances	**0.033**
Highly unlikely – though conceivable	**1**
Unlikely – but could occur	**1.5**
Possible – but unusual	**2**
Even Chance – could happen	**5**
Probable – not surprising	**8**
Likely – only to be expected	**10**
Certain – no doubt	**15**

Table 24. Scoring table for Table 16. L - Likelihood of Injury (probability of occurring).

C1, Prevention Measures scoring table (part 1)				**Scoring**
Where access to the danger zone is not required during normal operation	Fixed enclosing guard (fully enclosed)			**0.5**
	Fixed distance guard (fully surrounded)			**0.5**
	Interlocking guard			**0.5**
	Trip device	Sensitive screen or barrier – mechanical trip devices		**2**
		Electro-sensitive protective device i.e. light curtain, light beam		
		Pressure sensitive mat or floor		
Note. For fixed enclosing and distance guards – how much area is protected? – 100%, 75%, 50%, 25% or none at all			100%	**0.5**
			75%	**4**
			50%	**6**
			25%	**8**
			None	**10**
Where access to the danger zone is required during normal operation	Interlocking guard			**1**
	Push-away guard			**1**
	Trip device	Sensitive screen or barrier – mechanical trip devices		**2**
		Electro-sensitive protective device i.e. light curtain, light beam		
		Pressure sensitive mat or floor		
	Adjustable guard			**2**
	Self-adjusting guard			**4**
	Two-hand control device			**4**
	Hold-to-run control (two hand to hold)			**2**
Emergency Stop actuation	Situated next to start button			**2**
	Situated less than an arm length of normal working position			**4**
	Situated beyond arm length of normal working position			**6**
	Non-designated button e.g. machine normal stop or 'off' button			**8**
Start control	Two-hand and hold-to-run control			**4**
	Two-hand and no hold-to-run control			**8**
	Single hand and hold-to-run control			**6**
	Single hand and no hold-to-run control			**10**
	Trip device to start independently.			**6**
	Trip device with single hand and no hold-to-run control			**4**
	Trip device with single hand with hold-to-run control			**2**
	Trip device with two-hand and no hold-to-run control			**4**
	Trip device with two-hand and hold-to-run control			**1**
Noise Control	Full enclosed guard	Total Noise elimination		**0.5**
		Partial noise elimination		**2**
	Partial cover guard			**4**

Continue next page

Table 25.a. Scoring table for Table 17. C1 - Prevention Measures.

C1, Prevention Measures scoring table (part 2)			**Scoring**
Fume Control	Maximum fume extraction (no fume inhalation)		**1**
	Head breathing equipment – air supplied from elsewhere		**2**
	Simple face mask		**4**
Seating comfort	Customised ergonomic chair		**2**
	Fully adjustable ergonomic chair		**2**
	Chair with height adjustment		**4**
	Chair with no adjustments at all		**6**
Engineering controls	Partial mechanical support – semi automated		**2**
	Full mechanical support – fully automated		**0.5**
Administrative controls	Training to learn techniques to reduce stress and strain while performing task	Competent person – engineers, technicians, trainers.	**2**
		Fully trained (or newly trained under constant supervision)	**4**
		Newly trained (no supervision)	**8**
	Exposure limit to potential hazard	No more than 8 hours per day per person	**8**
		No more than 4 hours per day per person	**6**
		No more than 2 hours per day per person	**4**
		No more than 1 hour per day per person	**2**
		30 minutes a day limit only per person	**2**
		10 minutes a day limit only per person	**1**
		1 minute a day limit only per person	**1**
Personal Protection Equipment	Full body protection		**2**
	Partial body protection e.g. Leather apron		**4**
	Helmet		**2**
	Face screen		**2**
	Safety glasses		**4**
	Ear muffers		**4**
	Ear plugs		**4**
	Safety shoe		**2**
	Gloves		**4**

Table 25.b. Scoring table for Table 19. C1 - Prevention Measures.

Important Note for Table 25

Use the lowest prevention measures score for the protection of specific injury. E.g., injury to face or eyes – safety glasses or face screen.

Do not use prevention measures that are not related to specific injury just because the operator would wear safety shoes at all times as provided.

C2, Detection measures scoring table		
Detection by design/machinery control		**Scoring**
Absolute uncertainly that machinery controls will not and/or not detect potential hazard, or there is no design or machinery control.		**10**
Remote chance a design/machinery control will detect a potential hazard. Machinery control will provide indicator of imminent hazard.		**8**
Low chance a design/machinery control will detect a potential hazard. Machinery control will prevent an imminent hazard (e.g. stop machine)		**6**
Moderately chance a design/machinery will detect a potential hazard. Machinery control will prevent an imminent hazard and will isolate the cause. Machinery control may be required.		**4**
High chance a design/machinery control will detect a potential hazard. Machinery control will prevent an imminent hazard and will isolate the cause. Machinery control may be required.		**2**
Very high chance a design control will detect a potential hazard. Machinery control NOT necessary.		**1**
Almost certain that a design control will detect a potential hazard. Machinery control NOT necessary.		**0.5**
Detection by Administrative controls		
Training to recognise ergonomics risk factors	Competent person – trainer	**2**
	Fully trained person	**4**
	Newly trained person	**8**
	Unskilled	**10**
Process awareness	By Information (training or/and machinery manuals)	**6**
	By observation (ability to see a possible potential hazard)	**4**
	By warning signs and indicating lights	**2**
Detection by avoiding or limiting harm		
Impossible human reflexes to avoid or limit harm		**10**
Possible (under certain circumstance) human reflexes to limit harm		**8**
Possible human reflexes to limit harm		**6**
Possible human reflexes to avoid harm		**4**
Sudden appearance of hazard		**10**
Fast appearance of hazard		**8**
Slow appearance of hazard		**4**

Table 26. Scoring table for table 19. C2, Detection Measures. Scoring for countermeasures was developed by the author to create a balance and effectiveness of measures to reduce the risk levels.

Important Note for Table 26.

Use the lowest score of the detection measures for the specific injury.
E.g. "Process awareness by information" – a specific potential hazard is mentioned in the machinery manual or part of training.

4.5 CONCLUDING COMMENT

RIMAN is a live document, even after the design and build of the machinery. It must be constantly updated when there is a design modification or a change in the environment in which the machine is situated.

Initially it can be a protracted iterative process to achieve low risk machinery at minimal or optimum cost to a business. However, once the safety team have worked through a couple of designs, it should become easier and quicker to evaluate RIMAN as the collection of data becomes more readily available. British Standards and regulations when applied, newly expanding administrative and engineering controls when in place all assist to keep the risks to minimum. Checklists will develop and databanks will grow using risk scoring which will match similar identifiable hazards leading to shorter corrective action times.

The next few chapters will demonstrate how RIMAN has been used by evaluating a re-designed operator-centric assembly machine that is that was designed and built, in-house at H. R. Adcock Ltd. The next chapter will introduce Adcock's latest production cell of several operator-centric machines. One of the assembly machines will then be evaluated.

CHAPTER 5 H. R. ADCOCK LIMITED

The objective of this chapter is:

- To present information about the company and to provide an understanding of its approach to the design and development operator-centric assembly stations.

5.1 Introduction

H. R. Adcock Limited is currently a seat mechanisms manufacturer for the automotive industry and has a couple of production lines which feature a range of assembly stations from manual to fully automatic. Many of them were designed and built "in-house".

5.2 Background

Adcocks was established in 1956 as a manufacturer of precision turned parts, primarily for the automotive industry. Since 1990 the company has been designing and manufacturing seat adjuster mechanisms and drive spindles.

In the past, Adcocks has also supplied parts for other industries, such as mining, and has diversified many times to survive. Over the last 10 years there has been an expansion within the company, producing thread-rolled spindles. For the first time, during the last 5 years, it has introduced its own manufactured product – a seat height adjuster (SHA) for fitting into the driver seat of Ford Focus – and this has been its main focus of production. Adcocks had previously assembled parts in low volumes, using simple manual operations. With the introduction of the new SHA product, several stages of assembly operation were required to achieve the production volume of over 25,000 units per week.

The company uses in-house designed and built assembly machinery. This has been achieved as the outcome of a Process Failure Mode and Effects Analysis (FMEA) and Risk Assessment, conducted by a dedicated project team.

Adcocks' key aspects of design for maximum quality and productivity included:

- Inbuilt mistake proofing (poka yoke)
- Quality assured product
- Ease and efficiency of maintenance
- Safe system of work

5.3 Seat Height Adjuster (SHA) Mechanism

The SHA (see figures 7 to 11) consists of 16 parts, excluding the grease:

1. Spindle with thrust washer 'shoulder rolled' onto spindle
2. Bobbin
3. Drive Nut
4. Die cast body half
5. Die cast body half
6. Tube
7. Heat Shrink Sleeve
8. Thrust washer
9. Thrust Washer
10. Thrust Washer
11. Ball Race assembly (Each assembly consists 12 ball bearing in a cage)
12. Ball Race assembly (Each assembly consists 12 ball bearing in a cage)
13. Ferrule
14. Trunnion
15. Diaphragm
16. Spring

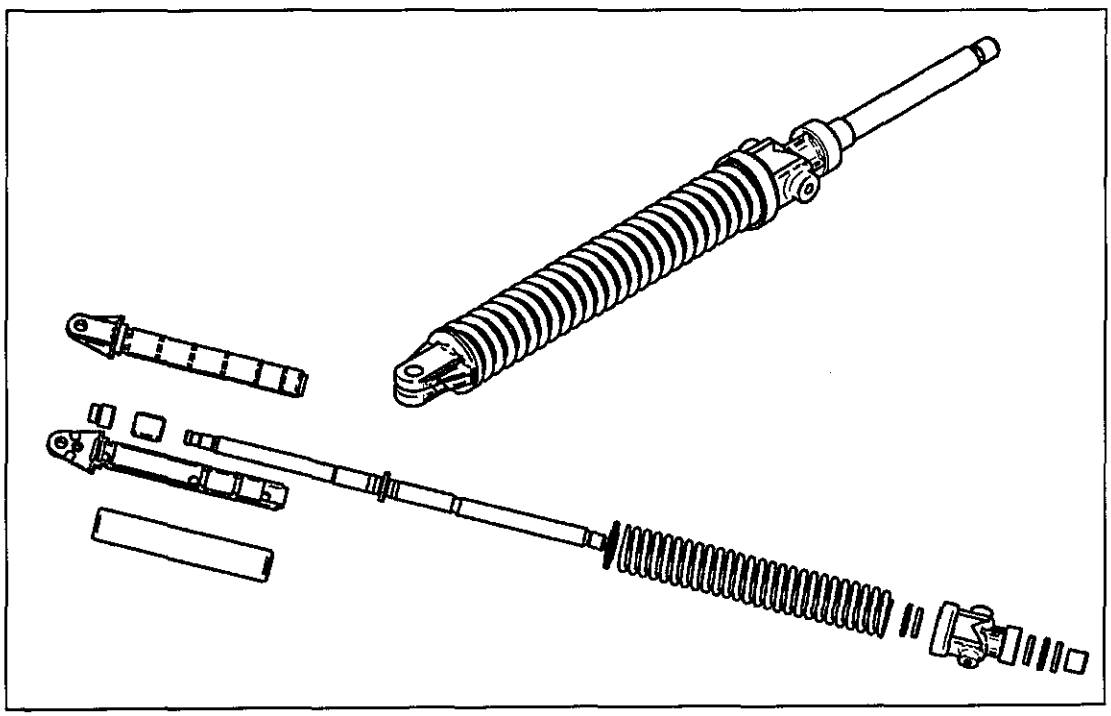


Figure 7. Exploded view of seat height adjuster (Heat shrink Sleeve not included)

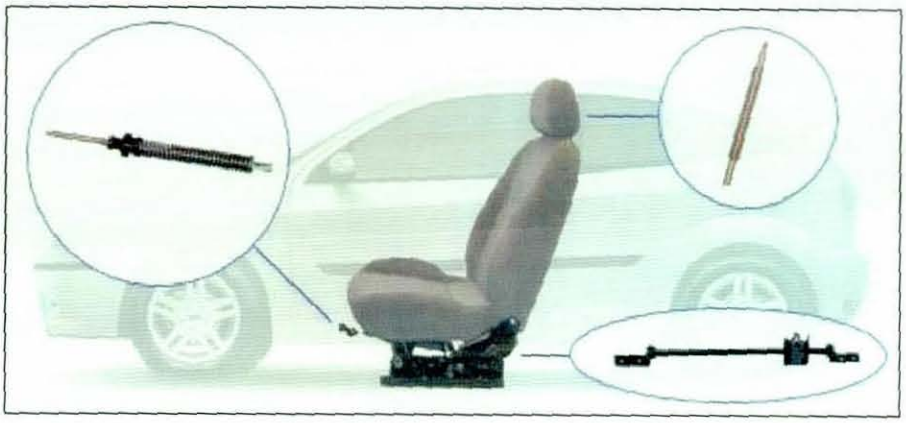


Figure 8. Photo of automotive seat mechanisms in the seat of a car. The left bubble shows the seat height adjuster.

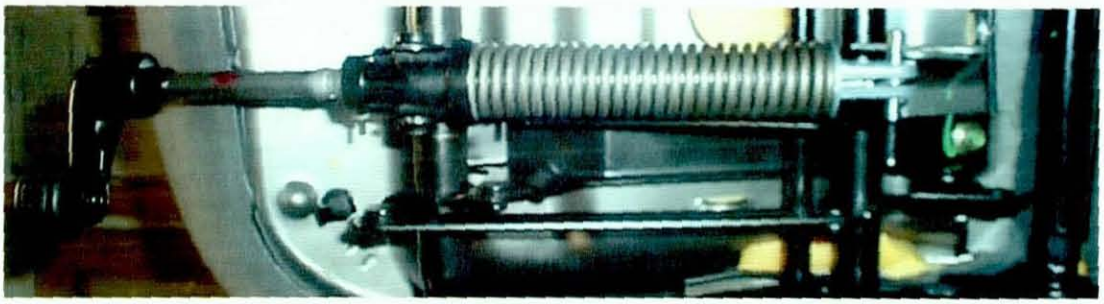


Figure 9. The seat height adjuster mechanism under the seat.

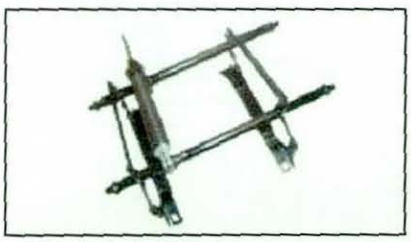


Figure 10. The base seat mechanism with seat height adjuster attached.

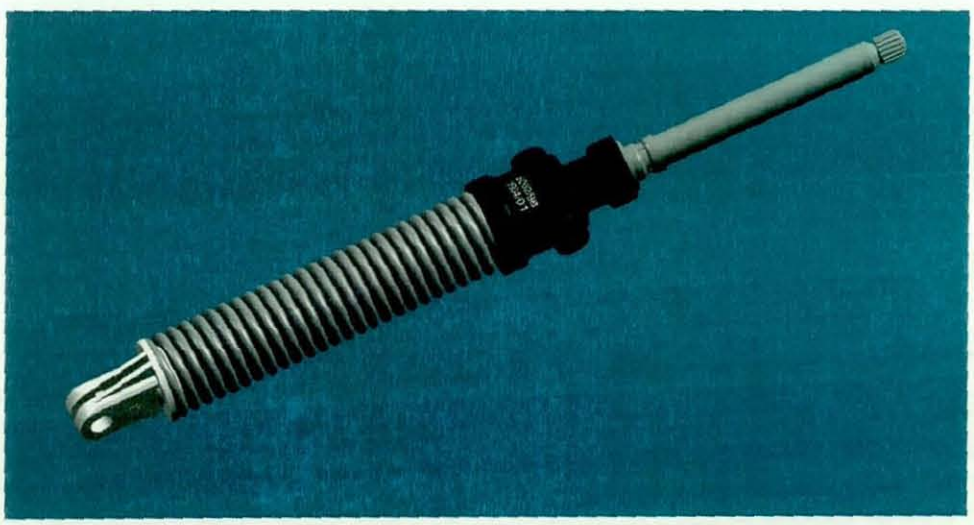


Figure 11. 3D render of seat height adjuster

5.4 Assembly History

Volume was low at the start of production increasing in stages to the current high volumes. The company began with full manual assembly operations before mechanically assisted operations were required.

Several stages were involved in the manual assembly sequence for the seat height adjuster as follows:

1. Hand-screw the nut on the spindle.
2. Crimp the bobbin onto the spindle. (Crimping devices were manufactured first to allow to crimp at the start of the production stage)
3. Apply grease on the spindle with a brush.
4. Place two die-cast body halves over the spindle and slide the tube on.
5. Hammer the tube onto the body halves until fully sheathed
6. Roll the tube in the rolling machine (modified existing process)
7. Mount the sub-assembly into a block with the yoke end at the bottom.
8. Assemble in order from the top over the spindle
    a. 1x Spring
    b. 1x Ball race bearing
    c. 1x Washer
    d. 1x Trunnion (manually greased)
    e. 1x Washer
    f. 1x Ball race bearing
    g. 1x Washer
    h. 1x Ferrule
9. Place the full assembly into a cylindrical tube and clamp spring
10. Wind the threaded rod at the back of the cylindrical tube to compress the spring
11. Place the assembly over a specially designed clamp and squeeze the ferrule into the groove of the spindle
12. Pack for distribution.

5.5 Assembly Machines

In the next phase new assembly stations began to replace manually intensive operations. Some assembly stations performed the task of two stages of manual operations.

- Operations 1 and 2 became Assembly 01
- Operations 3-5 became Assembly 02
- Operation 6 became Assembly 03
- A new component – plastic sleeve was later incorporated to eliminate metal contact vibration between the tube and spring during vehicle movement. Heat shrinkage in an oven – this became Assembly 04 with springs being added on after the oven process
- Operation 8 became Assembly 05
- Operations 9-11 became Assembly 06
- Assembly 07 was later added to drive the unit to a fully compressed position suitable for delivery
- Assembly 08 – Ink laser marking process for traceability of the part
- An independent process producing ball race bearings – quantity of 2 ball race bearings per unit. 12 balls per cage.

5.5.1. Assembly 01 – Nut and bobbin crimp operation

Components – Spindle, drive nut and bobbin

Task sequence

1. Drive nut onto spindle.
2. Place bobbin on end of spindle
3. Crimp bobbin to secure drive nut using a hydraulic-driven actuator.

5.5.2. Assembly 02 – Force fit tube assembly

Components – Sub assembly from assembly 01 station, 2 of zinc die cast body halves, fixed amount of grease and a tube. See figure 12.

Task sequence:

1. Place 1st die cast body half onto a holder
2. Apply fixed amount of grease onto 2 areas
3. Assemble sub-assembly and place 2nd body half on top
4. Place tube onto a mandrel
5. Activate machine after closing guard door
6. Machine force fit the tube over the body halves together
7. Open guard door and transfer assembled unit to a motorised device that drives the unit to maximum stroke.

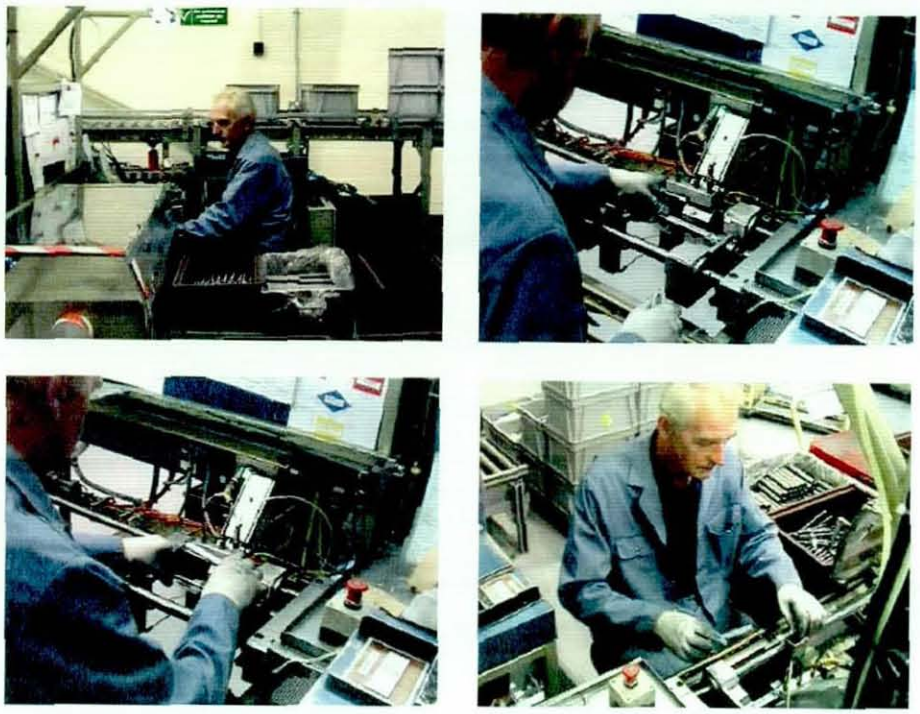


Figure 12. Assembly 02 station in action.

5.5.3. Assembly 03 – Tube Roll

Components – Sub assembly from assembly 02 station. See Figure 13 of Assembly 03 in action.

Task sequence:

1. Place sub-assembly between two pairs of driven rollers
2. Activate machine to plunge rolls against sub-assembly to 'roll' ends of tube over the body halves, thus securing the drive spindle with nut inside the body.

Figure 13. The operator placing unrolled sub-assembly into rolling process, at the same time removing previous rolled sub-assembly to his left.

5.5.4. Assembly 04 – Oven

Components – Sub assembly from assembly 03 station, a heat shrink sleeve and a spring. See figure 14.

Task sequence:

1. Place heat shrink sleeve over the rolled tube section of the sub assembly
2. Place the unit onto a rack
3. When there are 15 sub-assemblies with their heat shrink sleeves in position, the rack is automatically inserted into a controlled temperature oven for a set time to shrink the sleeves onto the rolled tubes and the rack is then automatically transferred onto the cooling stage of the oven.
4. When the tray has cooled the rack is transferred into the open
5. A spring is then located over the sub-assembly with the heat shrunk sleeve.

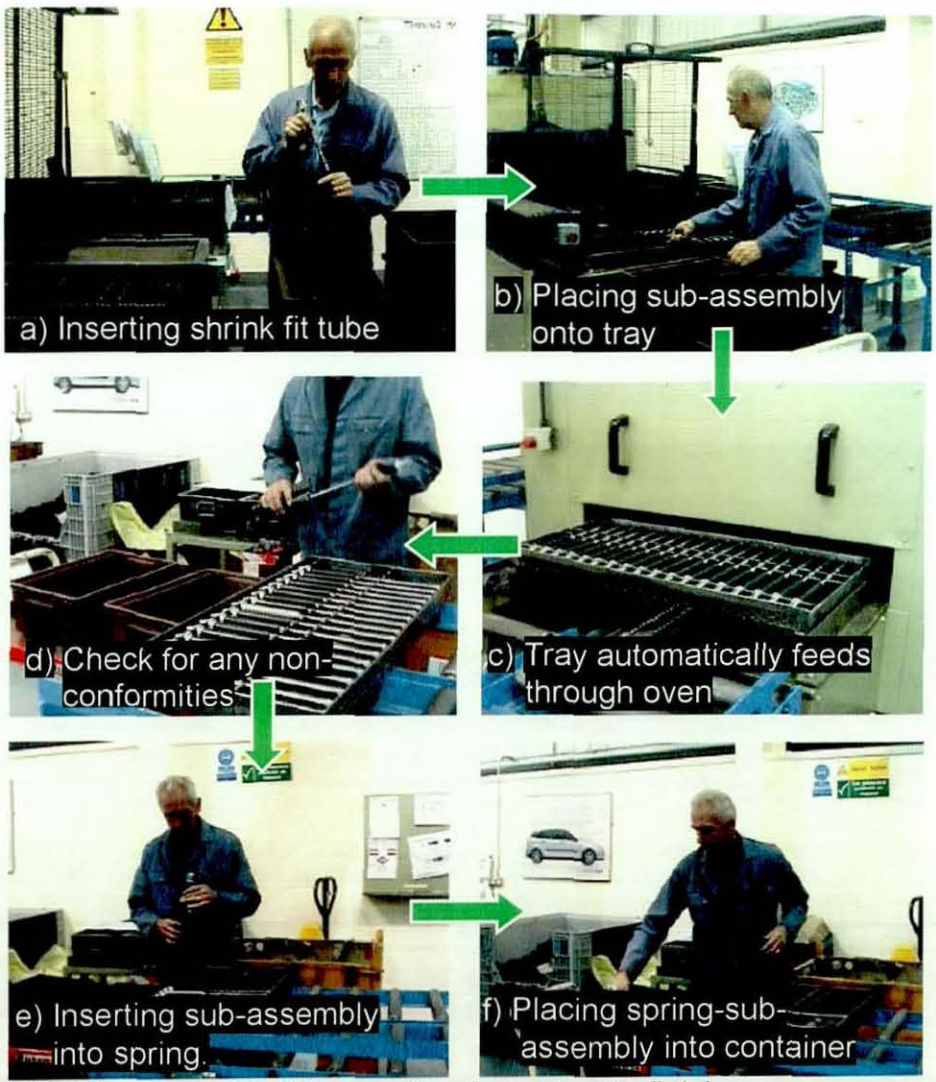


Figure 14. The assembly 04 operation from start to finish.

5.5.5. Assembly 05 – Complete component assembly

Components – Sub assembly from assembly 04 station, 3 steel washers, 2 ball bearings, an amount of grease, a trunnion and a ferrule. See figures 15 and 16.

Task sequence:

1. Sub-assembly placed into a holder
2. Pick and place all the components from Linbins into jig
3. Activate operation with two-start buttons – a lid carrying sensors clamps onto the components to check that all components are present
4. If OK, ram sub-assembly into jig through all holes of components.
5. A black cap is then fitted to prevent components' escape between operations 05 and 06.

Figure 15. *Original Assembly 05 station before replaced with an improved design as shown in next photographs below*

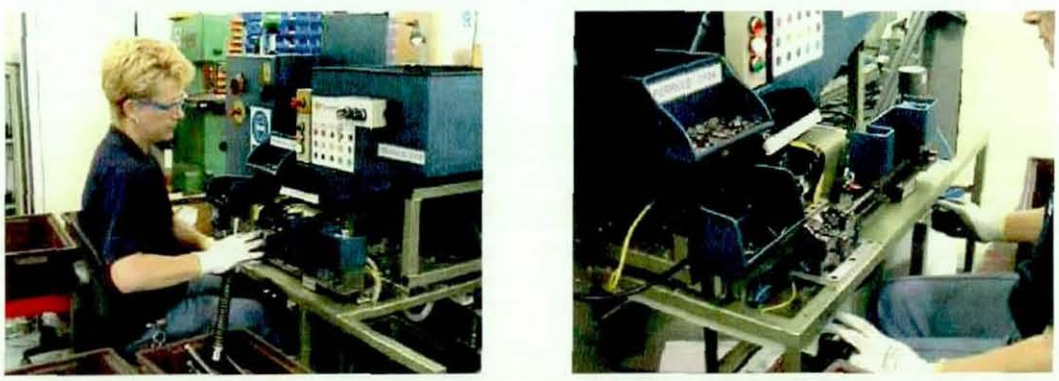


Figure 16. New assembly 05 station – Better design and double rate capacity.

5.5.6. Assembly 06 – Ferrule crimp and diaphragm

Components – Sub assembly from assembly 05 station and a diaphragm. See figure 17.

Task sequence:

1. Pick and place sub-assembly into a holder
2. Activate machine to compress spring
3. Push all the close components on spindle against a shouldered washer of the spindle
4. Activate machine again to crimp the ferrule into the groove of the spindle for secure fit
5. Insert diaphragm between the compressed spring and trunnion assembly
6. Activate machine to uncompress spring into pre-load compression.
7. Pull out complete unit.

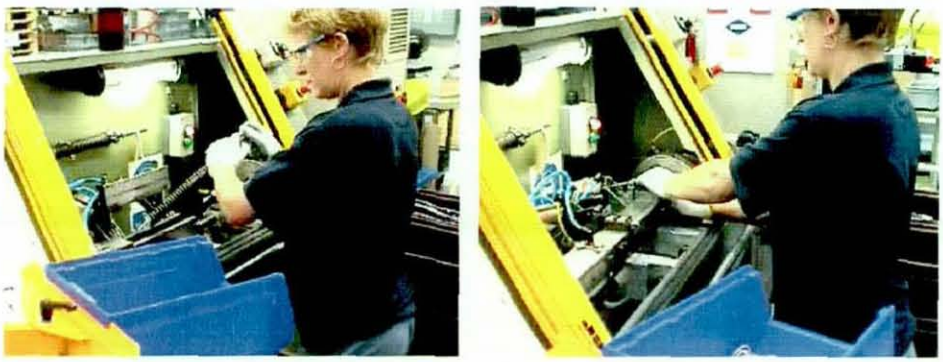


Figure 17. Assembly 06 station in action.

5.5.7. Assembly 07 - Wind-in operation

Components – Sub assembly from assembly 06 station.

Task sequence:

1. Load unit onto a holder
2. Activate the machine to drive the spindle to its shortest length by compressing the spring to its maximum
3. Pull unit out of holder.

5.5.8. Assembly 08 – ID marking operation

Components – Finished product to be marked

Task sequence:

1. Load unit onto a conveyor track into a marking box
2. ID mark using ink jet marker
3. Drop out onto tray prior to packing.

5.5.9. Ball Race Assembly

There was another assembly process involved which placed 12 ball bearings into a cage to complete a ball race bearing. This process was originally executed using a vacuum generator and a pneumatic punch. An operator carried a ladle with a simple cylindrical piece at one end to 'vacuum' hold the cage. The operator then picked up 12 balls under vacuum 1nto the cage with 12 holes. The balls were stored in a small container. The cylindrical piece was placed under a pneumatic punch which punched the cage and 12 balls together. It was a very physical operation and operators had to take their turns for a limited amount of time to reduce the risk of aching arms. This level of production required 2 full shifts to maintain the volume. The process was producing a cage every 30 seconds and the ideal cycle time was under 17 seconds (for the full volume of 25,000 units a week).

Figure 18. Ball Race automatic process, showing bowl feeder and rotary indexer

A new fully automatic machine (see figure 18) was then designed and developed with a target cycle time of under 10 seconds per ball race cage, Ultimately it achieved 2.5 seconds per cage.

A vibrating bowl feeder was used to feed cages into a chute dropping into a 4-station indexer complete with holders set equidistantly at 90 ^{o} in relation to each other. The sequence of manufacture is as follows:

- Station one places a cage into the first holder on a rotary disc.

- When the cage is in the second position it collects 12 balls from a specially designed mechanism. These balls are held in a hopper above the mechanism.
- At the third position the balls are punched into the cage by a pneumatic cylinder.
- The fourth position acts as a checking mechanism to ensure that exactly 12 balls are present in the cage.
- As the rotary disc moves between the fourth and first position, there is an ejection point where the assembled cages are pneumatically ejected into a container below.

This proved to be a successful process as it was fully automated.

However, where a manual system allowed for imperfect components manufactured to a wide tolerance, it was found that implementing a fully automated process demanded that the parts be manufactured to high specification.

The company found that designing an automated process demanded a degree of forethought at the beginning of product development, when parts must be designed for ease of automatic assembly. For example, injection-moulded plastic parts must be clear of any burr and have design features to allow easy orientation by the process.

The original plastic ball race cage was circular in design. However, It was redesigned for the automatic process to allow exact orientation to fit in with the 4 station indexer. Figure 19 compares the 2 ball race cages and it is self-evident how they are used.

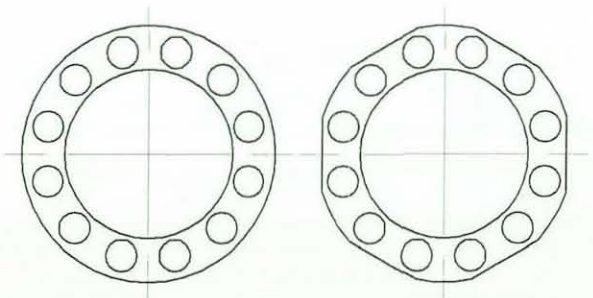


Figure 19. Ball race cages – original design (left side) and re-designed (right side)

5.6 CONCLUDING COMMENT

The complete component assembly as described above was chosen as a useful case study through which RIMAN could be evaluated as an effective risk assessment tool. Additionally, as the author was actively involved in the

redesign and build of a new, improved assembly station, detailed analysis was possible.

The next chapter will describe the process in detail, showing the event sequence contained within the original design and risks which have been identified as unacceptable. Following on, an account of the re-design project from conceptual design to complete build will be given. Finally, it will be explained how RIMAN evaluation was used to identify new hazards and their associated risks.

CHAPTER 6 CASE STUDY - ASSEMBLY 05 STATION

The objectives of this chapter are:

- To show the redesign and commissioning of assembly 05 station
- To demonstrate the application of RIMAN to the redesigned assembly station

6.1 Introduction

The function of the assembly station is to collate and assemble components into a sub-assembly and ensure the complete assembled product is ready for the next operation. Figure 20 shows an exploded drawing of components assembled in the order that they will be assembled onto a spindle shaft.

Components:

1 Sub-assembly (Spindle in sleeved tube and coiled spring),

2 Ball Race assemblies.

3 Thrust Washers,

1 Ferrule,

1 Trunnion

A quantity of grease.

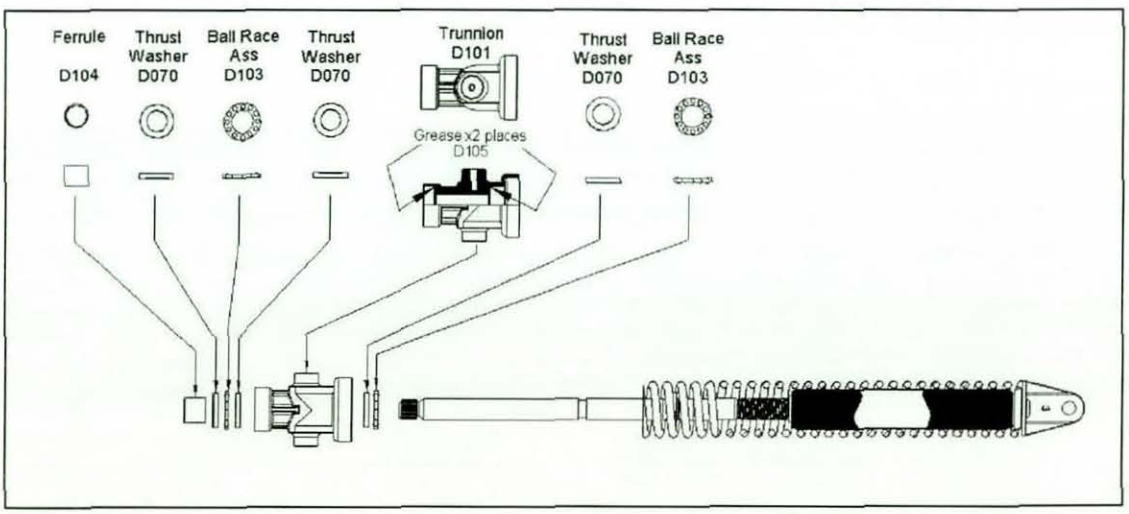


Figure 20. Drawing of components assembled in the correct order onto the spindle shaft for Assembly 05 station.

6.2 Sequence of events for original sub-assembly station

1. Operator picks up the sub-assembly from container on right-hand side and places it onto two guide rods.
   Ergonomic analysis: Slight twisting to the right and behind the body, then lifting sub-assembly from container onto guide rods. See figure 21.

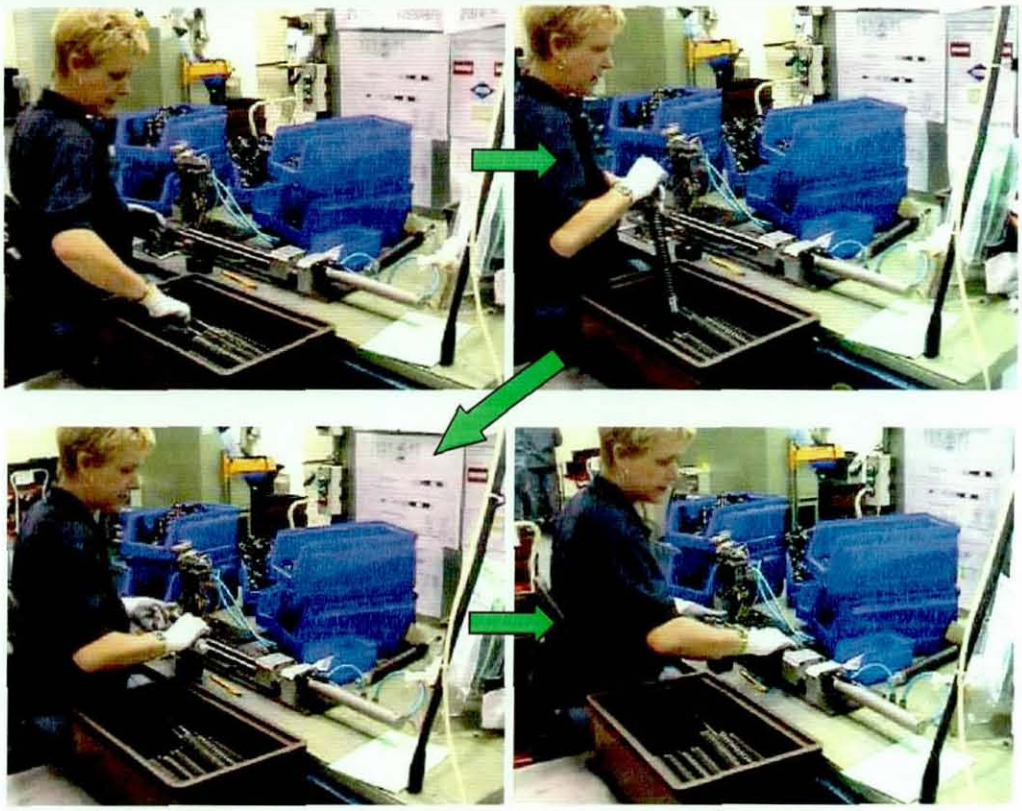


Figure 21. Step 1 of original sequence

2. With both hands the operator picks three washers and two bearings from their Linbins.
   Ergonomic analysis: Lower back leans forward, arms slightly stretched, with a slight twisting of trunk. See figure 22.

Figure 22. Step 2 of original sequence

3. Place washers and bearings in their designated slots in the jig.
   Ergonomic analysis: Pinching grip of washers and bearings creates a major discomfort to hand and fingers. See figure 23.

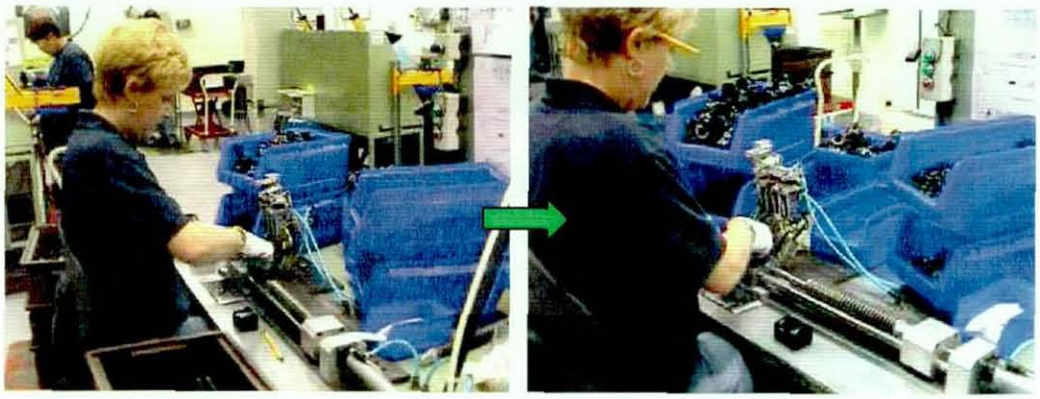


Figure 23. Step 3 of original sequence.

4. With right hand pick a ferrule from the Linbin and place it in the jig; *simultaneously, with the left hand, pick a trunnion and place it over the* grease dispenser.
   Hazard analysis: Ferrules have sharp edges – possible cut to hands. See figure 24.

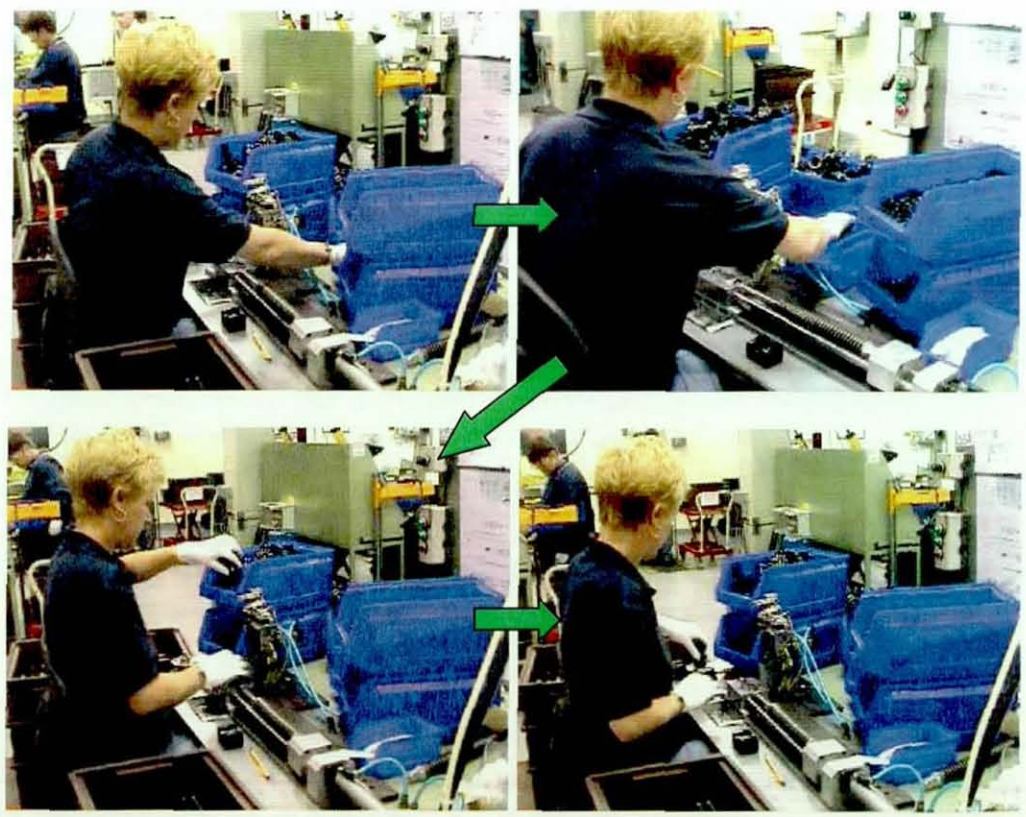


Figure 24. Step 4 of original sequence

5. Push down the trunnion to apply grease into its underside, then lift and rotate the trunnion 180° and apply grease again.

Ergonomic analysis: Major discomfort to the left wrist and hand due to the twisting action and static force application. See figure 25.

Figure 25. Step 5 of original sequence.

6. Place the greased trunnion in the jig. See figure 26.

Figure 26. Step 6 of original sequence

7. Pair of hands on buttons to start.
   Hazard analysis: The start button activates the machine and, simply, the position of the hands is ignored. See figure 27.

Figure 27. Step 7 of original sequence

8. A mechanism carrying sensors to each component for mistake proofing checks is lowered over the jig.
   Hazard analysis: Risk of hand being trapped under the lid. See figure 28.

Figure 28. Step 8 of original sequence

9. Once it has been confirmed that all components are present, the ram section pushes the sub-assembly into the jig and through the holes of the components.
   Hazard analysis: Risk of trapping the hand between the ram section and the sub-assembly. See figure 29.

Figure 29. Step 9 of original sequence

10. The operator picks up and places a black plastic cap on the end of the sub-assembly.

11. The machine lifts sensors away from jig and the operator collects the assembly and deposits it into the container on the left.
    Hazard analysis: There is a risk of the hand being in contact with the sensor mechanism and ram section when returning to its inactive position.

Ergonomic analysis: Lifting completed assembly into and slight twisting of lower back to the left with the shoulder and arms being behind the body when depositing the assembly into the container. S eel figure 30.

Figure 30. Step 11 of Original Sequence

6.3 Problems identified

1. PRODUCTION. Variation of cycle times from 10 to 25 seconds among operators.
2. ERGONOMICS. Twisting of hand and wrist causing a strain while greasing trunnion.
3. ERGONOMICS and PRODUCTION. Location of Linbins – arms slightly overstretched because of the position of the process jig at the front – worse when the Linbins are nearly empty requiring the operator to reach even further than before.
4. ERGONOMICS. Pinching action of fingers when collecting and inserting washers and bearings from Linbins into the jig. Three washers and two bearings for every assembly. Highly repetitive action.

5. QUALITY – Mistake proofing
    a. Poor reliability of sensors to distinguish between steel washers and plastic bearings.
    b. The difference between them is the material. Washers are made from steel and a non-contact proximity sensor works well but for plastic ball bearings an alternative form of sensing was required.
    c. Administrative control – Development of routine to pick the correct quantity of each component before inserting into the jig, thus minimising mistakes.

6. SAFETY - Risk of injury to operator. There was a danger of finger entrapment subsequent to operating the dual buttons to activate the machine cycle. This was identified as inflexibility in the programming of the machine.
7. SAFETY - When the lid mechanism carrying the array of sensors was activated it often failed. This was due to the lever contact sensors tending to slip sideways because of the thickness of the plastic bearings. Often they were caught under the ball bearing and when the mechanism was pulled back the lever sensors sprung back towards the operator's head. This startled the operator.

These problems were identified by observation and evaluated using Adcock's simple risk assessment analysis by trained personnel. See figure 31.

The shaded row in Figure 31 identified the hazard which scored the highest. A risk value (RR) of 20 and above indicates that urgent action is required. L (severity of injury) and C (likelihood of injury) are the two risk factors used in this simple assessment.

Production and Quality problems were identified from the experience of the operator working on the original assembly station. It was evident that the assembly station required radical improvement.

Risk Assessment

Location: D062/P05 | Assessor: D.Middleton J.Greasley | Date: 21.08.00

Ref. No.	Potential Hazard/Hazardous Event	Hazardous Event	Existing Controls	L	C	RR	Action CCAR
1	Working area	No significant hazerdous event	General housekeeping	2	1	2	
2	Seated working position unable to support back and unable to sit correctly at working height	Hip/back ache	Maximum time working on process 2-3 hours	3	4	12	
3	Picking parts up out of containers. On spring trolleys provided	Slight strain to arm,wrist,shoulder & slight twisting of body	Maximum time working on process 2-3 hours	4	4	16	
4	Placing of part into jig	Minor strain to arm,wrist & neck	Maximum time working on process 2-3 hours	3	3	9	
5	Picking up ball race cages and washers (over reaching)	Strain to shoulders Back wrist and thumbs	Maximum time working on process 2-3 hours	5	4	20	
6	No guards covering probe sensors	Stabbing to hands and wrist	Process awareness	5	2	10	
7	Unstable washer container (container of washers fall)	Bruising to hands	Process awareness	3	2	6	

Figure 31. Selection of H .R. Adcock Ltd's Risk Assessment analysis.

6.4 Redesign

Adcock's initial risk assessment process identified that the assembly station was unsafe. A decision was made to redesign the operation. A project team was set up where ideas were generated, concepts created and reviewed.

- The project team consisted of:
  - A process designer (with the author as team leader)
  - A production technician
  - Four assembly operators

- Conceptual ideas were generated and reviewed.
  - The following pictures show a variety of options.

Conceptual models

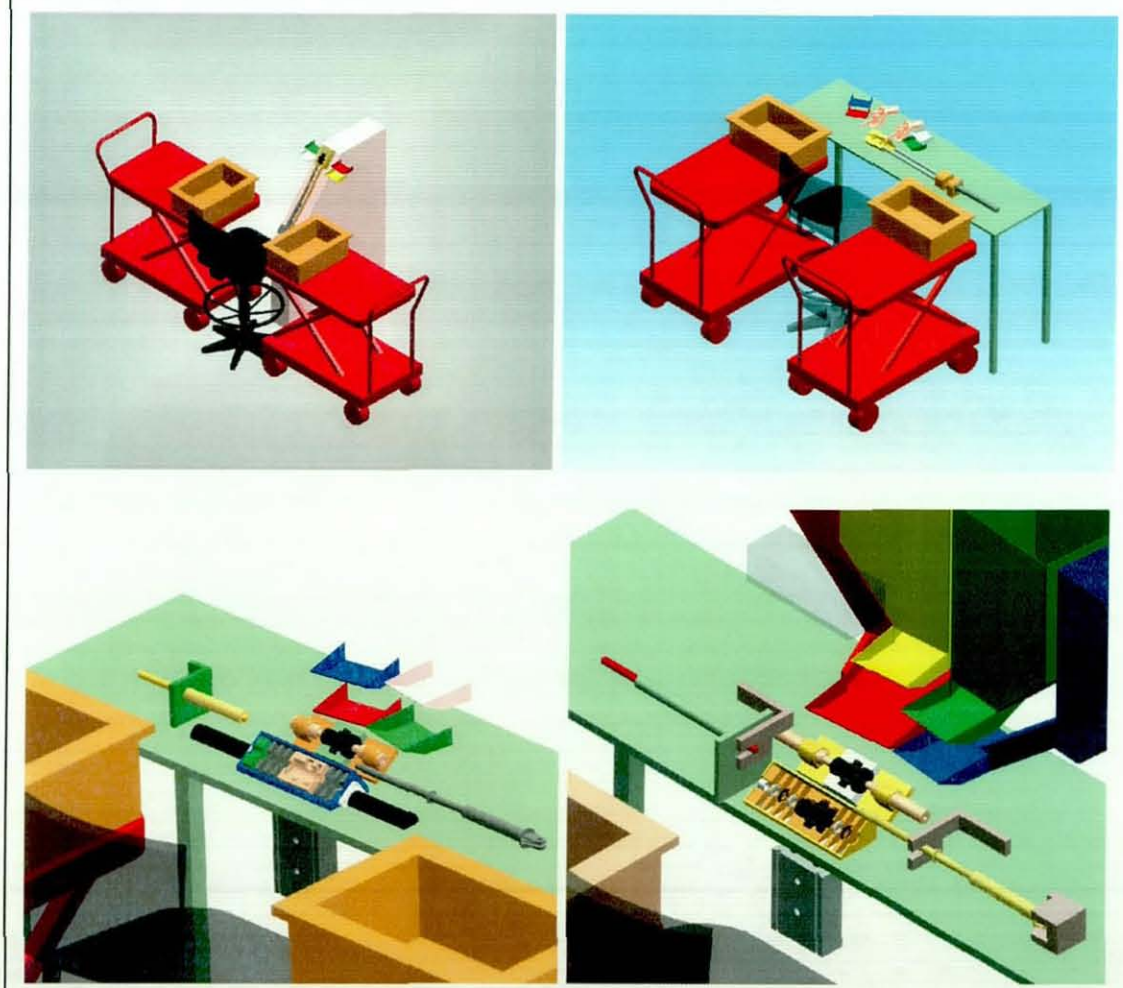


Figure 32. Conceptual designs of assembly 05 station

Finally, a new assembly machine was developed. The following figures 33-36 outline the arrangement.

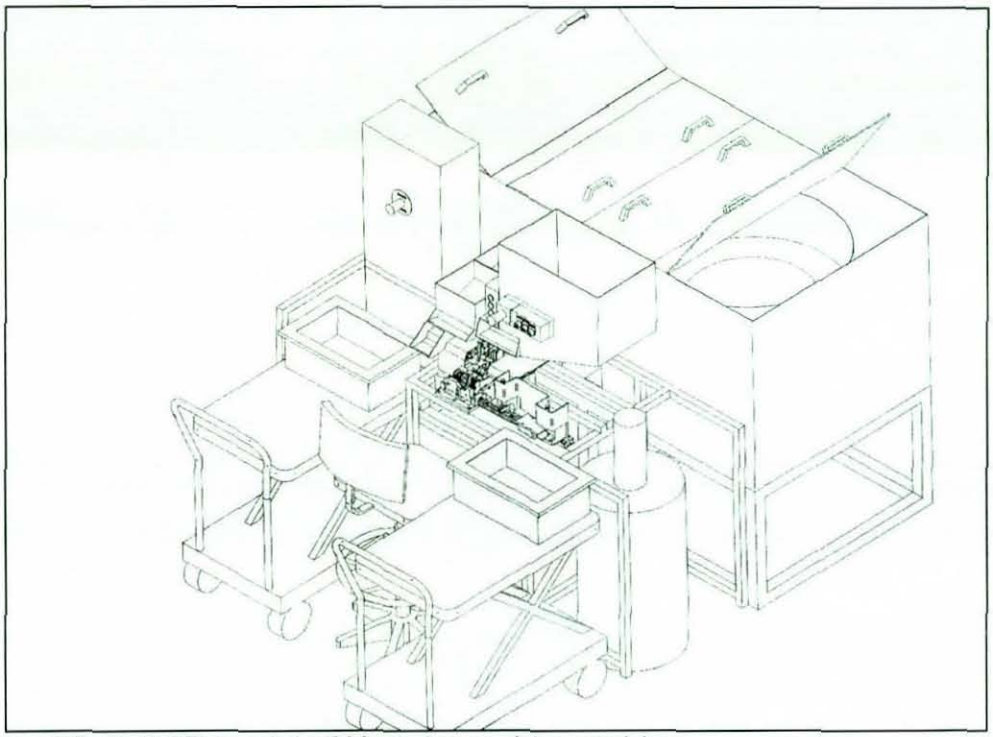


Figure 33. Full 3D model of New Assembly machine

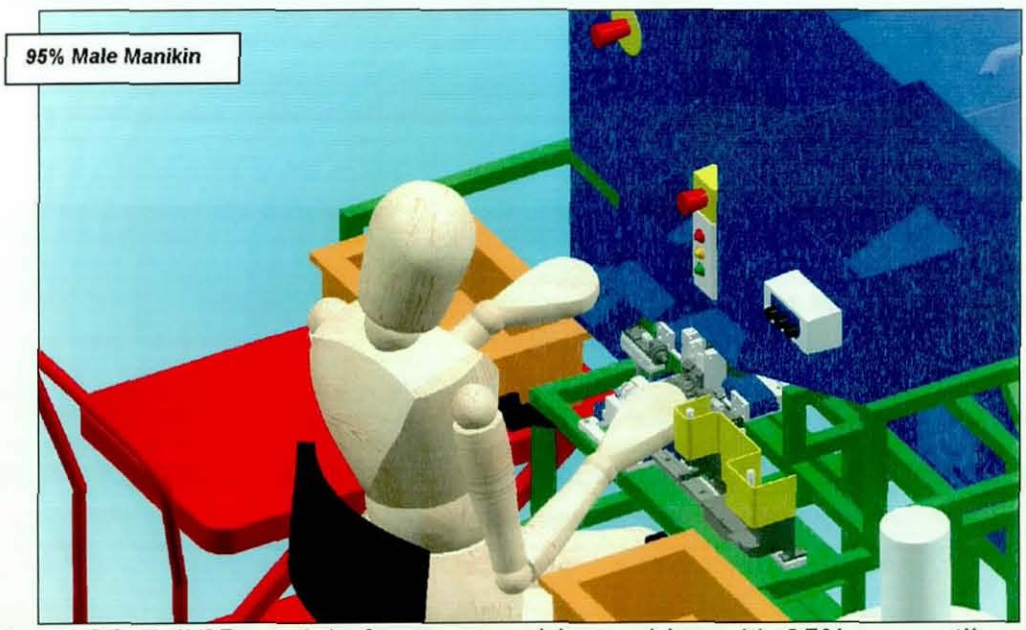


Figure 34. Full 3D model of new assembly machine with 95% percentile man

Key areas of redesigned assembly station:

- Use of bowl feeders to deliver washers and bearings to the assembly jig. This eliminates hand strain.
- Use of non-contact sensors to eliminate risk and avoid startling the operator during the operation.
- Incorporate automatic greasing operation to eliminate wrist strain.
- Sequence of events modified and reviewed.
- 100% mistake proofing in place.
- Reduce the cycle-time variation among operators by automating difficult tasks such as the picking and placing of washers and bearings.

Overlay techniques were used during the design stage to help other members of the team to visualise the machine in operation and its ergonomics. See figure 35.

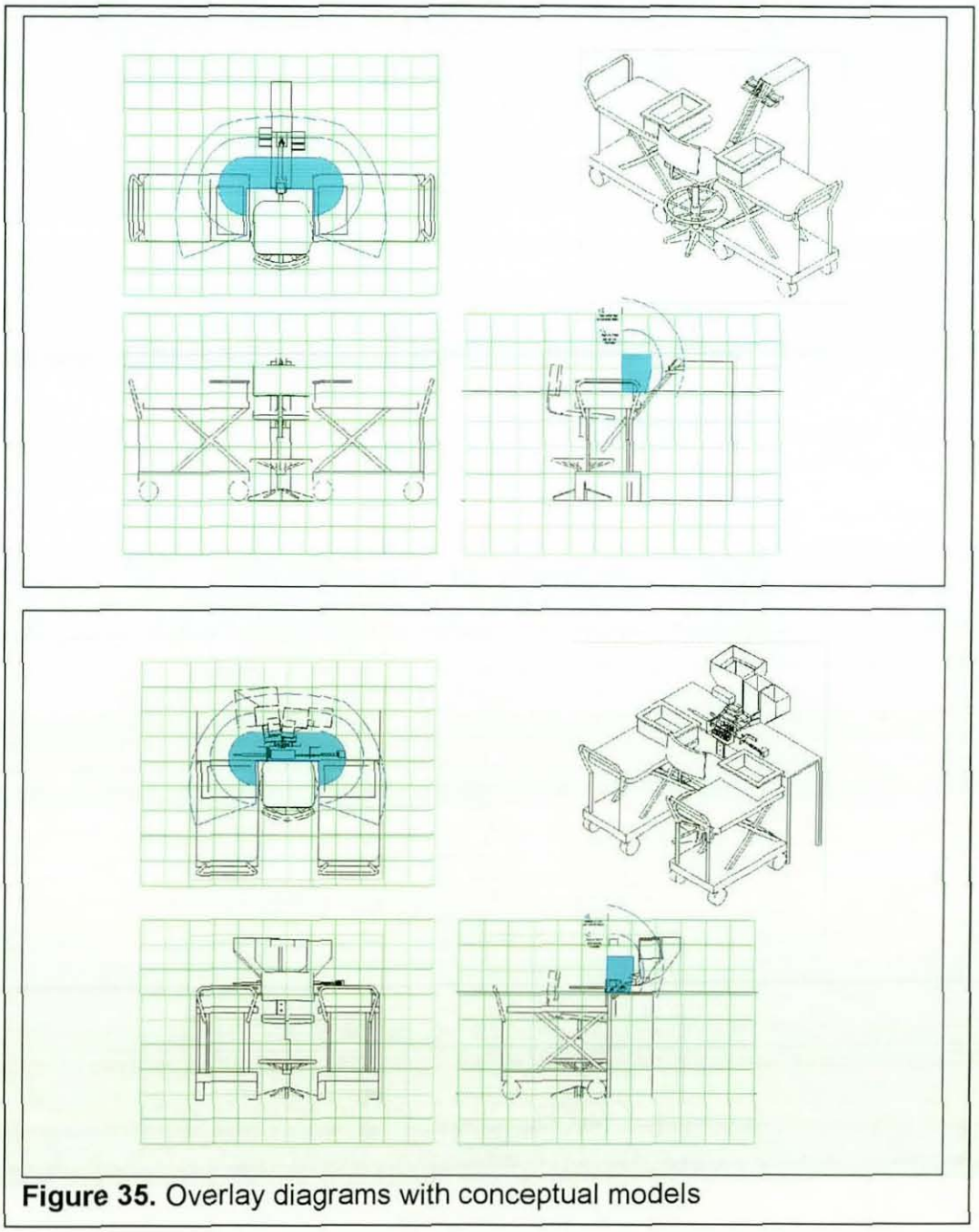


Figure 35. Overlay diagrams with conceptual models

Some of the examples in figure 35 show shaded areas highlighting comfort zones in high priority work areas. The overlays are copied grid by grid from book 'The Ergonomics of Workplaces and Machines' **[67]**.

The middle band shows the location of work and controls which are considered medium priority. The band furthest away from operator's seat shows the limits of maximum reach for locating work and controls and is deemed a low priority zone. The highest frequency and duration of operation, namely, high speed, large force or high accuracy is best in high priority zones, whilst the operation with the lowest frequency (short duration, low force, speed and accuracy) is recommended for low priority zones. Figure 36 shows the arrangement for the finalised design.

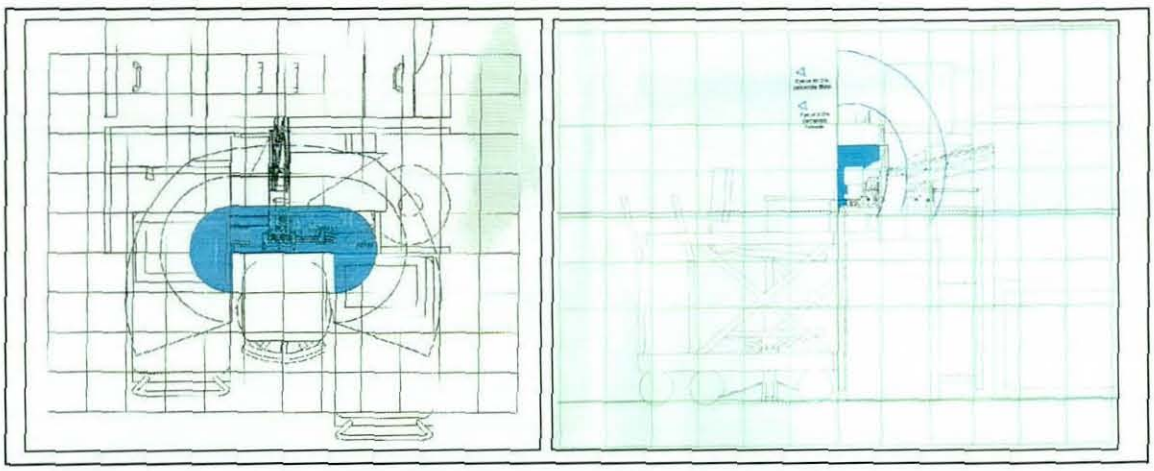


Figure 36. Overlay diagrams of final design.

At the time of this project, H. R. Adcock Ltd had few methods and techniques in place to aid the designer. However, the designer had access to 3D modelling and broke down the operations into their constituent parts. This assisted the designer to verify concepts and communicate ideas to the design team. Figures 37 and 38 show the various steps involved in an automatic greasing operation.

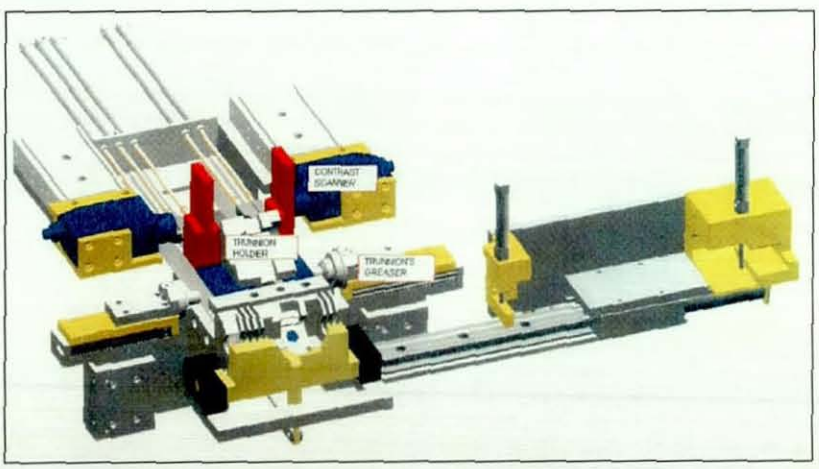
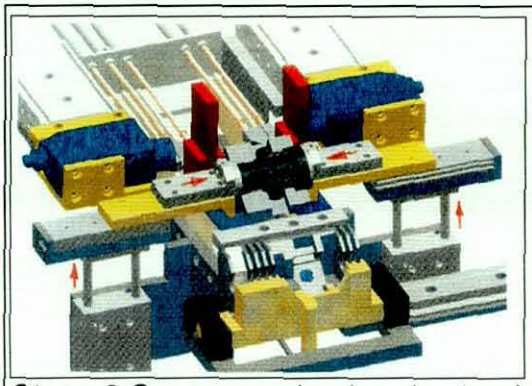
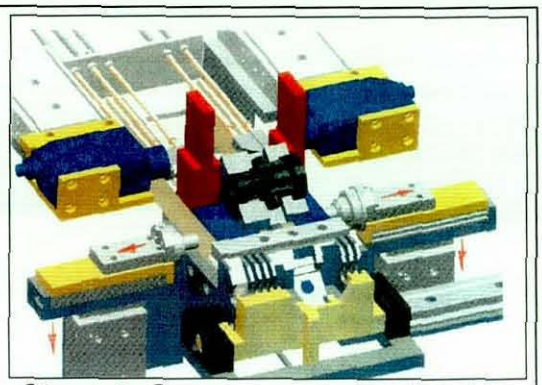


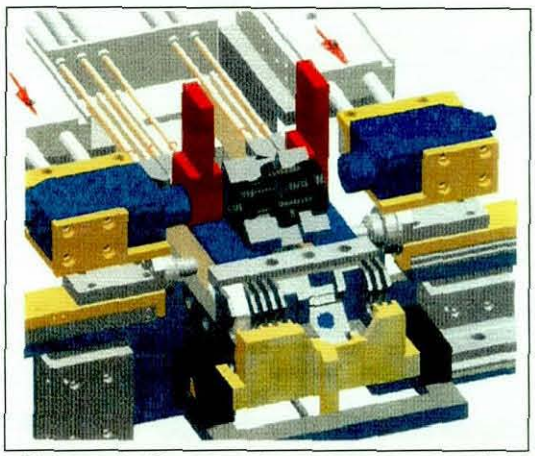
Figure 37. 1st stage of automatic greasing operation. Boxed texts show different devices used in this sequence.



Stage 2. Greasers raised and extended to apply grease into trunnion.



Stage 3. Greasers retracted and lowered.



Stage 4. Contrast scanner extended and verifies grease in trunnion.

Figure 38. Remaining stages of automatic greasing operation.

Using the appropriate drawings all the parts were manufactured in the company's tool-room and were assembled by the designer. The author also wired the control cabinet, installed pneumatic piping and assembled all the components to the point where functional part of the assembly station was complete. Programmable logic control software was then input into the system and, after several debugging stages, the mechanisms were deemed safe by the team. Mock-ups of gravity bins were made out of cardboard and mounted onto the machine. The assembly station was tested with real components and the sequence of the process was fully run. Further program modifications to the software were required and configurations of size, the positioning of outlet vents and volume requirements were constantly modified to satisfy the rest of the team. Figures 39 and 40 show the bare assembly workstation before adding the bins and control switches and lights.

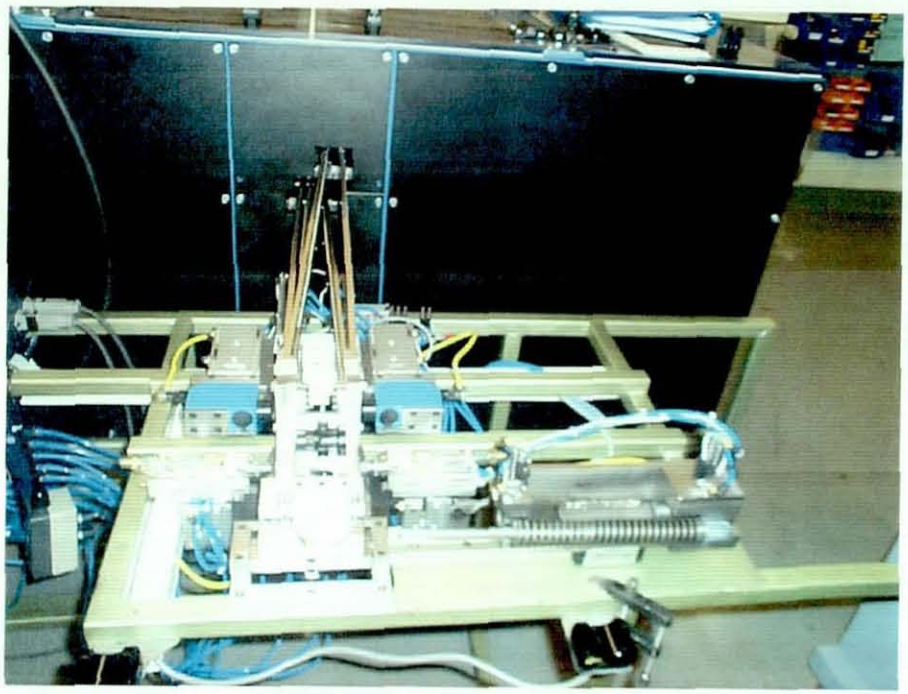


Figure 39. Bare assembly station before the installation of gravity bins.

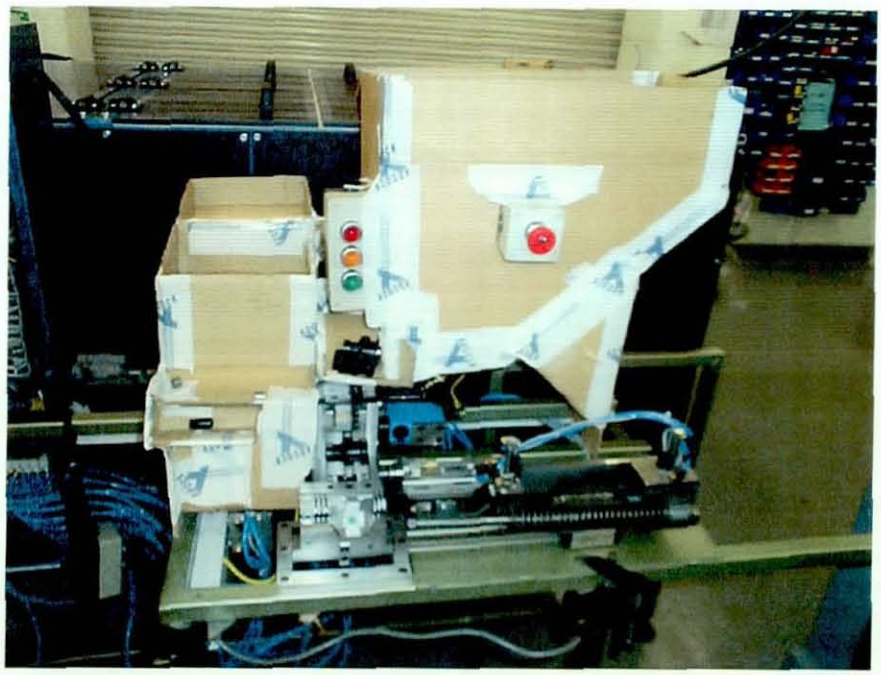


Figure 40. Mock-up gravity bins in use. Note the locations of the emergency stop button and the control lights box.

Once all the members were happy with the layout of the mock-up gravity bins for the larger components (trunnions, ferrules and plastic black caps), new gravity bins were manufactured out of steel sheet. Risk assessment was delayed until the assembly station was commissioned on the shop-floor area.

6.5 New Sequence of Events

1. With right hand the operator picks up 'greased' trunnion from upper 'greasing' jig and places it on the lower 'main' jig. See figure 41.

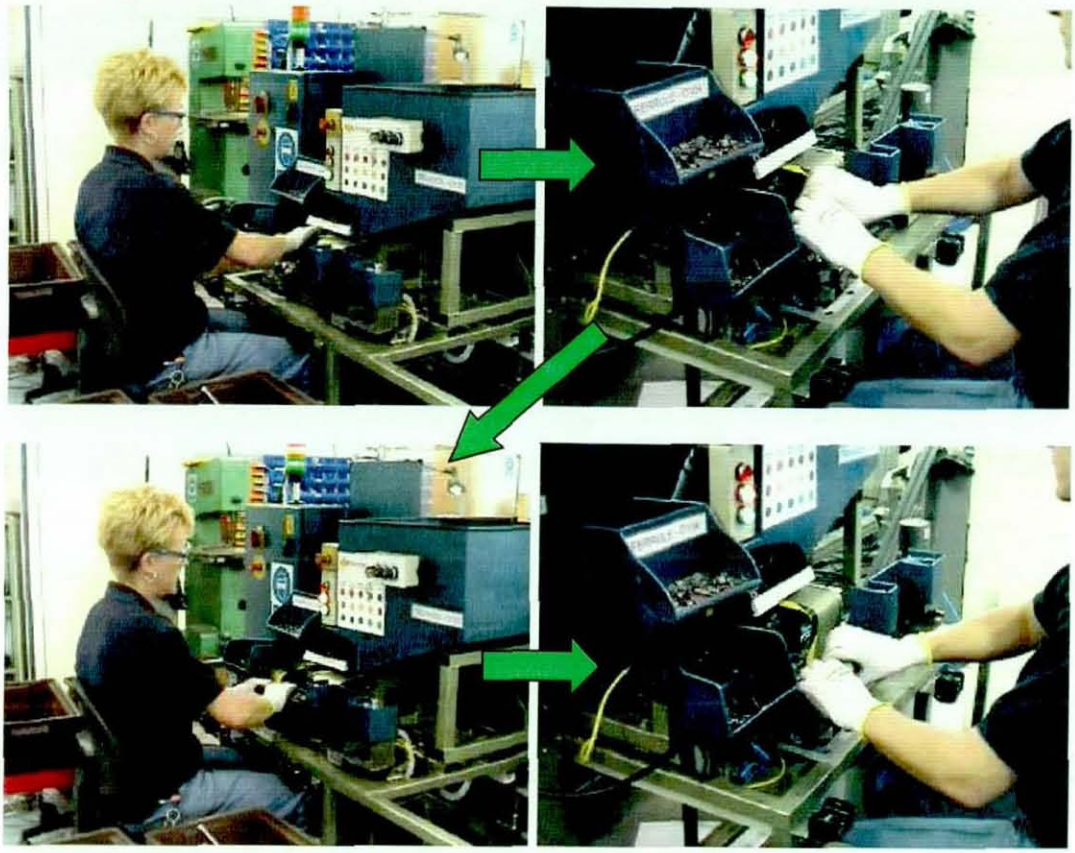


Figure 41. Step 1 of new sequence

2. Right hand picks clean (ungreased) trunnion from above the assembly jig and places it on lower main jig. See figure 42.

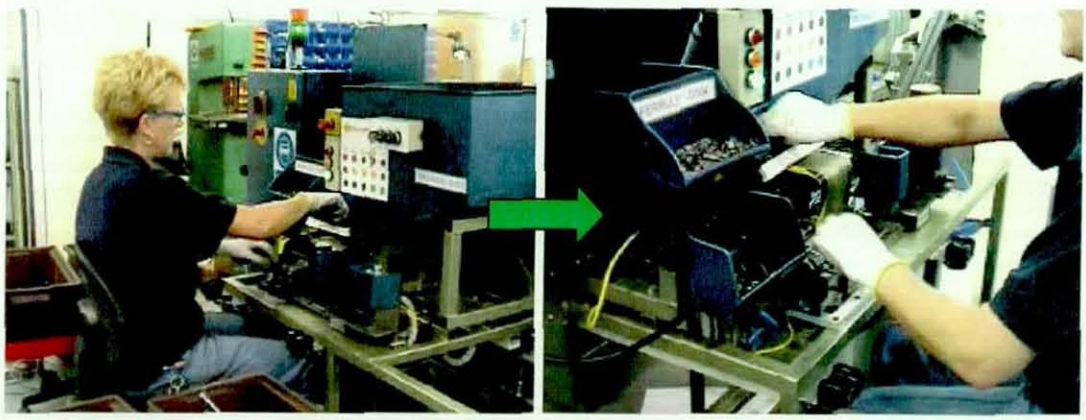


Figure 42. Step 2 of new sequence

3. With left hand the operator hand picks a ferrule and lowers it into the 'main' jig. See figure 43.

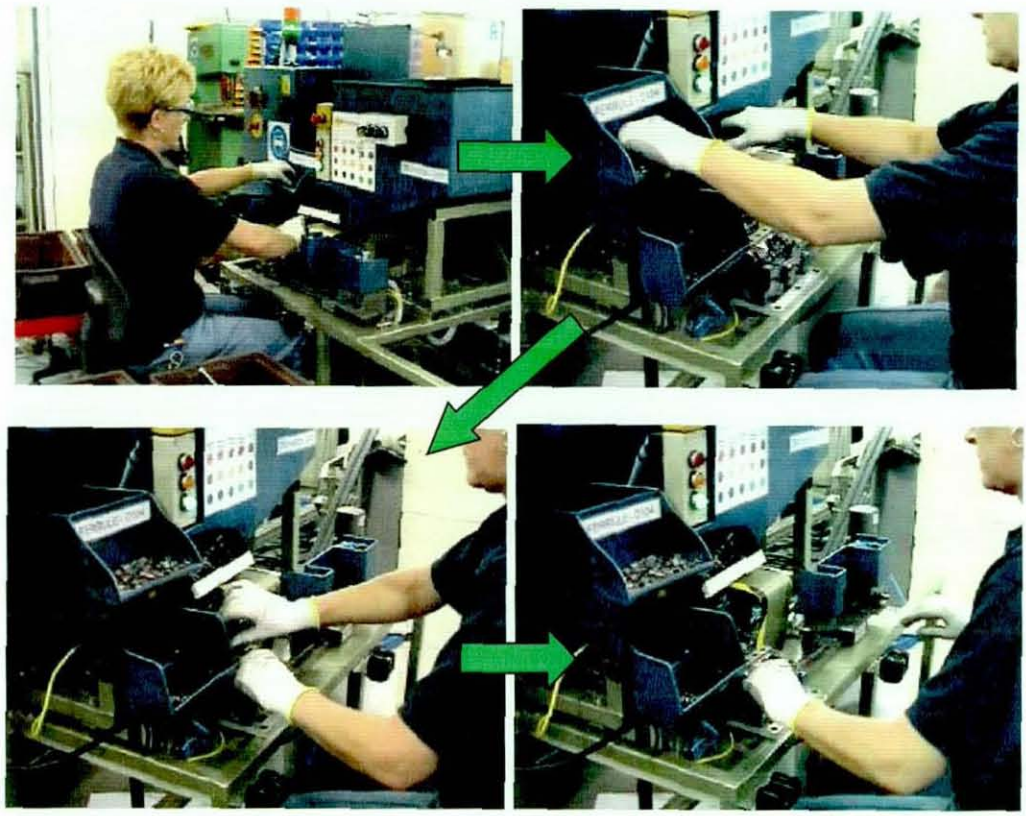


Figure 43. Step 3 of new sequence.

4. Operator picks sub-assembly from batch container on spring based trolley on the left side. See figure 44.

Figure 44. Step 4 of new sequence.

5. The operator positions the sub-assembly into a carriage and location pins are dropped in to secure the sub-assembly. See figure 45.

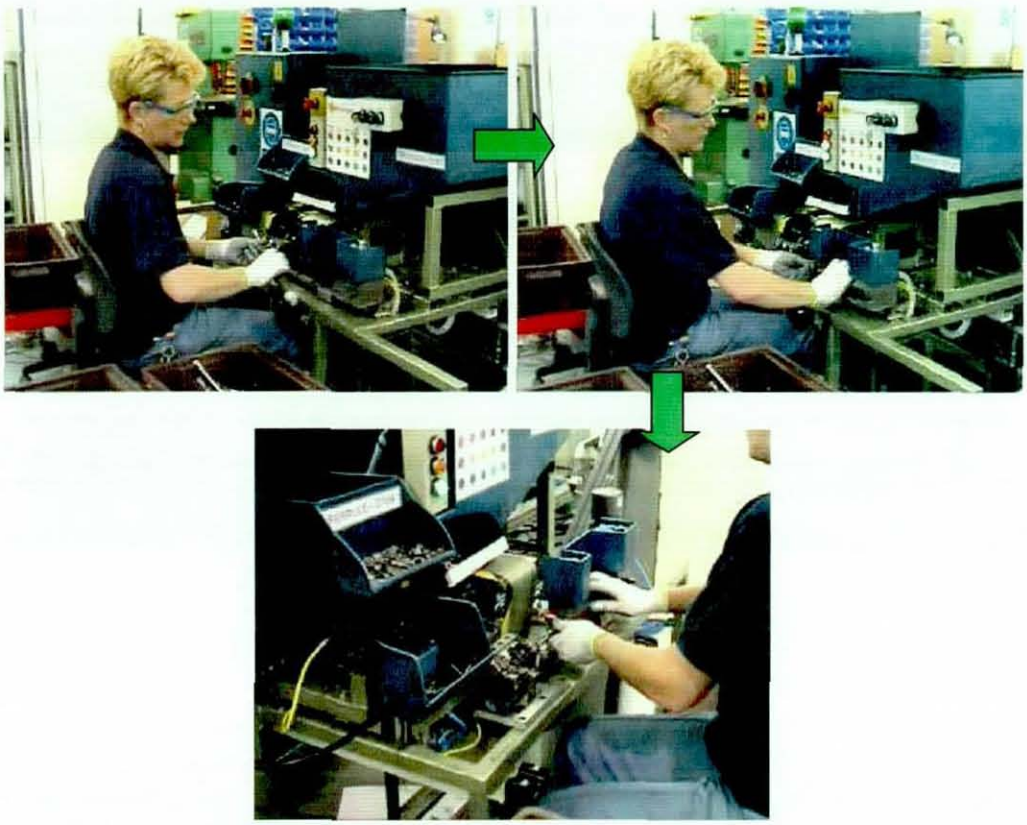


Figure 45. Step 5 of new sequence

6. Two buttons are activated and held until the operation is completed. See figure 46.

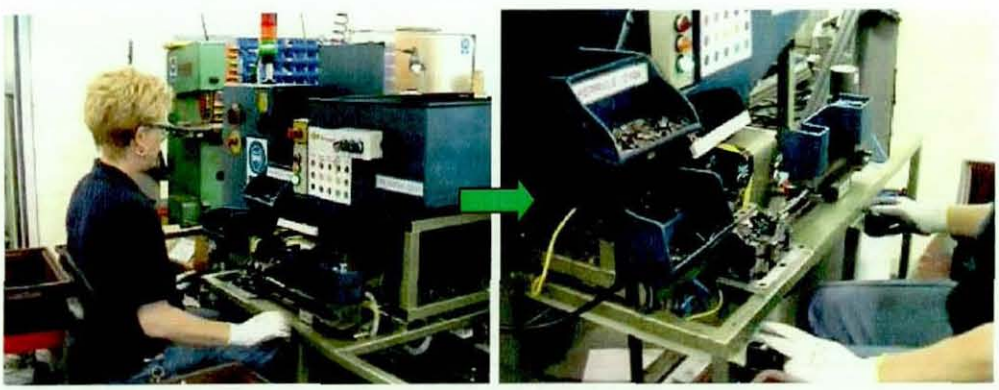


Figure 46. Step 6 of new sequence.

7. The machine cycle is as follows. Bowl Feeders feed both washers and ball race bearings into multiple chutes with individual sliders loading single parts into the lower 'main' jig. Simultaneously, twin grease ejectors raise and insert grease into the trunnion at the upper 'greasing' jig. Sensors confirm that all the parts are present in the lower 'main' jig and begin loading the components onto the carriage holding the sub-assembly. See figure 47.

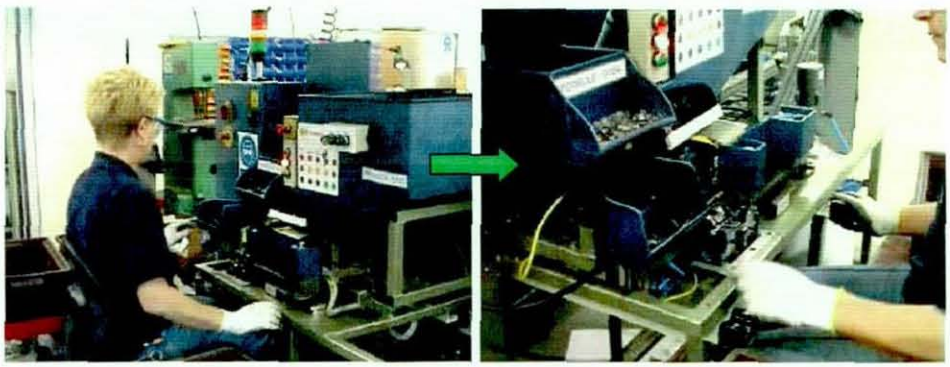


Figure 47. Step 7 of new sequence.

8. The operator picks up the black cap from the left side and inserts it onto the knurled end of the sub-assembly, thereby encasing all the components. See figure 48.

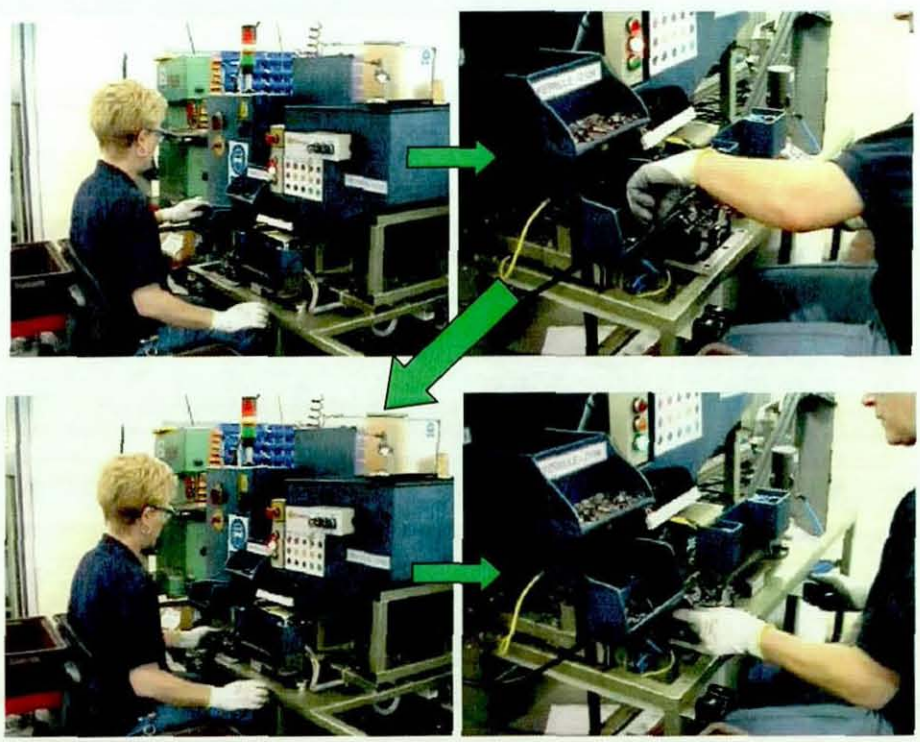


Figure 48. Step 8 of new sequence.

9. The upper 'greasing' jig is scanned by twin contrast scanners.

10. The operator activates dual buttons again to open the front trap door and the location pins on the carriage. See figure 49.

Figure 49. Step 10 of new sequence.

11. The operator pulls the assembly out of the carriage and 'main' jig. See figure 50.

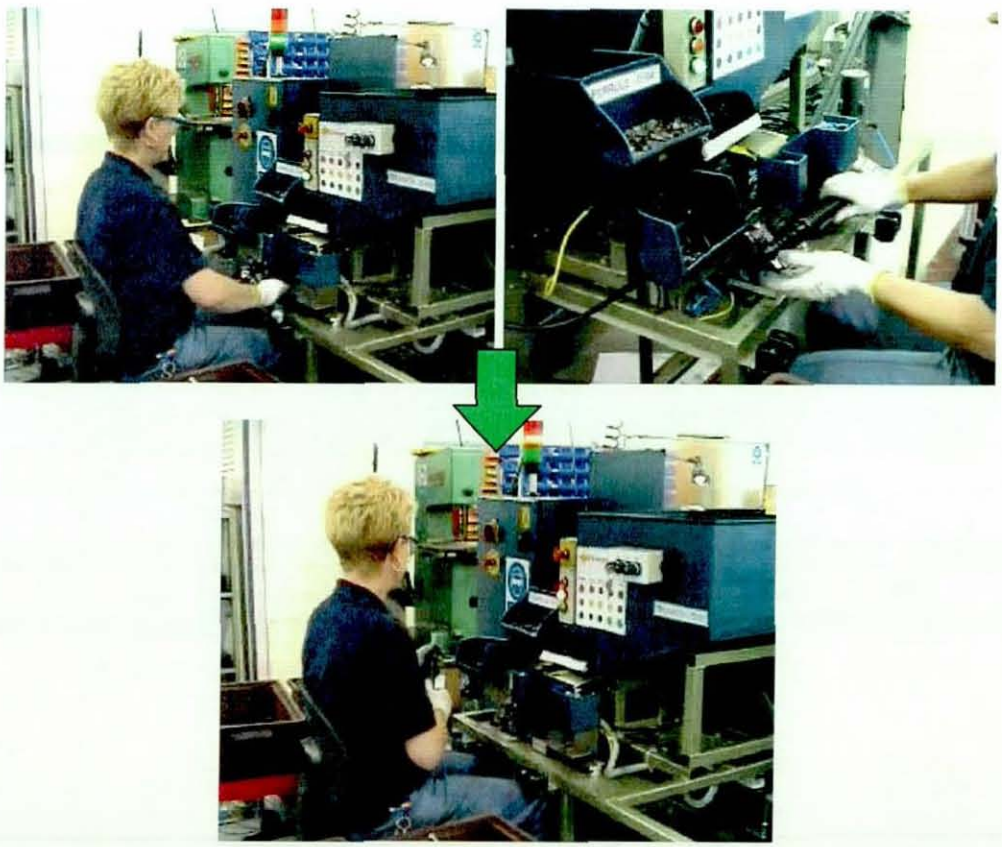


Figure 50. Step 11 of new sequence.

12. Implementing a time delay mechanism after the removal of assembly, the front trap door is closed and the carriage returned. The operator places the assembly into a container on a spring based trolley on the left side. See figure 51.

Figure 51. Step 12 of new sequence.

6.6 Improvements

- Reduction of cycle time to under 10 seconds – even by the slowest operators
- Mistake proofing using non-contact sensors
- Automatic greasing of trunnions
- Automatic sensing of grease present on the insides of greased trunnions
- Short reach for components – trunnions, ferrules and black caps
- Elimination of part pinching of washers and bearings - auto feeding

6.7 RIMAN evaluation

There were 38 potential hazards identified from both the normal operation and the maintenance phase of the machine's life. The other phases of machine life (such as machine installation and decommissioning) were ignored in this exercise as it was beyond of the scope of this thesis. However, it has the potential to be explored as further work as further work. The author did this evaluation on an individual basis but normally an assessment group should be part of this evaluation.

The next four pages show the 38 potential hazards identified and evaluated by RIMAN.

Assessment Reference:	
Type of machine:	Assembly machine
Machine location:	Factory Floor
Machine description:	Assembly machine
Machine manufacturer:	Adcocks
Machine Model:	Assembly 05 C
Machine serial number:	-
Modifications from 'as-supplied':	
Energy sources:	415Vac and Pneumatic
Assessment carried out by:	
Assessment dates:	
Assessment checked by:	
Assessment approved by:	

RIMAN

RISK MANAGEMENT PROCEDURE

Potential Severity of Harm

Hazard No.	Function / Process	Phase of machine life	Potential hazard	Type of hazard	Severity of Injury (S) **(assume running for 8 hours)**	Number of person/s exposed (P)	S	P	S*P
1	Lifting Sub-assembly from right hand side into holder	Operation	Twisting of body to right side	Physical	Slight strain	8-15	1	1	1
2	Lifting Sub-assembly from right hand side into holder	Operation	Shoulder and arm behind body	Physical	Slight strain	8-15	1	1	1
3	Picking up components from gravity bins	Operation	Arm above elbow line	Physical	Slight strain	8-15	1	1	1
4	Locating sub-assembly into holder	Operation	Impact contact from drop-down pins	Mechanical	Scratch or bruise	8-15	0.1	1	0.1
5	Locating components into jigs	Operation	Sharp edges	Mechanical	Scratch or bruise	8-15	0.1	1	0.1
6	Machine running sequence	Operation	Entanglement - catching in gaps between sub-assembly holder and lower jig	Mechanical	Break of minor bone (fingers, thumb and toes) (Temporary)	8-15	2	1	2
7	Machine running sequence	Operation	Entanglement - catching in gaps between trunnion at upper jig and grease ejectors from the sides	Mechanical	Break of minor bone (fingers, thumb and toes) (Temporary)	8-15	2	1	2
8	Machine running sequence	Operation	Entanglement - catching in gaps between the grease ejectors retracted positions and extending contrast sensors	Mechanical	Break of minor bone (fingers, thumb and toes) (Temporary)	8-15	2	1	2
9	Machine running sequence	Operation	Front lid opening	Mechanical	Break of minor bone (fingers, thumb and toes) (Temporary)	8-15	2	1	2
10	Machine running sequence	Operation	Front lid closing	Mechanical	Break of minor bone (fingers, thumb and toes) (Temporary)	8-15	2	1	2
11	Machine running sequence	Operation	Right carriage extending forward motion	Mechanical	Break of minor bone (fingers, thumb and toes) (Temporary)	8-15	2	1	2
12	Machine running sequence	Operation	Right carriage retracting motion	Mechanical	Break of minor bone (fingers, thumb and toes) (Temporary)	8-15	2	1	2
13	Machine running sequence	Operation	Sliders motions forward and back	Mechanical	Break of minor bone (fingers, thumb and toes) (Temporary)	8-15	2	1	2
14	Machine running sequence	Operation	Grease ejectors motion - up and down	Mechanical	Break of minor bone (fingers, thumb and toes) (Temporary)	8-15	2	1	2
15	Machine running sequence	Operation	Grease ejectors at up position - forward and back	Mechanical	Break of minor bone (fingers, thumb and toes) (Temporary)	8-15	2	1	2
16	Machine running sequence	Operation	Contrast sensors motion - forward and back	Mechanical	Break of minor bone (fingers, thumb and toes) (Temporary)	8-15	2	1	2
17	Machine running sequence	Operation	Entanglement - catching in gaps in jig with sliders coming forwards	Mechanical	Break of minor bone (fingers, thumb and toes) (Temporary)	8-15	2	1	2
18	Overall Operation	Operation	Repetitive operation	Physical	Slight strain	8-15	1	1	1
19	Machine activation	Operation	Finger contact to optic touch buttons	Physical	Scratch or bruise	8-15	0.1	1	0.1
20	Machine replenishing	Operation	Filling up trunnions in large gravity bin	Physical	Slight strain	8-15	1	1	1
21	Machine replenishing	Operation	Filling up ferrules	Physical	Slight strain	8-15	1	1	1
22	Machine replenishing	Operation	Filling up black caps	Physical	Slight strain	8-15	1	1	1
23	Machine replenishing	Operation	Filling up washer and bearings	Physical	Slight strain	8-15	1	1	1
24	Machine replenishing	Operation	Bowl feeder vibration	Physical	Slight strain	8-15	1	1	1
25	Machine replenishing	Operation	Bowl feeder noise	Non-Mechanical	Medical recordable	8-15	2	1	2
26	Cleaning	Cleaning	Sharp corners	Mechanical	Scratch or bruise	8-15	0.1	1	0.1
27	Replace grease barrels	Operation	Contact with grease when replacing barrels	Non-Mechanical	Skin allergy	8-15	1	1	1
28	Replace grease barrels	Operation	Lifting of grease pump	Physical	Slight strain	8-15	1	1	1
29	Material transfer	Operation	Pulling and pushing of trollies	Physical	Slight strain	8-15	1	1	1
30	Material transfer	Operation	Pulling and pushing of stacked containers on trollies while sitting	Physical	Minor strain	8-15	2	1	2
31	Repairs	Maintenance	Electric shock from broken sensors - 24VDC	Non-Mechanical	Shock	8-15	0.5	1	0.5
32	Repairs	Maintenance	Injury by compressed air	Non-Mechanical	Injury to eyes (temporary blindness)	8-15	4	1	4
33	Repairs	Maintenance	Lifting of fully loaded gravity bins to access inclined chutes	Physical	Minor strain	8-15	2	1	2
34	Repairs	Maintenance	2 grease manual valves for bleeding grease through pipework - ejection of grease (high pressure)	Non-Mechanical	Injury to face	8-15	2	1	2
35	Locating verification cap	Operation	Difficultfy of placing verfiication cap on knurl end of sub-assembly (Sideward motion)	Physical	Minor strain	8-15	2	1	2
36	Machine running sequence	Operation	Parts poping out of jig during run	Mechanical	Injury to eyes (temporary blindness)	8-15	4	1	4
37	Machine running sequence	Operation	Moving mechanism underneath - Entanglement	Mechanical	Break of minor bone (fingers, thumb and toes) (Temporary)	8-15	2	1	2
38	Locating verification cap	Operation	Twisting of body - static force	Physical	Minor strain	8-15	2	1	2

Occurrence of harm

Hazard No.	Function / Process	Potential hazard	Who will be exposed to that harm?	Frequency of exposure? (E1)	Duration of exposure (E2)	Likelihood of injury (L)	E1	E2	L	E1*E2*L
1	Lifting Sub-assembly from right hand side into holder	Twisting of body to right side	Operators	More than once every minutes	16 Hours (double shifts)	Possible	6	2	2	24
2	Lifting Sub-assembly from right hand side into holder	Shoulder and arm behind body	Operators	More than once every minutes	16 Hours (double shifts)	Possible	6	2	2	24
3	Picking up components from gravity bins	Arm above elbow line	Operators	More than once every minutes	16 Hours (double shifts)	Possible	6	2	2	24
4	Locating sub-assembly into holder	Impact contact from drop-down pins	Operators	More than once every minutes	16 Hours (double shifts)	Possible	6	2	2	24
5	Locating components into jigs	Sharp edges	Operators	More than once every minutes	16 Hours (double shifts)	Possible	6	2	2	24
6	Machine running sequence	Entanglement - catching in gaps between sub-assembly holder and lower jig	Operators	More than once every minutes	16 Hours (double shifts)	Probable	6	2	8	96
7	Machine running sequence	Entanglement - catching in gaps between trunnion at upper jig and grease ejectors from the sides	Operators	More than once every minutes	16 Hours (double shifts)	Probable	6	2	8	96
8	Machine running sequence	Entanglement - catching in gaps between the grease ejectors retracted positions and extending contrast sensors	Operators	More than once every minutes	16 Hours (double shifts)	Probable	6	2	8	96
9	Machine running sequence	Front lid opening	Operators	More than once every minutes	16 Hours (double shifts)	Even Chance	6	2	5	60
10	Machine running sequence	Front lid closing	Operators	More than once every minutes	16 Hours (double shifts)	Even Chance	6	2	5	60
11	Machine running sequence	Right carriage extending forward motion	Operators	More than once every minutes	16 Hours (double shifts)	Even Chance	6	2	5	60
12	Machine running sequence	Right carriage retracting motion	Operators	More than once every minutes	16 Hours (double shifts)	Even Chance	6	2	5	60
13	Machine running sequence	Sliders motions forward and back	Operators	More than once every minutes	16 Hours (double shifts)	Even Chance	6	2	5	60
14	Machine running sequence	Grease ejectors motion - up and down	Operators	More than once every minutes	16 Hours (double shifts)	Even Chance	6	2	5	60
15	Machine running sequence	Grease ejectors at up position - forward and back	Operators	More than once every minutes	16 Hours (double shifts)	Even Chance	6	2	5	60
16	Machine running sequence	Contrast sensors motion - forward and back	Operators	More than once every minutes	16 Hours (double shifts)	Even Chance	6	2	5	60
17	Machine running sequence	Entanglement - catching in gaps in jig with sliders coming forwards	Operators	More than once every minutes	16 Hours (double shifts)	Possible	6	2	2	24
18	Overall Operation	Repetitive operation	Operators	More than once every minutes	16 Hours (double shifts)	Possible	6	2	2	24
19	Machine activation	Finger contact to optic touch buttons	Operators	More than once every minutes	16 Hours (double shifts)	Possible	6	2	2	24
20	Machine replenishing	Filling up trunnions in large gravity bin	Labours	Once an hour	16 Hours (double shifts)	Possible	2	2	2	8
21	Machine replenishing	Filling up ferrules	Operators	Once an hour	16 Hours (double shifts)	Unlikely	2	2	1.5	6
22	Machine replenishing	Filling up black caps	Operators	Once an hour	16 Hours (double shifts)	Unlikely	2	2	1.5	6
23	Machine replenishing	Filling up washer and bearings	Labours	Once a day	16 Hours (double shifts)	Possible	1	2	2	4
24	Machine replenishing	Bowl feeder vibration	Operators	More than once every minutes	16 Hours (double shifts)	Possible	6	2	2	24
25	Machine replenishing	Bowl feeder noise	Operators	Several times a minutes (Constantly)	16 Hours (double shifts)	Unlikely	8	2	1.5	24
26	Cleaning	Sharp corners	Operators	Once a day	16 Hours (double shifts)	Possible	1	2	2	4
27	Replace grease barrels	Contact with grease when replacing barrels	Technicians	Once a Month	16 Hours (double shifts)	Possible	0.1	2	2	0.4
28	Replace grease barrels	Lifting of grease pump	Technicians	Once a Month	16 Hours (double shifts)	Even Chance	0.1	2	5	1
29	Material transfer	Pulling and pushing of trollies	Operators	Once a day	16 Hours (double shifts)	Even Chance	1	2	5	10
30	Material transfer	Pulling and pushing of stacked containers on trollies while sitting	Operators	Once an hour	16 Hours (double shifts)	Probable	2	2	8	32
31	Repairs	Electric shock from broken sensors - 24VDC	Technicians	Once a Month	16 Hours (double shifts)	Possible	0.1	2	2	0.4
32	Repairs	Injury by compressed air	Technicians	Once a day	16 Hours (double shifts)	Even Chance	1	2	5	10
33	Repairs	Lifting of fully loaded gravity bins to access inclined chutes	Technicians	Once a Month	16 Hours (double shifts)	Possible	0.1	2	2	0.4
34	Repairs	2 grease manual valves for bleeding grease through pipework - ejection of grease (high pressure)	Technicians	Once a Month	16 Hours (double shifts)	Unlikely	0.1	2	1.5	0.3
35	Locating verification cap	Difficultly of placing verfication cap on knurl end of sub-assembly (Sideward motion)	Operators	More than once every minutes	16 Hours (double shifts)	Possible	6	2	2	24
36	Machine running sequence	Parts poping out of jig during run	Operators	More than once every minutes	8 Hours (single shift)	Possible	6	1	2	12
37	Machine running sequence	Moving mechanism underneath - Entanglement	Operators	More than once every minutes	16 Hours (double shifts)	Possible	6	2	2	24
38	Locating verification cap	Twisting of body - static force	Operators	More than once every minutes	16 Hours (double shifts)	Possible	6	2	2	24

Countermeasures

Hazard No.	Function / Process	Potential hazard	Scoring so far = S*P*E*L *(if 5 or less = countermeasures are not required)*	Prevention measures (existing controls) (C1)	Detection measures (Existing training and information) (C2)	C1	C2	(C1+C2)/10
1	Lifting Sub-assembly from right hand side into holder	*Twisting of body to right side*	24	Exposure limit to no more than 2 hours per day per person	Fully trained person	4	4	0.8
2	Lifting Sub-assembly from right hand side into holder	Shoulder and arm behind body	24	Exposure limit to no more than 2 hours per day per person	Fully trained person	4	4	0.8
3	Picking up components from *gravity bins*	Arm above elbow line	24	Exposure limit to no more than 2 hours per day per person	Fully trained person	4	4	0.8
4	Locating sub-assembly into holder	Impact contact from drop-down pins	2.4	-				
5	Locating components into jigs	Sharp edges	2.4	-				
6	Machine running sequence	Entanglement - catching in gaps *between sub-assembly holder* and lower jig	192	Two hand to hold-to-run control	Fully trained person	2	4	0.6
7	Machine running sequence	Entanglement - catching in gaps between trunnion at upper jig and grease ejectors from the sides	192	Two hand to hold-to-run control	Fully trained person	2	4	0.6
8	Machine running sequence	Entanglement - catching in gaps between the grease ejectors *retracted positions* and extending contrast sensors	192	Two hand to hold-to-run control	Fully trained person	2	4	0.6
9	Machine running sequence	Front lid opening	120	Two hand to hold-to-run control	Fully trained person	2	4	0.6
10	Machine running sequence	Front lid closing	120	Two hand to hold-to-run control	Fully trained person	2	4	0.6
11	Machine running sequence	Right carriage extending forward motion	120	Two hand *to hold-to-run control*	Fully trained person	2	4	0.6
12	Machine running sequence	Right carriage retracting motion	120	Two hand to hold-to-run control	Fully trained person	2	4	0.6
13	Machine running sequence	Sliders motions forward and back	120	Two hand to hold-to-run control	Fully trained person	2	4	0.6
14	Machine running sequence	Grease ejectors motion - up and down	120	Two hand to hold-to-run control	*Fully trained person*	2	4	0.6
15	Machine running sequence	Grease ejectors at up position - *forward and back*	120	Two hand to hold-to-run control	Fully trained person	2	4	0.6
16	Machine running sequence	Contrast sensors motion - forward and back	120	Two hand to hold-to-run control	Fully trained person	2	4	0.6
17	Machine running sequence	Entanglement - catching in gaps in jig with sliders coming forwards	48	Two hand to hold-to-run control	Fully trained person	2	4	0.6
18	Overall Operation	Repetitive operation	24	Exposure limit to no more than 2 hours per day per person	Fully trained person	4	4	0.8
19	Machine activation	Finger contact to optic touch buttons	2.4	-				
20	Machine replenishing	Filling up trunnions in large *gravity bin*	8	Weight limit while filling - Competent person - Labourer	Competent person	2	2	0.4
21	Machine replenishing	Filling up ferrules	8	Weight limit while filling - Competent person - Labourer	Competent person	2	2	0.4
22	*Machine replenishing*	Filling up black caps	6	Weight limit while filling - Competent person - Labourer	Competent person	2	2	0.4
23	Machine replenishing	Filling up washer and bearings	4	Weight limit while filling - Competent person - Labourer	Competent person	2	2	0.4
24	*Machine replenishing*	Bowl feeder vibration	24	Exposure limit to no more than 2 hours per day per person	Slow appearance of hazard	4	4	0.8
25	Machine replenishing	Bowl feeder noise	48	Full noise enclosure - partial noise elimination	Slow appearance of hazard	2	4	0.6
26	*Cleaning*	Sharp corners	0.4	-				
27	Replace grease barrels	Contact with grease when replacing barrels	0.4	-				
28	Replace grease barrels	Lifting of grease pump	1	-				
29	Material transfer	Pulling and pushing of trollies	10	Fully Trained	Fully trained person	4	4	0.8
30	Material transfer	Pulling and pushing of stacked containers on trollies while sitting	64	Fully Trained	Fully trained person	4	4	0.8
31	Repairs	Electric shock from broken sensors - 24VDC	0.2	-				
32	Repairs	Injury by compressed air	40	Complusory safety glasses	*Competent person*	4	2	0.6
33	Repairs	Lifting of fully loaded gravity bins *to access inclined chutes*	0.8	-				
34	Repairs	2 grease manual valves for bleeding grease through pipework - ejection of grease (high pressure)	0.6	-				
35	*Locating verification cap*	Difficultly of placing verfication cap on knurl end of sub-assembly (Sideward motion)	48	Fully Trained	Fully trained person	4	4	0.8
36	Machine running sequence	*Parts poping out of jig during run*	48	Complusory safety glasses	Fully trained person	4	4	0.8
37	Machine running sequence	Moving mechanism underneath - Entanglement	48	Partial guard - 75%	Fully trained person	4	4	0.8
38	Locating verification cap	Twisting of body - static force	48	Exposure limit to no more than 2 hours per day per person	Fully trained person	4	4	0.8

Risk estimation

Hazard No.	Function / Process	Potential hazard	RISK HPN (S*P*E*L*C)	Risk Level	Root Cause	Recommended action/s	Responsibility & target completion date	New Hazard Number
1	Lifting Sub-assembly from right hand side into holder	Twisting of body to right side	19.2	Low				
2	Lifting Sub-assembly from right hand side into holder	Shoulder and arm behind body	19.2	Low				
3	Picking up components from gravity bins	Arm above elbow line	19.2	Low				
4	Locating sub-assembly into holder	Impact contact from drop-down pins	2.4	Negligible		No action is required		
5	Locating components into jigs	Sharp edges	2.4	Negligible		No action is required		
6	Machine running sequence	Entanglement - catching in gaps between sub-assembly holder and lower jig	115.2	High				
7	Machine running sequence	Entanglement - catching in gaps between trunnion at upper jig and grease ejectors from the sides	115.2	High				
8	Machine running sequence	Entanglement - catching in gaps between the grease ejectors retracted positions and extending contrast sensors	115.2	High				
9	Machine running sequence	Front lid opening	72	High				
10	Machine running sequence	Front lid closing	72	High				
11	Machine running sequence	Right carriage extending forward motion	72	High				
12	Machine running sequence	Right carriage retracting motion	72	High				
13	Machine running sequence	Sliders motions forward and back	72	High				
14	Machine running sequence	Grease ejectors motion - up and down	72	High				
15	Machine running sequence	Grease ejectors at up position - forward and back	72	High				
16	Machine running sequence	Contrast sensors motion - forward and back	72	High				
17	Machine running sequence	Entanglement - catching in gaps in jig with sliders coming forwards	28.8	Low				
18	Overall Operation	Repetitive operation	19.2	Low				
19	Machine activation	Finger contact to optic touch buttons	2.4	Negligible		No action is required		
20	Machine replenishing	Filling up trunnions in large gravity bin	3.2	Negligible		No action is required		
21	Machine replenishing	Filling up ferrules	2.4	Negligible		No action is required		
22	Machine replenishing	Filling up black caps	2.4	Negligible		No action is required		
23	Machine replenishing	Filling up washer and bearings	4	Negligible		No action is required		
24	Machine replenishing	Bowl feeder vibration	19.2	Low				
25	Machine replenishing	Bowl feeder noise	28.8	Low				
26	Cleaning	Sharp corners	0.4	Negligible		No action is required		
27	Replace grease barrels	Contact with grease when replacing barrels	0.4	Negligible		No action is required		
28	Replace grease barrels	Lifting of grease pump	1	Negligible		No action is required		
29	Material transfer	Pulling and pushing of trollies	8	Low				
30	Material transfer	Pulling and pushing of stacked containers on trollies while sitting	51.2	High				
31	Repairs	Electric shock from broken sensors - 24VDC	0.2	Negligible		No action is required		
32	Repairs	Injury by compressed air	24	Low				
33	Repairs	Lifting of fully loaded gravity bins to access inclined chutes	0.8	Negligible		No action is required		
34	Repairs	2 grease manual valves for bleeding grease through pipework - ejection of grease (high pressure)	0.6	Negligible		No action is required		
35	Locating verification cap	Difficultly of placing verfiication cap on knurl end of sub-assembly (Sideward motion)	38.4	Low				
36	Machine running sequence	Parts poping out of jig during run	38.4	Low				
37	Machine running sequence	Moving mechanism underneath - Entanglement	38.4	Low				
38	Locating verification cap	Twisting of body - static force	38.4	Low				

6.8 Results

There were no UNACCEPTABLE risk levels found and the highest risk level score was 115.2, which is classified as a HIGH-risk level. The redesigned Assembly 05 station was considered successful in terms of safety by the RIMAN evaluation.

UNACCEPTABLE risk level	= 0
HIGH risk level	= 12
LOW risk level	= 13
NEGLIGIBLE risk level	= 13

The majority of the potential hazards with HIGH-risk levels were from entanglement, by catching in gaps and moving parts during the normal machine sequence.

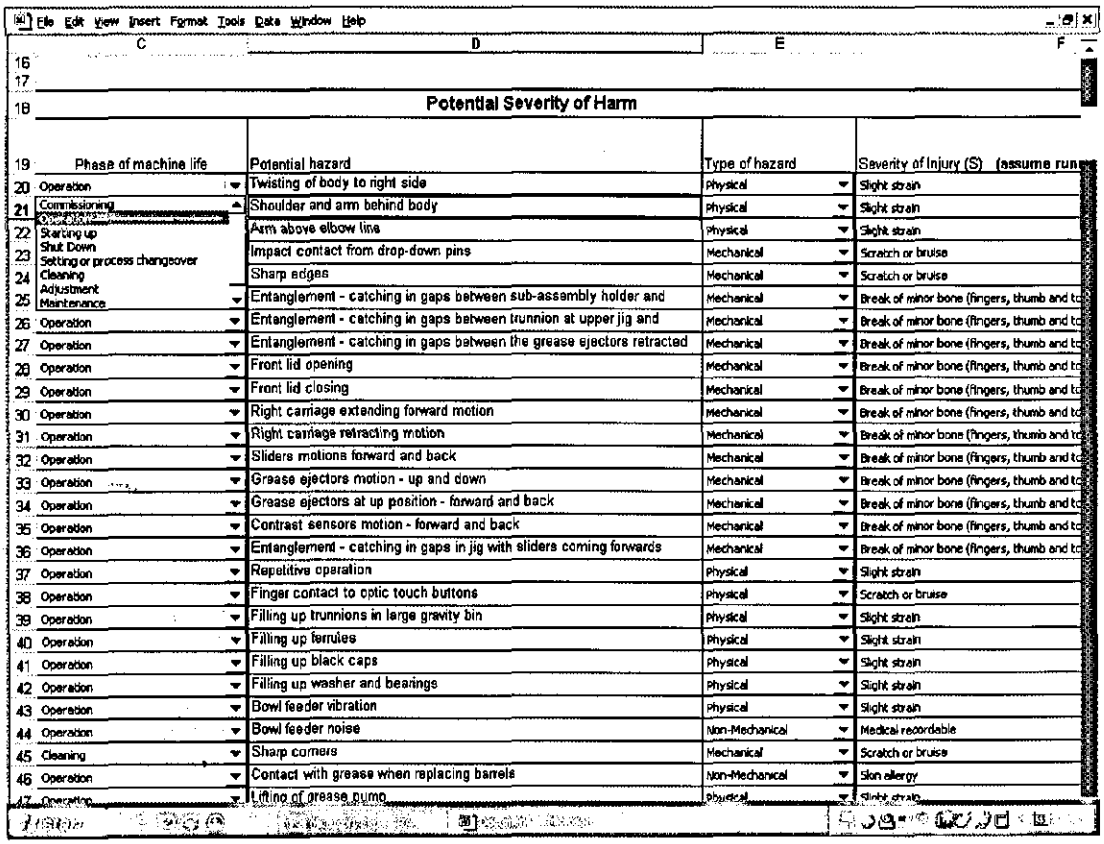
The frequency and duration of exposure are the main factors that raise the risk scoring levels. The aim of production is always to seek to reduce cycle time, thus increasing value added time during an assembly. Consequently, the designer had to be aware that high volume production, where the number of assembled units produced is more than one per minute, might increase the risk levels, even if the severity of injury is low.

In this redesign, a movable interlocking guard was introduced to protect all the catching gaps and moving parts from the operator and standby supervisor. An additional interlocking device activated the run and operated until the end of the cycle before being released. Having an interlocking guard may add a few seconds to an overall cycle time but safety demands best practice.

Another HIGH-risk level was material transfer. The operator had to shift stacked containers holding the sub-assembled units on a spring based trolley. This was amended to single tier container height and the trolley was fitted with ball bearings to allow the transfer of containers with a minimum of effort.

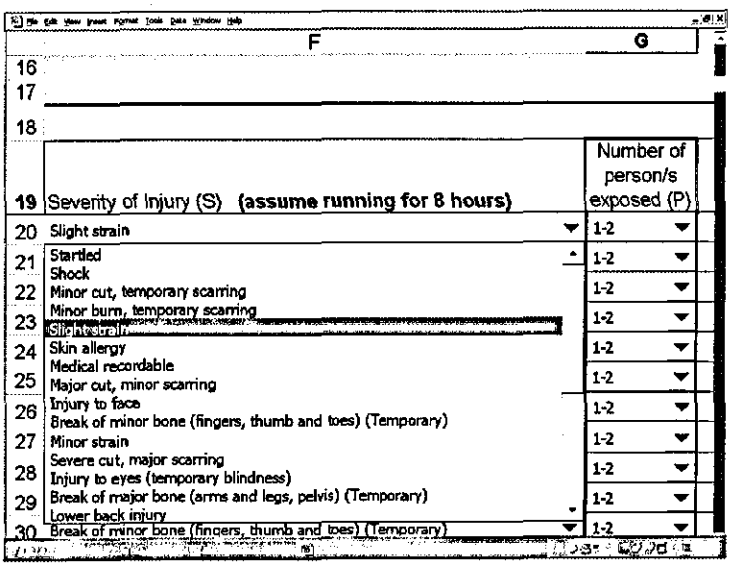
6.9 RIMAN version 2

The author had the opportunity to explore the use of Excel spreadsheets in developing the second version of RIMAN (RIMAN V2) with pop-up lists for every column but it is incomplete and needs further development. It has potential for further work beyond this thesis and it could be developed as a computer software tool. Figures 52 and 53 shows a screen copy of RIMAN V2 with pop-up checklists in use. When a selection had been made, the scoring was updated and calculated automatically. This reduces work time looking at paper checklists, their corresponding scores, making comparisons and, finally, calculating the results. The central part of this development is that it is suitable for small and medium sized enterprises whose budgets are small and who cannot necessarily afford to allocate funds to purchase powerful software tools, such as CAD simulations with built-in analysis.



	C	D	E	F
16				
17				
18		**Potential Severity of Harm**		
19	Phase of machine life	Potential hazard	Type of hazard	Severity of Injury (S) (assume run
20	Operation	Twisting of body to right side	Physical	Slight strain
21	Commissioning	Shoulder and arm behind body	Physical	Slight strain
22	Starting up	Arm above elbow line	Physical	Slight strain
23	Shut Down	Impact contact from drop-down pins	Mechanical	Scratch or bruise
24	Setting or process changeover	Sharp edges	Mechanical	Scratch or bruise
25	Cleaning Adjustment Maintenance	Entanglement - catching in gaps between sub-assembly holder and	Mechanical	Break of minor bone (fingers, thumb and to
26	Operation	Entanglement - catching in gaps between trunnion at upper jig and	Mechanical	Break of minor bone (fingers, thumb and to
27	Operation	Entanglement - catching in gaps between the grease ejectors retracted	Mechanical	Break of minor bone (fingers, thumb and to
28	Operation	Front lid opening	Mechanical	Break of minor bone (fingers, thumb and to
29	Operation	Front lid closing	Mechanical	Break of minor bone (fingers, thumb and to
30	Operation	Right carriage extending forward motion	Mechanical	Break of minor bone (fingers, thumb and to
31	Operation	Right carriage retracting motion	Mechanical	Break of minor bone (fingers, thumb and to
32	Operation	Sliders motions forward and back	Mechanical	Break of minor bone (fingers, thumb and to
33	Operation	Grease ejectors motion - up and down	Mechanical	Break of minor bone (fingers, thumb and to
34	Operation	Grease ejectors at up position - forward and back	Mechanical	Break of minor bone (fingers, thumb and to
35	Operation	Contrast sensors motion - forward and back	Mechanical	Break of minor bone (fingers, thumb and to
36	Operation	Entanglement - catching in gaps in jig with sliders coming forwards	Mechanical	Break of minor bone (fingers, thumb and to
37	Operation	Repetitive operation	Physical	Slight strain
38	Operation	Finger contact to optic touch buttons	Physical	Scratch or bruise
39	Operation	Filling up trunnions in large gravity bin	Physical	Slight strain
40	Operation	Filling up ferrules	Physical	Slight strain
41	Operation	Filling up black caps	Physical	Slight strain
42	Operation	Filling up washer and bearings	Physical	Slight strain
43	Operation	Bowl feeder vibration	Physical	Slight strain
44	Operation	Bowl feeder noise	Non-Mechanical	Medical recordable
45	Cleaning	Sharp corners	Mechanical	Scratch or bruise
46	Operation	Contact with grease when replacing barrels	Non-Mechanical	Skin allergy
47	Operation	Lifting of grease pump	Physical	Slight strain

Figure 52. RIMAN V2 shows pop-up arrow buttons at the end of each cell with an automated scoring system in place.



	F	G
16		
17		
18		
19	Severity of Injury (S) **(assume running for 8 hours)**	Number of person/s exposed (P)
20	Slight strain	1-2
21	Startled Shock	1-2
22	Minor cut, temporary scarring	1-2
23	Minor burn, temporary scarring Slight strain	1-2
24	Skin allergy Medical recordable	1-2
25	Major cut, minor scarring	1-2
26	Injury to face Break of minor bone (fingers, thumb and toes) (Temporary)	1-2
27	Minor strain	1-2
28	Severe cut, major scarring Injury to eyes (temporary blindness)	1-2
29	Break of major bone (arms and legs, pelvis) (Temporary)	1-2
30	Lower back injury Break of minor bone (fingers, thumb and toes) (Temporary)	1-2

Figure 53. RIMAN V2 close-up with the pop-up menu at each cell, which automatically gives a score at the end of the row.

CHAPTER 7 DISCUSSION

The objectives of this chapter are:

- To analyse how the use of RIMAN as a management tool was approached in this case study.
- To discuss a proposal to H. R. Adcock Ltd for the use of RIMAN as a management tool for in-house 'design and build' operator-centric assembly stations.

7.1 RIMAN

RIMAN started with an idea of a risk assessment tool that could analyse risk levels with more detailed information than previously used. In small and medium-sized enterprises, the designer may not have the luxury or opportunity to design and build with the help of specialists in machine building to advise on the design. For example, these specialists may be software programmers and engineers knowledgeable in control wiring hydraulic and pneumatic control.

A lone designer may have to rely on the experience of others within the company, such as machine operators, production staff, maintenance operators and those who will be the end-users of the assembly station.

The designer has to understand human biomechanics, regulations, guidelines and bring these together to achieve a good design, in addition to using methods and techniques that are fundamental to the construction of an effective production machine. The end users, namely, the operators and maintenance engineers, are vital to good design, preferably being involved in the early stages.

7.2 RIMAN in practice

RIMAN can become a communication tool to allow the development of a design specification that will allow the designer to create a successful assembly station that considers the well being of the operator.

Risk assessment is a tool that evaluates the effectiveness of the protection of the operator. However, it is not the over-riding consideration in the construction of an effective design specification, which of course must satisfy health and safety regulations.

Figure 53 shows the key factors, which will assist in the development of an effective design specification.

This thesis demonstrates that RIMAN is at an early stage in its development but the indications suggest that it can become a powerful communication tool to develop practical machine design with safe operation, producing high

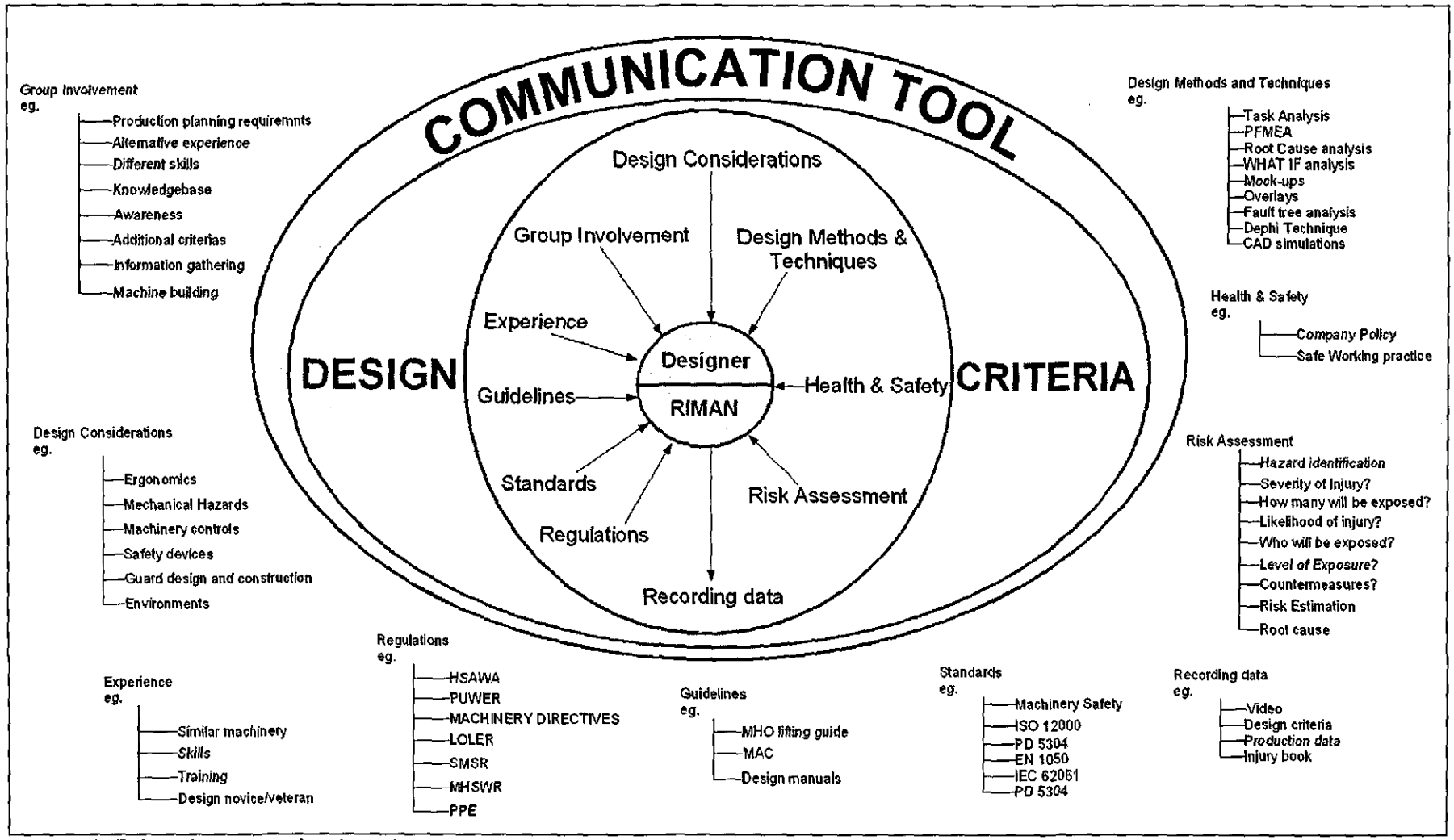


Figure 54. RIMAN communication chart.

quality products. So far it has shown that it can identify more problems than those of simple risk assessment that could easily be missed by a designer.

RIMAN has the merit of being more holistic than those previous systems that address some of the design problems. However, the author believes that, with use, it can be further refined and made more adaptable to a given company's requirements.

Key advantages of RIMAN

1. Risk evaluation tool with greater amount of data for design improvement. Eg. How many and who will be exposed to that hazards? Frequency of exposure? Documentation of root causes to the potential hazard.
2. Using the group involvement - to increase awareness of the project – in small and medium enterprise – many of the staff are multi-skilled in different ranges of tasks within the company. Tapping into their skills is key to this design process.
3. Documenting the information as a technical folder outlining the regulations and standards used in the design criteria, and the risk levels from risk evaluation.

Risk assessment identified risks but RIMAN is more sophisticated which breaks down the problem to the point that it may suggest a solution for example shown below, information from standards as guidelines.

- BS EN 294:1992 – Safety of machinery – Safety distances to prevent danger zones being reached by the upper limbs.

  This is self-explanatory, it has pictures to show what part of the upper limbs, and what are the recommended size and distance of access to prevent a person to try to use arms and hands to clean out discharge and/or feed openings.

- BS EN 418:1992 – Safety of machinery – Emergency stop equipment, functional aspects – principles for design.

  This standard defines what emergency stop function that is intended:

  - To avert arising or to reduce existing hazards to persons, damage to machinery or to work in progress,
  - To be initiated by a single human action when the normal stopping function is inadequate for this purpose.

  Section 4.1.5 Safety requirements – The emergency stop shall function as:

  - Either stop category 0, i.e. Stopping by:
    - Immediate removal of power to the machine actuator(s)
    - Or mechanical disconnection (declutching) between the hazardous elements and their machine actuator(s)

And, if necessary, braking (uncontrolled stop);

Alternatively, stop category 1, i.e. a controlled stop with power to the machine actuator(s) available to achieve the stop and then removal of power when the stop is achieved.

7.3 CASE STUDY

In order to gather information for the development of RIMAN a video recording was made of both the original and the redesigned assembly stations.

The redesigned assembly station was designed and built before RIMAN was developed. The focus of this case study was to evaluate the success of the redesign and identify potential hazards that may have been overlooked without the use of RIMAN.

Firstly, it was necessary to consider how the redesign was derived from the original (unsafe) design. This analysis was aided by the use of video clips of the original assembly station in operation, supported by captions describing the task sequences.

Using paper-based analysis alone to examine the task sequences is inadequate. However, using video camera footage with complementary written analysis identifies hazards more clearly.

If RIMAN had been involved from day one of the redesign, a conceptual design would have portrayed the task sequences to the team using 3D drawings, as shown in figures 37 and 38. Full-scale layout drawings on A0 or A1 paper, simulating the sequence of the operation could provide information for small and medium-sized companies. Another paper-based method, which could be used for design evaluation, is the use of overlays showing the priority bands around the operator, as shown in figures 35 and 36. Larger companies would probably use CAD simulations with computerised manikins to demonstrate the effectiveness of the design.

As machine mechanisms are the core of the operation, later adaptations can be difficult or even impossible to carry out. Therefore, 'design right first time' is paramount. The designer had to ensure that the layout of the mechanism suited the operator in terms of ease of placing components at the beginning of the operation cycle and removing complete assembled units at the end.

In addition to the use of CAD to conceptualise a machine, the use of mock-ups can both complement and affirm the design. In the case of the assembly station, the machine had incorporated three main features:

1 The operator mechanism

2 The feeding chutes and bowl feeders, kept inside the noise-reduction guarding

3 Gravity bins

The gravity bins were 'mocked up' in cardboard, full-scale, and fitted to a machine before the specification for the bins was carried out.

The RIMAN procedure was followed, as explained in Chapter 4. Each of the sheets was completed so that a scoring could be carried out.

When adding the data from a paper checklist to the RIMAN Excel spreadsheet, adjustment was made to include any new measures that had not been previously identified and included on RIMAN. Working checklists are live documents and are constantly updated during the development of a new design. This can provide the company with knowledge of potential hazards found in the workplace, the possible level of injury and the identification of countermeasures.

Thirty-eight potential hazards were identified in this case study. More could have been identified with an assessment group each representing their own interests using their experience and skills. Similarly with countermeasures and solutions to high-risk problems, representatives would have their own emphasis on the design that could be shared with rest of the group. RIMAN could be used to record their some of their input.

In H. R. Adcock Ltd a simple risk assessment was assessed by a trained person using observation methods but did not consider possible entanglement gaps. A simple risk assessment focuses on the actions of the operator during the operation cycle, components filling gravity bins and bowl feeders. This data is invaluable to RIMAN as ergonomic data. Indeed, without RIMAN, entanglement hazards would have been overlooked.

The assessor had no information on how the process was designed and programmed, so therefore these additional hazards were not identified.

RIMAN, in the case study, has shown certain advantages over the simple risk assessment method used by the company. It extends the procedures to include man-machine interaction in addition to hardware and software control.

The re-design had an overabundance of information at the beginning but had the advantage of experienced operators who gave their opinions on possible improvements. The strength of RIMAN is that data could be collected and recorded, risk levels evaluated and, when HIGH-risk problems were identified, solutions could be sought.

The difference between Adcock's risk assessment and RIMAN's is that in RIMAN everyone is involved. For example, the designer, machine builders and software programmers are aware of how safe the machine is, having knowledge of its internal workings, where simple risk analysis may not. The inclusion of a risk assessor in the team is obvious.

7.4 PROPOSAL

The proposal to H. R. Adcock Ltd is to develop RIMAN as a management tool using best practice for the design of operator-centric assembly stations.

The following team, representing each department, could be set up within the company:

- Process – Designer - to design and be involved in the building of the machine
- Quality – PFMEA to ensure that defective assembled units are detected early and for action to be taken.
- Production – Production capacity requirements, methods to supply components for assembly and collect assembled units as finished item or ready for next operation. Specific training requirements for the operators and supervisors.
- Technical – Tool room to manufacture parts to build the machine and maintenance of the machine. New skill requirements for the maintenance technicians. Assist the designer in the build – toolmakers, maintenance staff, control wiring, pneumatics, hydraulics and software programming.
- Product Design – designing products for manufacture with assembly in mind.
- Operators – using their valuable experience with the opportunity to develop new skills if required.
- Health and safety – provide relevant set of regulations, guidelines and standards in the design.

The next step is to set up a design criteria from the representatives of all departments.

A Delphi technique could be used to obtain design parameters from the group. The use of the internal email system and regular meetings should keep everyone updated with the progress of the design and build. Using the RIMAN system, which may identify unacceptable risk levels, further background information may be required.

During the design process, a compromise may have to be made between the design of the machine and its manufacturing requirements.

Only when the design is considered safe and the group has reached a consensus can the final specification be set. RIMAN has a unique opportunity to provide communication links between interested parties in the company by identifying problems and providing solutions.

RIMAN is a live document which, when the machine is built and operational, can be used to continuously collect new data, identify unforeseen risks and add them to the data bank. This improves company knowledge and its ability to design and build new assembly machines that are safe for their employees in a clean working environment.

CHAPTER 8 CONCLUSION AND FURTHER WORK

The objectives of this chapter are:

- To present findings, draw conclusions and identify opportunities for further work.

8.1 CONCLUSION

In the light of the aims and objectives established in chapter 1, the following conclusions have been drawn:

- The literature was reviewed and was found to be extensive. This has been significant in developing the RIMAN concept.
- 'Best practice' was identified as a management tool to assess the risk levels. Based on this RIMAN was developed to assist designers to create operator-centric assembly stations. Four tabular sheets with accompanying checklists were developed with their related scorings.
- Early work on this thesis involved two case studies. However, as it progressed, it was found that the redesigned assembly stations used similar procedures. Consequently, one case study was found to be adequate in the assessment of RIMAN as an effective system.
- The assembly 05 station cited in this thesis was built before RIMAN was developed. The author had no opportunity to design an additional operator-centric assembly station within the period of this research.
- Using RIMAN has shown how ergonomic design can be improved even after the redesigned assembly station had been built and commissioned. Additional hazards were identified, risk levels evaluated and possible solutions to eliminate or reduce the risk were established.
- A proposal should be made to H. R. Adcock Ltd to use RIMAN as 'best practice' for the design of operator-centric assembly stations.
- A proposal should be made to H. R. Adcock Ltd that they should be proactive to ensure that systems are in place to minimise or eliminate risk factors in the workplace, using RIMAN as a management tool.

8.2 FURTHER WORK

RIMAN has the potential to become a powerful management tool for raising the health and safety culture within the company and be continuously improved. It can become part of a company's approach to new business in terms of high quality products being manufactured and assembled in a clean and safe production environment. Additionally it might provide opportunities to involve more staff in product development.

RIMAN has the potential to be used for evaluating risks for all aspects of the business, not just for health and safety. For example, it might be used to assess cost implications for the business. Cost implications could include: machine downtimes, the repair of new equipment, special skills requirements, the introduction of new products into the marketplace and diversification.

Suggestions for further work resulting from this thesis include:

- Complete RIMAN version 2. Transfer paper-based methods to computer spreadsheets with computer-generated scoring systems and the use of pop-up checklists. There is a potential for software development using Visual Basic or similar programming tools.

- Evaluate RIMAN through the design of a new and complete assembly station using a full safety group from the design concept to commissioning and production operations. New rules and guidelines would be developed.

- Apply RIMAN to a fully automated assembly station, where emphasis is on the maintenance staff and automatic detection measures.

- Incorporate the use of safety integrity levels (SILs) and reliability factors as part of the RIMAN.

- Expand RIMAN into product design, the production environment, the tool-room environment and factory maintenance. There is great potential for the company to a have an enhanced health and safety culture. It could be part of a package to attract new business customers demonstrating continuity of production, in addition to a clean and safe working manufacturing environment.

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APPENDIX 1

Provision and Use of Work Equipment Regulations 1998

CONTENTS

LIST OF FIGURES

APPENDIX 1 Provision and Use of Work Equipment Regulations 1998

A1.1 Background

The PUWER Regulations were made under the Health and Safety at Work Regulations (MHSWR). **[1 & 2]** They were originally introduced in 1992 and placed wide-ranging responsibilities for health and safety in the workplace on employers and employees alike. Regulation 3 of the MHSWR requires every employer to assess the risks to the health and safety of people in their workplace. This means that it is the employer's responsibility to look not only at work equipment but at the whole working environment (from the front door to the back gate).

A1.2 The Regulations

There are 39 regulations, divided into Parts 1 to 5:

Part 1 (Introduction) contains Regulations 1 to 3

- Regulation 1: Citation and commencement
- Regulation 2: Interpretation
- Regulation 3: Application

Part 2 (General) contains Regulations 4 to 24

- Regulation 4: Suitability of work equipment
- Regulation 5: Maintenance
- Regulation 6: Inspection
- Regulation 7: Specific risks
- Regulation 8: Information and instructions
- Regulation 9: Training
- Regulation 10: Conformity with Community requirements
- Regulation 11: Dangerous parts of machinery
- Regulation 12: Protection against specified hazards
- Regulation 13: High or very low temperature
- Regulation 14: Controls for starting or making a significant change in operating conditions
- Regulation 15: Stop controls
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Regulation 17: Controls

Regulation 18: Control systems

Regulation 19: Isolation from sources of energy

Regulation 20: Stability

Regulation 21: Lighting

Regulation 22: Maintenance operations

Regulation 23: Markings

Regulation 24: Warnings

Part 3 (Mobile Work Equipment) contains Regulations 25 to 30

Regulation 25: Employees carried on mobile work equipment

Regulation 26: Rolling over of mobile work equipment

Regulation 27: Overturning of fork-lift trucks

Regulation 28: Self-propelled work equipment

Regulation 29: Remote-controlled self-propelled work equipment

Regulation 30: Drive shafts

Part 4 (Power Presses) contains Regulations 31 to 35

Regulation 31: Power presses to which Part 4 does not apply

Regulation 32: Thorough examination of power presses, guards and protection devices

Regulation 33: Inspection of guards and protection devices

Regulation 34: Reports

Regulation 35: Keeping of information

Part 5 (Miscellaneous) contains Regulations 36 to 39.

Regulation 36: Exemption for the armed forces

Regulation 37: Transitional provision

Regulations 38 and 39: Repeals and revocations

The application of PUWER must be addressed by different skills and can be regarded as shown below. For example, it would be the task of the maintenance engineer to address the section on maintenance, and the responsibility of the production engineer to look at the section on personnel, but both would be involved in the sections looking at equipment.

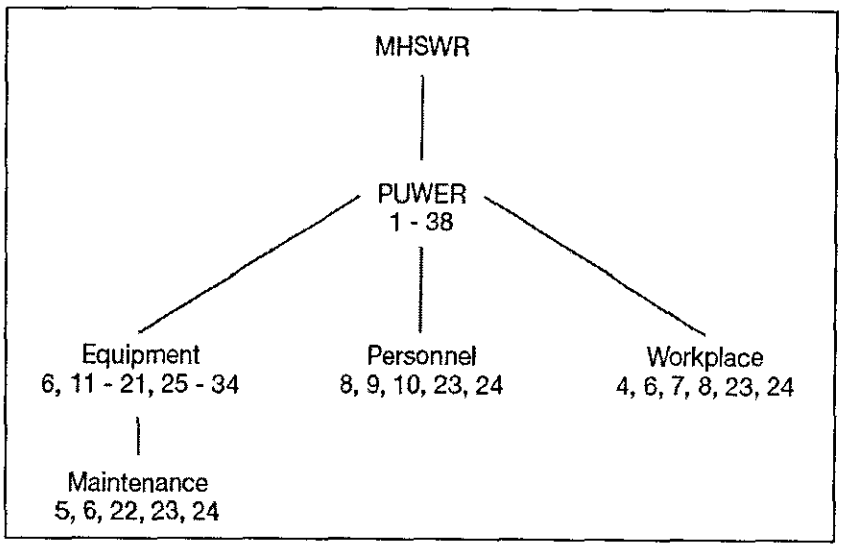


Figure A1.1. The different aspects of PUWER

Regulation 2: Interpretation

"employer" except in regulation 3(2) and (3) includes a person to whom the requirements imposed by these Regulations apply by virtue of regulation 3(3)(a) and (b);

"essential requirements" means requirements described in regulation 10(1);

"the Executive" means the Health and Safety Executive;

"inspection" in relation to an inspection under paragraph (1) or (2) of regulation 6 -

(a) means such visual or more rigorous inspection by a competent person as is appropriate for the purpose described in the paragraph;
(b) where it is appropriate to carry out testing for the purpose, includes testing the nature and extent of which are appropriate for the purpose;

"use" in relation to work equipment means any activity involving work equipment and includes starting, stopping, programming, setting, transporting, repairing, modifying, maintaining, servicing and cleaning;

"work equipment" means any machinery, appliance, apparatus, tool or installation for use at work (whether exclusively or not);

This regulation defines work equipment as any machinery, appliance, apparatus, tool or installation for use at work. Any item used during work is covered by this regulation, with the exception of private cars, livestock, substances and structural items. The regulations also cover any activity involving the use of work equipment, such as modification, repair, cleaning, starting, stopping and servicing. Employers must ensure that all work equipment meets the essential

requirements of the regulations laid down for the manufacture of that equipment, and that inspections are carried out in the right manner, by the appropriate person.

Regulation 3: Application

(1) These Regulations shall apply -

(a) in Great Britain; and

(b) outside Great Britain as sections 1 to 59 and 80 to 82 of the 1974 Act apply by virtue of the Health and Safety at Work etc. Act 1974 (Application outside Great Britain) Order 1995("the 1995 Order").

(2) The requirements imposed by these Regulations on an employer in respect of work equipment shall apply to such equipment provided for use or used by an employee of his at work.

(3) The requirements imposed by these Regulations on an employer shall also apply -

(a) to a self-employed person, in respect of work equipment he uses at work;

(b) subject to paragraph (5), to a person who has control to any extent of -

(i) work equipment;

(ii) a person at work who uses or supervises or manages the use of work equipment; or

(iii) the way in which work equipment is used at work,

and to the extent of his control.

(4) Any reference in paragraph (3)(b) to a person having control is a reference to a person having control in connection with the carrying on by him of a trade, business or other undertaking (whether for profit or not).

(5) The requirements imposed by these Regulations shall not apply to a person in respect of work equipment supplied by him by way of sale, agreement for sale or hire-purchase agreement.

This regulation defines where the duties lie. In general, these regulations involve duties placed on employers (whether individuals, partners or companies) in respect of work equipment provided for or used by an employee at work. It also applies to the self-employed person in respect of work equipment used at work. It even extends beyond this to those who have control of work equipment, and to those who use, supervise or manage its use or the way it is used, to the extent of their control. These requirements do not apply to a person supplying work equipment for sale, sale agreement or hire purchase (machinery factors etc.).

Regulation 4: Suitability of work equipment

(1) Every employer shall ensure that work equipment is so constructed or adapted as to be suitable for the purpose for which it is used or provided.

(2) In selecting work equipment, every employer shall have regard to the working conditions and to the risks to the health and safety of persons which exist in the premises or undertaking in which that work equipment is to be used and any additional risk posed by the use of that work equipment.

(3) Every employer shall ensure that work equipment is used only for operations for which, and under conditions for which, it is suitable.

(4) In this regulation "suitable" means suitable in any respect which it is reasonably foreseeable will affect the health or safety of any person.

Every employer shall ensure that work equipment is:

- Constructed or adapted in a way that is suitable for the purpose for which it is provided
- Only used for the purpose for which it is provided
- Only used in the place and under the provisions for which it is provided.

These three aspects are the main thrust of this regulation. The first suggests that work equipment must have integrity, either in its initial design and construction or in the way it is adapted to meet the functional requirements of the task it performs. It must function correctly and it must not present a hazard to anyone exposed to it.

The second aspect stresses that work equipment can only be safe when used within its design criteria. An example of unsafe practice would be to use a one tonne sling to lift a five tonne load.

The third point concerns where work equipment is used. Design limits are again important, for example, equipment designed for use indoors or in dry conditions could become hazardous if used outdoors or during a thunderstorm.

Regulation 5: Maintenance

> *(1) Every employer shall ensure that work equipment is maintained in an efficient state, in efficient working order and in good repair.*
>
> *(2) Every employer shall ensure that where any machinery has a maintenance log, the log is kept up to date.*

Work equipment must be efficiently maintained and kept fit and suitable for its intended purpose. It must not be allowed to deteriorate in function or performance to such a level that it puts people at risk. This means that regular, routine and planned maintenance regimes must be considered if hazardous problems can arise. Machinery is not required to have a maintenance log, but where one exists, it must be kept up-to-date.

Regulation 6: Inspection

> *(1) Every employer shall ensure that, where the safety of work equipment depends on the installation conditions, it is inspected -*
>
> (a) after installation and before being put into service for the first time; or
>
> (b) after assembly at a new site or in a new location, to ensure that it has been installed correctly and is safe to operate.
>
> *(2) Every employer shall ensure that work equipment exposed to conditions causing deterioration which is liable to result in dangerous situations is inspected –*
>
> *(a) at suitable intervals; and*
>
> *(b) each time that exceptional circumstances which are liable to jeopardise the safety of the work equipment have occurred,*
>
> *to ensure that health and safety conditions are maintained and that any deterioration can be detected and remedied in good time.*
>
> *(3) Every employer shall ensure that the result of an inspection made under this regulation is recorded and kept until the next inspection under this regulation is recorded.*
>
> *(4) Every employer shall ensure that no work equipment –*
>
> *(a) leaves his undertaking; or*
>
> *(b) if obtained from the undertaking of another person, is used in his undertaking,*
>
> *unless it is accompanied by physical evidence that the last inspection required to be carried out under this regulation has been carried out.*

Where the safety of work equipment depends on the installation conditions, it is now the duty of every employer to ensure that these are inspected after installation and before the equipment is put into service for the first time, or after it is assembled at a new site or location. This inspection must be appropriate for the particular equipment (i.e. may be visual or more rigorous). Where necessary, appropriate testing must be carried out. A competent person who has had suitable training on the equipment and knows what has to be assessed and who to report to must carry out the inspection.

Regulation 7: Specific risks

> *(1) Where the use of work equipment is likely to involve a specific risk to health or safety, every employer shall ensure that -*
>
> *(a) the use of that work equipment is restricted to those persons given the task of using it; and*
>
> *(b) repairs, modifications, maintenance or servicing of that work equipment is restricted to those persons who have been specifically designated to perform operations of that description (whether or not also authorised to perform other operations).*
>
> *(2) The employer shall ensure that the persons designated for the purposes of sub-paragraph (b) of paragraph (1) have received adequate training related to any operations in respect of which they have been so designated.*

Where the use of work equipment involves specific risks to health and safety, employers must ensure that only personnel with suitable and sufficient training are allowed to operate or maintain such equipment.

Regulation 8: Information and instructions

(1) Every employer shall ensure that all persons who use work equipment have available to them adequate health and safety information and, where appropriate, written instructions pertaining to the use of the work equipment.

(2) Every employer shall ensure that any of his employees who supervises or manages the use of work equipment has available to him adequate health and safety information and, where appropriate, written instructions pertaining to the use of the work equipment.

(3) Without prejudice to the generality of paragraphs (1) or (2), the information and instructions required by either of those paragraphs shall include information and, where appropriate, written instructions on -

a) the conditions in which and the methods by which the work equipment may be used;
b) foreseeable abnormal situations and the action to be taken if such a situation were to occur; and
c) any conclusions to be drawn from experience in using the work equipment.

(4) Information and instructions required by this regulation shall be readily comprehensible to those concerned

All personnel involved with the use, maintenance and supervision of work equipment must have access to adequate information and, where necessary, written details concerning its safe use. This information must include details of:

- How the equipment should be use
- Restrictions on its use
- Foreseeable abnormal situations that could occur
- Action to be taken in case of the above.

Regulation 9: Training

(1) Every employer shall ensure that all persons who use work equipment have received adequate training for purposes of health and safety, including training in the methods which may be adopted when using the work equipment, any risks which such use may entail and precautions to be taken.

(2) Every employer shall ensure that any of his employees who supervises or manages the use of work equipment has received adequate training for purposes of health and safety, including training in the methods which may be adopted when using the work equipment, any risks which such use may entail and precautions to be taken.

Anyone who will use work equipment must be given adequate training in its use and must be well informed as to specific precautions that may be required. Employers must ensure that the same training is given to supervisors and managers. Training should detail the correct methods to adopt when using the equipment and any precautions required combating residual risks.

Regulation 10: Conformity with Community requirements

1) Every employer shall ensure that an item of work equipment has been designed and constructed in compliance with any essential requirements, that is to say requirements relating to its design or construction in any of the instruments listed in Schedule 1 (being instruments which give effect to Community directives concerning the safety of products).

2) Where an essential requirement applied to the design or construction of an item of work equipment, the requirements of regulations 11 to 19 and 22 to 29 shall apply in respect of that item only to the extent that the essential requirement did not apply to it.

3) This regulation applies to items of work equipment provided for use in the premises or undertaking of the employer for the first time after 31st December 1992.

If work equipment is subject to any European Directive ratified through Parliament (Statutory Instrument), it must comply with the essential requirements relating to its design or construction before it is supplied for use. As far as machinery is concerned, this means that any unit supplied after 1 January 1993 must comply with The Supply of Machinery (Safety) Regulations before it is used. Secondhand machinery acquired from outside the European Economic Area must also comply with this regulation before it is put into service. This means that all such units must carry the CE mark and must be supplied with a declaration of

conformity with the Essential Health and Safety Requirements. Before being put into use, all work equipment must be inspected.

Regulation 11: Dangerous parts of machinery

1) Every employer shall ensure that measures are taken in accordance with paragraph (2) which are effective -

(a) to prevent access to any dangerous part of machinery or to any rotating stock-bar; or
(b) to stop the movement of any dangerous part of machinery or rotating stock-bar before any part of a person enters a danger zone.

2) The measures required by paragraph (1) shall consist of -

(a) the provision of fixed guards enclosing every dangerous part or rotating stock-bar where and to the extent that it is practicable to do so, but where or to the extent that it is not, then
(b) the provision of other guards or protection devices where and to the extent that it is practicable to do so, but where or to the extent that it is not, then
(c) the provision of jigs, holders, push-sticks or similar protection appliances used in conjunction with the machinery where and to the extent that it is practicable to do so, but where or to the extent that it is not, then
(d) the provision of information, instruction, training and supervision.

3) All guards and protection devices provided under sub-paragraphs (a) or (b) of paragraph (2) shall -

(a) be suitable for the purpose for which they are provided;
(b) be of good construction, sound material and adequate strength;
(c) be maintained in an efficient state, in efficient working order and in good repair;
(d) not give rise to any increased risk to health or safety;
(e) not be easily bypassed or disabled;
(f) be situated at sufficient distance from the danger zone;
(g) not unduly restrict the view of the operating cycle of the machinery, where such a view is necessary;
(h) be so constructed or adapted that they allow operations necessary to fit or replace parts and for maintenance work, restricting access so that it is allowed only to the area where the work is to be carried out and, if possible, without having to dismantle the guard or protection device.

4) All protection appliances provided under sub-paragraph (c) of paragraph (2) shall comply with sub-paragraphs (a) to (d) and (g) of paragraph (3).

Measures must be taken to prevent access to dangerous parts of machinery or to stop dangerous movement before any part of an exposed person can enter a danger zone. Essentially these measures are laid out in a hierarchy, as detailed below:

- Where possible, fixed guards must be provided in order to enclose the dangerous parts (e.g. covering the drive belts, where access is not required on a regular basis).
- If this is not practical, movable guards and/or other protection devices shall be applied (e.g. using interlocked guards in areas where frequent access is required; using light curtains, mechanical trip devices and pressure mats to stop dangerous movements before personnel can reach hazardous areas).
- Where this is not possible, the next step would be to use jigs or push sticks. These must be used in conjunction with specialized training to allow the task to be performed while the body is kept as far away from the hazard(s) as possible (e.g. using a push stick to complete the cut when using a circular saw).
- When all the other measures have been applied as far as is reasonably practicable, the final step is to "warn and inform" by providing special training and, where necessary, supervision.

As implied in the final paragraph, each step must be analysed and, where practicable, put in place before deferring to a lower level of protection. This can only be achieved by carrying out a detailed risk assessment. This regulation also details the basic requirements for the construction of guards, as well as their maintenance and possible misuse.

Regulation 14: Controls for starting or making a significant change in operating conditions

> *1) Every employer shall ensure that, where appropriate, work equipment is provided with one or more controls for the purposes of -*
>
> *(a) starting the work equipment (including re-starting after a stoppage for any reason); or*
> *(b) controlling any change in the speed, pressure or other operating conditions of the work equipment where such conditions after the change result in risk to health and safety which is greater than or of a different nature from such risks before the change.*
>
> *2) Subject to paragraph (3), every employer shall ensure that, where a control is required by paragraph (1), it shall not be possible to perform any operation mentioned in sub-paragraph (a) or (b) of that paragraph except by a deliberate action on such control.*
>
> *3) Paragraph (1) shall not apply to re-starting or changing operating conditions as a result of the normal operating cycle of an automatic device.*

Machinery must be provided with one or more controls to start or regulate any change in speed, pressure or other condition that could increase the risk to the health and safety of the exposed person. All controls to start or restart machinery (after a stoppage) shall be by deliberate action. One exception is the case of an automatic machine operating in a normal cycle. However, if an operator interrupts the cycle to make adjustments or clear blockages, restart shall only be by deliberate action. If changing the mode of operation could present hazards to the operator (e.g. changing from automatic to manual or maintenance mode), this should only be possible by using a key or access code, for example.

Regulation 15: Stop controls

All work equipment, where appropriate, must be provided with one or more readily accessible controls that will bring the equipment to a safe condition in a safe manner. This control shall have priority over start commands. If required for reasons of health and safety, this control shall bring the work equipment to a complete stop and remove or switch off all forms of energy when the stop is achieved. In some cases, a stop command will only stop machine movement, leaving devices such as pumps or fans running. This is permitted if such devices do not present a danger to exposed persons.

1) *Every employer shall ensure that, where appropriate, work equipment is provided with one or more readily accessible controls the operation of which will bring the work equipment to a safe condition in a safe manner.*

2) *Any control required by paragraph (1) shall bring the work equipment to a complete stop where necessary for reasons of health and safety.*

3) *Any control required by paragraph (1) shall, if necessary for reasons of health and safety, switch off all sources of energy after stopping the functioning of the work equipment.*

4) *Any control required by paragraph (1) shall operate in priority to any control which starts or changes the operating conditions of the work equipment.*

Regulation 16: Emergency stop controls

One or more emergency stop controls must be provided, unless their operation would not reduce the risk. These will have priority over all other controls. Their operation will bring the equipment to a safe condition in the quickest possible time, without causing other hazards.

1) *Every employer shall ensure that, where appropriate, work equipment is provided with one or more readily accessible emergency stop controls unless it is not necessary by reason of the nature of the hazards and the time taken for the work equipment to come to a complete stop as a result of the action of any control provided by virtue of regulation 15(1).*

2) *Any control required by paragraph (1) shall operate in priority to any control required by regulation 15(1).*

The standards explain that, where appropriate, the stop function shall operate as a category 0 or 1 stop. These stops will be provided at workstations and other appropriate positions as directed by the risk assessment. Emergency stop devices include devices such as:

- Mushroom-headed buttons
- Bars
- Levers
- Kick-plates
- Pressure-sensitive cables.

All such devices must be well marked and easily recognised. Where possible, they must lock in the off position and require a definite action to reset. Resetting the emergency stop should not allow an automatic restart. This must only be possible by an additional voluntary action.

Regulation 17: Controls

1. *Every employer shall ensure that all controls for work equipment are clearly visible and identifiable, including by appropriate marking where necessary.*

2. *Except where necessary, the employer shall ensure that no control for work equipment is in a position where any person operating the control is exposed to a risk to his health or safety.*

3. *Every employer shall ensure where appropriate -*

   (a) that, so far as is reasonably practicable, the operator of any control is able to ensure from the position of that control that no person is in a place where he would be exposed to any risk to his health or safety as a result of the operation of that control, but where or to the extent that it is not reasonably practicable;

   (b) that, so far as is reasonably practicable, systems of work are effective to ensure that, when work equipment is about to start, no person is in a place where he would be exposed to a risk to his health or safety as a result of the work equipment starting, but where neither of these is reasonably practicable;

   (c) that an audible, visible or other suitable warning is given by virtue of regulation 24 whenever work equipment is about to start.

4. *Every employer shall take appropriate measures to ensure that any person who is in a place where he would be exposed to a risk to his health or safety as a result of the starting or stopping of work equipment has sufficient time and suitable means to avoid that risk*

Controls should be clearly visible and identifiable, and should be positioned so that operators can use them without risk to their health and safety. Where possible, they should be positioned so that operators can see that all areas are clear; if this is not possible, suitable additional measures should be put in place.

These can include audible and visual warnings to serve as alarms prior to the machine starting up. Good advice is available in the harmonised standards.

Regulation 18: Control systems

> *1) Every employer shall -*
>
> *(a) ensure, so far as is reasonably practicable, that all control systems of work equipment are safe; and*
> *(b) are chosen making due allowance for the failures, faults and constraints to be expected in the planned circumstances of use.*
>
> *2) Without prejudice to the generality of paragraph (1), a control system shall not be safe unless -*
>
> *(a) its operation does not create any increased risk to health or safety;*
> *(b) it ensures, so far as is reasonably practicable, that any fault in or damage to any part of the control system or the loss of supply of any source of energy used by the work equipment cannot result in additional or increased risk to health or safety;*
> *(c) it does not impede the operation of any control required by regulation 15 or 16.*

The control system must be safe and its operation must not cause risks to health and safety. The action of the control system must be assessed in all modes of use, taking into account the demand rate on the work equipment and making allowances for failures and faults that could affect health or safety. This is where the safety-related parts of the control system must be assessed and the application of the relevant specifications applied. As stated in Regulations 15 and 16, stops and emergency stops must always take precedence. The most significant part of this regulation is the requirement that a control system should fail to a safe condition, or that the possibility of it failing to danger should be minimised, as far as is reasonably practicable.

Regulation 19: Isolation from sources of energy

It must be possible to isolate the work equipment from all forms of energy. This isolation must be free from risk and, where practical, a means to lock off the energy source must be supplied.

Regulation 19 aims to enable functions such as maintenance, setting and cleaning to be carried out without risk.

> 1) *Every employer shall ensure that where appropriate work equipment is provided with suitable means to isolate it from all its sources of energy.*
>
> 2) *Without prejudice to the generality of paragraph (1), the means mentioned in that paragraph shall not be suitable unless they are clearly identifiable and readily accessible.*
>
> 3) *Every employer shall take appropriate measures to ensure that re-connection of any energy source to work equipment does not expose any person using the work equipment to any risk to his health or safety.*

Regulation 23: Markings

> *Every employer shall ensure that work equipment is marked in a clearly visible manner with any marking appropriate for reasons of health and safety.*

Any markings on work equipment that are appropriate to health and safety must be clear. Controls must be unambiguous and, if relevant, maximum speeds and directions must be indicated together with information on safe working loads and pressures. This requirement also covers individual machine identification for the employer's own purposes (e.g. for maintenance and, most importantly, for isolation).

Regulation 24: Warnings

> (1) Every employer shall ensure that work equipment incorporates any warnings or warning devices which are appropriate for reasons of health and safety.
>
> *(2) Without prejudice to the generality of paragraph (1), warnings given by warning devices on work equipment shall not be appropriate unless they are unambiguous, easily perceived and easily understood.*

Warning notices shall be fitted to all work equipment that presents a risk to health and safety. When all the risks from the use of work equipment have been addressed as per the regulations (as far as is reasonably practicable), any residual risk must carry sufficient visual or audible warnings to enable it to be used safely, i.e.:

"WARN AND INFORM".

It is important to note that this is the final and not the first step towards meeting the requirements of PUWER.

A1.3 References

[X1] *Safe Use of Work Equipment, Approved Code of Practice and Guidance, Provision and Use of Work Equipment Regulations 1998.* 1998, HSC. ISBN 0-7176-1626-6

[X2] Http://www.hse.gov.uk/hsebook *Simple guide to the provision and use of work equipment regulation 1998.* INDG291 6/04 HSE.

APPENDIX 2

METHODS AND TECHNIQUES

CONTENTS

LIST OF FIGURES AND TABLES

APPENDIX 2 – METHODS AND TECHNIQUES

The aim of this appendix is:

- To identify various widely-used methods and techniques along with more recently introduced procedures

The objectives of this appendix are:

- To provide a brief description of each method and technique
- To analyse the pros and cons of each method and technique

A2.1 Introduction

Ergonomic methods are designed to improve product design by understanding or predicting human interaction with those devices. Different methods tap different aspects of this interaction.

Each of the methods considered focuses on different aspects of human performance. The methods may be broadly classified as quantitative or qualitative approaches. All of the methods make predictions about the user, device, or the user and device. The quantitative methods predict speed of performance (e.g. MTM), errors (e.g. predictive human error analysis (PHEA) and task analysis for error identification (TAFEI)) and speed and errors (e.g. observations). The qualitative methods predict user satisfaction (e.g. questionnaires), device optimisation (e.g. checklists) or user and device interaction (e.g. hierarchical task analysis (HTA) and interviews).

The methods may have the greatest impact at the prototyping stages, particularly considering one of the key design stages – analytic prototyping, which, with the help of computer aided design technology that made retooling much easier, may allow alternative designs to be compared at this stage.

It is important to remember that each analytical technique described in this appendix complements (rather than supplants) the others. This is so because each technique attacks the system to be analysed differently - some are top-down, others are bottom-up. There is no 'jack of all trades' technique that answers all questions and is suitable for all situations

A2.2 List of Methods and Techniques

A) Methods-time measurements - MTM
B) Checklists
C) Questionnaires
D) Interviews
E) Observation
F) Task Analysis
G) Hierarchical Task Analysis - HTA
H) Predictive Human Error Analysis - PHEA
I) Potential Failure Mode and Effect Analysis - PFMEA
J) What-If Method
K) Fault Tree Analysis
L) Preliminary Hazard Analysis - PHA
M) Delphi Technique
N) Event Tree Analysis
O) CAD based simulations
P) NIOSH 81 and 91
Q) Rapid Entire Body Assessment - REBA

A) Methods-Time Measurements - MTM

Overview

MTM is one of 'Pre-determined Motion time' systems that were developed in 1946 by Maynard, Stegmerten and Schwab. MTM 'analyses any manual operation or method into the basic motions required to perform it and assigns to each motion a pre-determined time standard which is governed by the nature of the motion and the conditions under which it is made' **[X1]**

'MTM has become the most widely used and universally recognised such system in the world' (Prabhn and Baker, 1986 **[X1]**). It is recognised for it consistency and reliability.

Brief History of MTM

In the early 1900s, Frederick W Taylor spoke of time study in much the same sense that we use the time term. Amongst other things, he used stopwatch measurements to select the quickest and best method of making each elementary movement. Frank B Gilbreth and Lillian M Gilbreth applied motion study to subdivide elementary movements into 17 elements that they called therbligs. In the 1920s Asa B Segar concluded that, within practical limits, the time required for average qualified workers to perform a particular motion element is a constant. In the 1930s a number of time study analysts proposed schemes for combining these elementary motion times. Such combinations yielded synthetic times for a wide variety of manual methods of performing ordinary manual tasks. These techniques, which avoided the direct use of the stopwatch, became the first rudimentary pre-determined time systems.

After the Second World War, modern extensions of motion study were used at Westinghouse to collect a large data store of elementary motion times. Maynard, Stegmerten, and Schwab developed the Methods-Time Measurements pre-determined time system (then MTM and now MTM-1) based on the Westinghouse data. This and a number of derivative systems are still in use.

Procedure

MTM permit quick and efficient determination of cycle times with high precision. MTM use operators such as:

- Reach (R)
- Move (M)
- Grasp (G)
- Position (P)
- Turn (T)
- Apply Pressure (AP)
- Release (RL)
- Disengage (D)
- Eye travel time (ET)
- Eye focus (EF)

Each of these operators has its own list of data given TMU – Time Measurement Unit, as shown in Table 1, as an example on one of the operators – Reach, R. It is a simple matter of determining the components of the task in question and summing the times of the associated operators to arrive at an overall cycle time prediction.

Distance Moved Inches	TIME TMU				Case and Description
	A	B	C or D	E	
½ or less	2.0	2.0	2.0	2.0	A - Reach to object in fixed location
1	2.5	2.5	3.6	2.4	or to object in other hand or on
2	.	.	.	.	which other hand rests.
3	.	.	.	.	B - Reach to single object in
4	.	.	.	.	location which may vary slightly
5	.	.	.	.	from cycle to cycle
	.	.	.	.	C - Reach to object jumbled with
and so on	.	.	.	.	other objects in a group so that
.	.	.	.	.	search and select occur
.	.	.	.	.	D – Reach to a vary small object or
.	.	.	.	.	where accurate grasp is required
.	.	.	.	.	E – Reach to indefinite location to
.	.	.	.	.	get hand in position for body
.					balance or next motion or out of way.

Table A2.1. Time Measurement Unit for Reach - R **[X2]**

MTM is applied to actual tasks. Concrete design is needed before analysis can be carried out. It is used for predicting error-free performance times for defined tasks. Therefore, an exhaustive list of tasks with the process under analysis must be made.

The strength of MTM lies in choosing between alternative designs for a process because of performance times.

Pros

- Very straightforward and quick to apply
- Little training required
- Comparative tool among alternative designs

Cons

- Limited prediction
- Restrictive
- Requires validation outside specific operators
- Difference between real time and synthetic (flawless) performances

B) Checklists

Overview

Checklists need very little introduction; they are simply pre-defined lists of points against which an assessor can check the design of a process. There must be some form of the device (either on paper or in prototype) available to be checked.

There are many checklists that already exist and many can be found in design manuals with examples such as Motion Economy Checklist **[X3]** and Posture Checklist **[X4]**.

Technique

A checklist is an exposure assessment tool that can be used by persons with relatively little formal training in either ergonomics or process design. They are used in situations when the primary goal is to quickly analyse a number of tasks and use as a preliminary screening tool that classifies a job as either "acceptable" or "requiring further study".

A checklist can also be a reminder tool for machine design to ensure that all areas of design work are covered in order to move on to the next stage from concept to detail to prototype/initial build.

Another criterion used with a checklist is prioritisation to design and continuous improvements.

There is an interesting note about checklists on job analysis.
'The answers to checklist questions range from qualitative and subjective to quantitative and objective. For example, a subjective checklist may ask the question: "Does the worker appear to be out of breath?" A more objective, but more difficult to answer question would be: "What is the average energy expenditure of the employee in kilocalories per minute over the working day?".'**[X5]**

Pros

- Quickest techniques to train, practice and apply
- Execution is a simple matter of ticking boxes
- Most consistent of all method used here
- Ease of use
- Can be used as guidelines such as safety regulations
- Based on established knowledge
- Procedural analysis ensures all aspects are covered

Cons

- Checklists tend to overestimate the seriousness of certain exposures
- Do not provide precise quantitative measures of exposure or identify root causes of any "unacceptable" job
- Errors and cognitive problems not handled
- Limited transferability – excessive generality or specificity

C) Questionnaires

Overview

Questionnaires **[X5]** are ubiquitous among ergonomic methods. They are usually given to a cross-section of the operators for purposes of research, so access to them by designers would be advantageous.

They are ideal for accessing quick opinions from target people about usability or other aspects of an assembly process. In that sense – a working form of the assembly process must be in existence.

Method

The participant should undertake a thorough user trial with the assembly process in question, executing an exhaustive list of tasks. Having completed the tasks, the participant then fills in the questionnaire based on subjective opinion. It is merely a matter of answering the questions using the score of 1 (strongly disagree with accompanying statement) to 5 (Strongly agree).

Pros

- Efficient means of data collection
- Very low on resource usage in execution and analysis
- Facilitates comparisons between processes
- Auditing tool
- Quick to train and apply
- Use for continuous improvement on existing processes for re-design

Cons

- Limited outputs
- A very blunt tool
- Can only be usefully applied to an existing process

Motion Economy Checklist.

Suboperations	Yes	No
1. Can a suboperation be eliminated?	☐	☐
a. As unnecessary?	☐	☐
b. By a change in the order of the work?	☐	☐
c. By a change of tools or equipment?	☐	☐
d. By a change in layout of the workplace?	☐	☐
e. By combining tools?	☐	☐
f. By a slight change of material?	☐	☐
g. By a slight change in product?	☐	☐
h. By a quick-acting clamp on the jigs or fixtures?	☐	☐
2. Can a suboperation be made easier?	☐	☐
a. By better tools?	☐	☐
b. By changing leverages?	☐	☐
c. By changing positions of controls or tools?	☐	☐
d. By better material containers?	☐	☐
e. By using inertia where possible?	☐	☐
f. By lessening visual requirements?	☐	☐
g. By better workplace heights?	☐	☐

Movements	Yes	No
1. Can a movement be eliminated?	☐	☐
a. As unnecessary?	☐	☐
b. By a change in the order of work?	☐	☐
c. By combining tools?	☐	☐
d. By a change in tools or equipment?	☐	☐
e. By a drop disposal of finished material?	☐	☐
2. Can a movement be made easier?	☐	☐
a. By a change in layout, shortening distances?	☐	☐
b. By changing the direction of movements?	☐	☐
c. By using different muscles?	☐	☐
Use the first muscle group that is strong enough for the task:		
(1) Finger?	☐	☐
(2) Wrist?	☐	☐
(3) Forearm?	☐	☐
(4) Upper arm?	☐	☐
(5) Trunk?	☐	☐
d. By making movements continuous rather than jerky?	☐	☐

Holds	Yes	No
1. Can a hold be eliminated? (Holding is extremely fatiguing.)	☐	☐
a. As unnecessary?	☐	☐
b. By a simple holding device or fixture?	☐	☐
2. Can a hold be made easier?	☐	☐
a. By shortening its duration?	☐	☐
b. By using stronger muscle groups, such as the legs with foot-operated vises?	☐	☐

Delays	Yes	No
1. Can a delay be eliminated or shortened?	☐	☐
a. As unnecessary?	☐	☐
b. By a change in the work each body member does?	☐	☐
c. By balancing the work between the body members?	☐	☐
d. By working simultaneously on two items?	☐	☐
e. By alternating the work, each hand doing the same job, but out of phase?	☐	☐

Cycles	Yes	No
1. Can the cycle be rearranged so that more of the handwork is done during running time?	☐	☐
a. By automatic feed?	☐	☐
b. By automatic supply of material?	☐	☐
c. By change of man and machine phase relationship?	☐	☐
d. By automatic power cutoff at completion of cut or in case of tool or material failure?	☐	☐

Machine Time	Yes	No
1. Can the machine time be shortened?	☐	☐
a. By better tools?	☐	☐
b. By combined tools?	☐	☐
c. By higher feeds or speeds?	☐	☐

Table A2.2. Motion Economy Checklist. **[X3]**

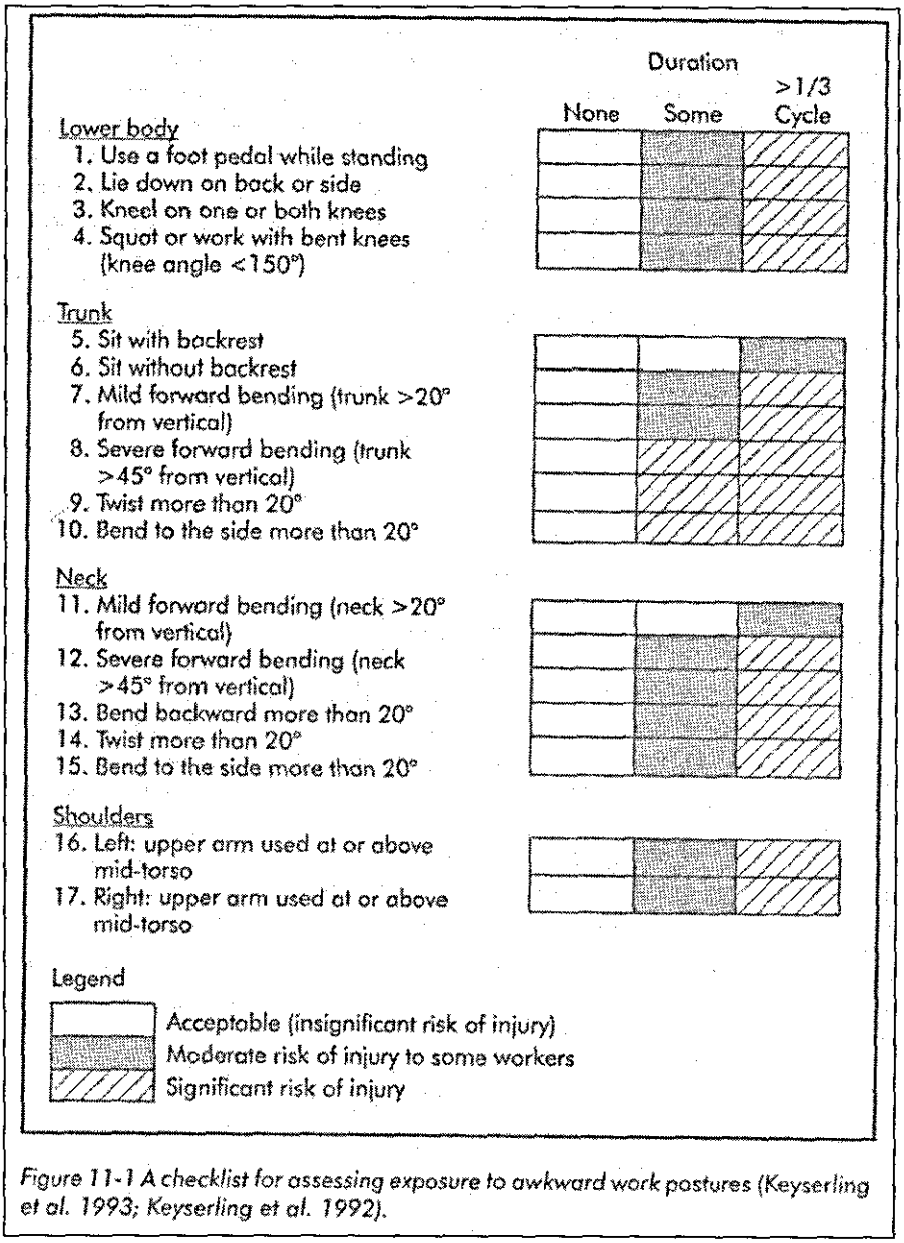


Figure 11-1 A checklist for assessing exposure to awkward work postures (Keyserling et al. 1993; Keyserling et al. 1992).

Table A2.3. Posture Checklist **[X4]**.

D) Interviews

Interviews **[X5]** are general information-gathering exercises, in this ergonomic context intended to elicit users' and designers' views about a particular task or system.

They possess great flexibility in application, although in usability evaluations a user trial is implied before carrying out an interview.

The interview may take one of these forms:

- Structured – orally administrated questionnaire

- Semi-structured – a more flexible approach, with questioning being guided but both restricted by a crib sheet
- Unstructured – a free form discussion

The main advantage of an interview is its familiarity to the respondent as a technique and this, combined with the face-to-face nature, is likely to elicit more information and probably more accurate information. In addition, because it is administrated, the interviewer can pursue intriguing lines of inquiry. Access to the end-users, operators, the output would be more revealing using these people as interviewees.

The interviewee should be granted an exhaustive user trial with an assembly machine under analysis, and then interviewed for their thoughts.
The interviewer should direct the questioning from open questions, such as 'what did you think of this aspect?' Through probing questions such as 'why do you think that?' to more closed ones such as 'is this good thing?' It may be useful to keep a protocol sheet to hand as a prompt for this - like a checklist.

The idea is that the interviewer opens a line of inquiry with an open question, and then follows it up. When one line of inquiry is exhausted, the interviewer moves to another line of inquiry. By doing this for every aspect of the process, one can be sure of having conducted a thorough interview. It is helpful to have prepared a data sheet for filling in responses during the interview.

As with checklists, interviews are adaptive, and if the interviewer feels that any particular section is irrelevant, they are free to exclude it. The professional wisdom of the interviewer can be an advantage for this technique.

Interviews can be applied at a stage in the design process, from asking people what they want in a process to eliciting opinions about the existing design.

Pros

- Familiar technique to most respondents
- Flexibility – information can be followed up 'on-line'
- Structured interview offers consistency and thoroughness

Cons

- Necessitates a user trial
- Time-consuming analysis
- Demand characteristics of situation may lead to misleading results.

E) Observation

Observation **[X5]** can be a very useful tool for recording physical task sequences or interactions between workers. It has the potential as a

technique for usability evaluation and it provides helpful guidelines for researchers.

The wide variety of observational techniques available fall into three broad categories:

1. Direct
2. Indirect
3. Participant

The applications and limitations are similar for each of them, and each generally requires at least two people (the observer and the participant). It is an advantage if the participant is the end user of the system. A working example of the assembly station needs to exist for observation to be viable.

The observational method begins with a scenario – the observer should present the participant with the assembly station and a list of tasks to perform. The observer may then sit back and record aspects of human-assembly station interaction that are of interest. Typical measures are execution times and any errors observed. This information can be integrated into the design process for the next generation of assembly stations.

Video observation can be a valuable tool, particularly with the computer-assisted analysis techniques now available. These techniques can greatly reduce the amount of data and time to collect it.

One of the main concerns with observation is the intrusiveness of the observational method; it is well known that the behaviour of the people can change purely as a result of being watched. Another problem is that one cannot infer causality from simple observation. That is, the data recorded must be purely objective record of what actually happened, without any conjecture as to why.

Pros

- Provides objective information which can be compared and ratified by other means
- Can be used to identify individual differences in task performance
- Gives "real-life" insight into human-machine interactions

Cons

- Observation requires at least a prototype (dummy) and outputs can be fed back into the design process to refine future generations of the assembly stations
- Very resource intensive, particularly during analysis
- Lab versus field trade-offs
- Does not reveal any cognitive information.

F) Task Analysis

Task analysis **[X5]** is one of the basic tools used by ergonomists to design and evaluate systems. The goal of ergonomics is to design jobs and tasks around the users' limitations and capabilities. Prior to designing equipment, the designer needs a clear understanding of how people will use it, build it, maintain it or even misuse it. The design of the system must incorporate the worker, equipment, and environment as a whole.

Task analysis is a process of assessing what a user does and why, step-by-step, and using this information to design a new system or analyse an existing system. The term task analysis refers to a methodology that can be carried out by many specific techniques. These techniques are used to describe or evaluate the interactions between humans and equipment or machines. They can be used to make a systematic comparison of the capabilities and limitations of the operator with the requirements of the system. The resulting information is useful for designing not only equipment but also procedures and training.

Task analysis seeks to identify all the various sub-tasks required to achieve the system's objectives. The various sources of information required by the users are identified, as are the actions they are required to take, the postures and movements needed and the loads under which the work is undertaken.

Evaluation and design of a system using task analysis more effectively integrates the human element into the system design and operations. System design must consider the human as a component of the system to ensure efficient and safe operation. The entire system must be thought of as being comprised of the following components: human operator, equipment (hardware and software), and environment. This systematic analysis of the tasks required of the user can result in equipment that is safer to use, easier to maintain, and operated using effective procedures.

By performing a task analysis early on in the system design, the users' capabilities and limitations can be incorporated into the design of the equipment, procedures, and training.

Task analysis is an iterative process. After the results of the task analysis are incorporated into the system design, it is necessary to perform the analysis again to ensure that the changes do not produce an unforeseen consequence. In addition to providing useful information to incorporate into the design of system, task analysis information can be used to develop and improve the personnel and training requirements. Task analysis can also be used to evaluate an existing system. If a problem is identified or a new piece of equipment is added, a task analysis can be used to enhance the system.

The better the quality of this information, the more readily can the designer meet the demands of the specification.

The procedure involves three closely linked stages:

- Information collection
- Information recording
- Information analysis

Step 1 - Information Collection

To decide what type of information should be collected and how it should be gathered, it is necessary to identify the focus of the analysis. That is, not only what system is to be the focus, but also what the results will be used for, such as redesigning a new system, modifying an existing system, or developing training.

For the system that is to be analysed, it is necessary to identify the task information requirements. The table below presents some types of information that might be required. The type of information required will help to determine the data collection technique.

Task Information	Description
Identification of subtasks	A listing of the activities involved with a task.
Grouping of subtasks	An organized, often hierarchical listing of the activities involved in a task.
Commonalities and interrelationships between subtasks	An indication of the extent to which subtasks have features in common and are linked to each other.
Importance or priorities of subtasks	Assessment of the criticality of subtasks.
Frequency of subtasks	Information on the relative frequency of occurrence of subtasks under different conditions.
Sequencing of subtasks	Information on the order of occurrence of subtasks under different conditions.
Decisions made in the execution of subtasks	Part of the sequencing may be based on a decision needed to choose the branch of activity and thus a given set of subtasks.
'Trigger' conditions for subtask execution	Execution of a subtask may depend upon the occurrence of a particular event or a decision made in during a previous task or subtask.
Objectives or goals of each subtask	A key feature of an analysis is the recording of the objectives of each subtask.
Performance criteria for each subtask	Recording of objectives may include statements about performance criteria.
Information required by each subtask	The items of information needed and their sources.
Information generated by each subtask	Information that the user inputs into the system.
Knowledge employed in making decisions	Information that the user utilizes in decision-making.
Knowledge of system employed in performing subtasks	Understanding that the user has of how the system functions.

Table A2.4. Type of task information collection

Within a given system, there is a job or jobs that are performed toward a common goal. A job can be broken down into tasks that must be executed in order to complete the job. Each of the tasks can be broken down into subtasks or steps. It may be helpful to consider that a job may have more than one person working to complete the assignment. In this instance it would be sensible to define a task as a single unit of the job for one individual, rather than sharing between two. Each task is made up of subtasks that are the steps taken to accomplish the task. Although jobs, tasks, and subtasks are defined differently by various people and for different applications, what matters the most is that there is consistency in these units and definitions within a given analysis.

Information collection can be an iterative process. Preliminary information must be collected about the system, specifically, data concerning the jobs and tasks and to break them down into subtasks. Once the details of the tasks and subtasks have been established, it may be necessary to collect more information and details. Potential methods of collecting information to be used in a task analysis have been outlined in the table below.

Potential Data Collection Methods	
Data Collection Method	Description
Observation	Observe and record information about the worker-performing job. May first observe the worker and subsequently ask the worker to provide verbal explanation while walking through the steps.
Interview	Ask the operator questions about job. Questions can be open-ended to learn more about the job. May conduct while worker is performing job or may do away from job site. Worker must know that the information collected will remain confidential and anonymous.
Focus group	Discussion with a group of typically 8 to 12 people, away from work site. A moderator is used to focus the discussion on a series of topics or issues. Useful for collecting exploratory or preliminary information that can be used to determine the questions needed for a subsequent structured survey or interview.
Existing documentation	Review any existing operating manuals, training manuals, safety reports, and previous analyses.
Checklist	Use a structured checklist to identify particular components or issues associated with the job. Available for a range of ergonomic issues, including workplace concerns, human-machine interfaces, environmental concerns.
Questionnaire	Use to collect systematically individual's views of a system or task. Questions should be structured, although can be open-ended.
Videotape	Tape the worker performing the job or specific tasks. Provides record of the job and ability to repeatedly study the tasks.

Table A2.5. Methods of collecting potential data

Step 2 - Information Recording

As information is gathered through methods such as those described above, it will need to be documented. The raw data may be collected in note form; however, as it is collected, it will be necessary to record and present the information in a format that can be used to analyse and process it. A simple and straightforward format that can be used to organize and record the collected data is a column format (see the figure below). With this type of format, the tasks and subtasks are listed down the left-hand side of the page and the information categories are listed across the top of the page. For each task or subtask, the task information collected is recorded throughout the page.

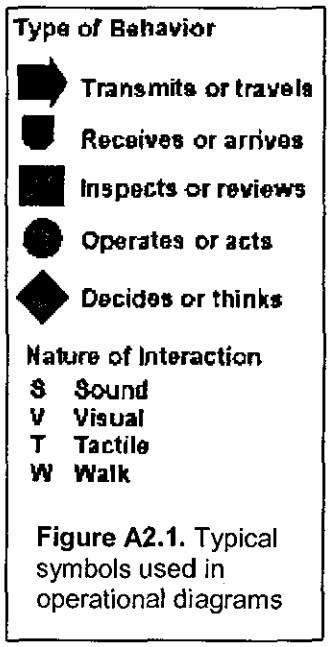


Figure A2.1. Typical symbols used in operational diagrams

Other examples of formats that can be used to break down and present the task information include hierarchical diagrams, operational sequence diagrams, and timelines. A hierarchical format can be used to break down the tasks into subtasks. The top of the diagram lists the more general tasks, each in an individual box. Detailed subtasks that comprise each task branch off the appropriate task box. Operational sequence diagrams are used to show the sequence of steps and the relationships between them in completing the task. This method requires making a flow chart of the task using standard symbols to present the information. (See Figure A1 for illustration of typical symbols used in operational diagrams). Finally, timelines are used to define not only the sequence of steps that make up the task, but also the time that they occur and duration. This presentation is particularly useful when there are several workers and machines interacting and can help to identify when worker and/or machines are being overloaded or under loaded during the completion of a task.

Step 3 - Information Analysis

The final step is using the information to yield the basic data for design decisions. The five selected techniques outlined below may be relevant to equipment design. One of these techniques may be appropriate to do a simple analysis; however, analyses that are more complex may require additional resources or perhaps an expert to conduct the analysis.

Suggested Task Analysis Techniques for Equipment Design	
Analysis Technique	Description
Hierarchical Task Analysis	A broad approach to task analysis used to represent relationship between tasks and subtasks. Documents system requirements and order in which tasks must take place. Useful to determine how the work should be organized to meet the systems goals. Applications range from taking a global look at a system to looking at specific details of a system, such as interface design.
Interface Surveys	A group of methods used for task and interface design to identify specific human factors problems or deficiencies, such as labelling of controls and displays. These methods require an analyst to systematically conduct an evaluation of the operator-machine interface and record specific features. Examples of these methods include control/display analysis, labelling surveys, and coding consistency surveys.
Link analysis	Used to identify relationships between components of a system. Provides a means to represent the nature, frequency, and/or importance of links between components within a system.
Operations sequence diagrams	Used to illustrate relations between personnel, equipment, and time. Identifies operations in the order in which they are carried out using standard symbols. Flowchart represents information flow and behaviour rather than the observable process.
Timeline analysis	Set of principles rather than a precisely defined technique. Used to map operator's tasks along time to take into account task frequency, duration, and interactions with other tasks and personnel.

Table A2.6. Type of analysis techniques for design

G) Hierarchical Task Analysis (HTA)

As the name implies **[X5 & X6]**, this breaks down the task under analysis into a hierarchy of goals, operations and plans. Goals are the unobservable task goals associated with operation of the process. Operations are the observable behaviours or activities that can accomplish the goals. Plans are unobservable decisions and planning on the behalf of the operator.

The task is described by a task statement, which states the overall goal of the task. This forms the top level of the hierarchy, which is then decomposed into sub goals. Sub goals can be decomposed further until an appropriate stopping point is reached.

The sub goals at any level of the hierarchy must completely describe the superordinate goal; conversely, a subordinate goal must be exhaustively described by its sub goals.

Plans are inserted between levels to provide structure and order to the subtasks immediately below them. Essentially, a plan describes the way in which the sub tasks combine to form the superordinate task. Thus, plans are very important elements of HTA.

It is useful, although not essential, to have access to the specifications for the design in question.

Pros

- Easily implemented, once initial concepts have been understood.
- Rapid execution – this provides user satisfaction, as good progress is made in little time.

Cons

- HTA is the most time-intensive method in training and practice
- Provides more descriptive information than analytical information.
- Little which can be used to directly provide design solutions
- Does not handle cognitive components of tasks (e.g. decision making), only observable elements.

H) Predictive Human Error Analysis (PHEA)

Overview

PHEA is a development of HTA (Hierarchical Task Analysis) **[X5]** in that it uses each bottom level task of the hierarchy as its inputs. These tasks are categorised according to a pre-determined taxonomy and form the basis of subsequent error identification. Thus, the first step of a PHEA must be to devise an HTA if one is not already available.

Human error taxonomy is used to classify tasks into one of five error types (action, retrieval, checking, selection and information communication). The analyst then refers to the taxonomy to access credible error modes for each task.

For each potential error, the analyst then evaluates consequentiality, ordinal probability and criticality. Then, based on the subjective judgement of the analyst, possible remedial actions are proposed, along with recovery steps at which they may be affected.

Procedure

For every bottom-level task in the HTA, the following procedure is adopted.

1. Assign the task step into type provided in the PHEA taxonomy:

   - Action,
   - Retrieval,
   - Checking,
   - Selection and
   - Information communication.

2. Analyst decides whether any of the types are credible for the current situation for each error type:

- Description of error
- Determine the consequence
- Provide recovery steps
- The ordinal probability of it occurring
  - Low (hardly ever occur)
  - Medium (has occurred once or twice)
  - High (occurs fairly frequently)
- Its criticality
- Its all or none
- Any proposed remedies

3. Are there any more error types in the task? If so go back to 2.
If not go to next task and start from 1.

This procedure is repeated for every bottom-level task in the HTA.

Pros

- Structured and comprehensive procedure
- Taxonomy prompts analyst for potential errors
- Encouraging validity and reliability data
- Ideal for use in system control - control panel with buttons and switches.
- Error reduction strategies offered as part of the analysis, in addition to predicted errors such as control programming of a process
- Substantial time economy compared to observation e.g. doesn't wait until it occurred!
- Very useful before or around commissioning stages e.g. the output (predicted errors) may be used in redesign/re-program

Cons

- One of the longest methods to train and practice in
- Can be tedious and time-consuming for complex tasks
- Extra work involved if HTA not already available

I) PFMEA Potential Failure Mode and Effect Analysis

Overview

A Potential Failure Mode and Effects Analysis **[X7]** is a forward logic (bottom-up), tabular technique that explores the ways or modes in which each system element can fail and assesses the consequences of each of these failures. PFMEAs are useful tools for cost and benefit studies, to implement effective risk mitigation and countermeasures

As a tool it enables potential errors or faults to be predicted during the early design stages.

Description

Many companies use PFMEA as a central pillar of their design process. PFMEA provides a structured approach to the analysis of the root causes (of

failure), the estimation of severity or impact and the effectiveness of strategies for prevention. The ultimate output is the generation of action plans to prevent, detect or reduce the impact of potential modes of failure. In a nutshell, it encourages the design team to consider:

- Recognise and evaluate the potential failure of a product/process and the effects of that failure.
- Identify actions that could eliminate or reduce the chance of the potential failure occurring, and
- Document the entire process.

PFMEA emerged from the US Military in the late 1940s as a tool to improve the evaluation of reliability of equipment. Its benefits quickly became apparent and it was adopted by aerospace industries and NASA during the Apollo program in the 1960s. It was later taken up by many of the larger automotive companies, including Ford in the 1970s. It has since become a core tool in product development in many organisations and is recommended as a part of an organisation's quality management system.

The basic logic can be applied at a number of levels, including organisational issues, strategy issues, product design issues, production processes and individual components. Typically, it is used to analyse either a product design or production process:

One of the most important factors for the successful implementation of a PFMEA program is timeliness. It is meant to be a "before-the-event" action, not an "after-the-fact" exercise. To achieve the greatest value, the PFMEA must be done before a process failure mode has been incorporated into a process. Up-front time spent properly completing a PFMEA, when process changes can be most easily and inexpensively implemented, will minimise late changes crises. A PFMEA can reduce or eliminate the chance of implementing a preventive/corrective change that would create an even larger concern. Communication and coordination should occur among all PFMEA teams.

There are three basis cases for which PFMEA's are generated, each with a different scope or focus:

1. Case 1: New designs, new technology, or new process. The scope of the PFMEA is the complete design, technology, or process.

2. Case 2: Modifications to existing design or process (assumes there is a PFMEA for the existing design or process). The scope of the PFMEA should focus on the modification to design process, possible interactions due to the modification, and field history.

3. Case 3: Use of existing design or process in a new environment, location, or application (assumes there is a PFMEA for the existing design or process). The scope of the PFMEA is the impact of the new environment or location on the existing design or process.

Procedure

A Process PFMEA is an analytical technique used by a manufacturing/Assembly-Responsible Engineer/Team as a means to ensure that, to the extent possible, potential failure modes and their associated causes/mechanisms have been considered and addressed. In its most rigorous form, a PFMEA is a summary of the team's thoughts (including an analysis of items that could go wrong based on experience) as a process is developed. This systematic approach parallels and formalises the mental discipline that an engineer normally goes through in any manufacturing planning process.

FMEA worksheet

Project: Product: System: ①					Date: Prepared by: ②					FMEA Number:: Reference documents: ③	
System / Component / Function	Potential failure mode	Potential effect(s) of failure	Severity	Critical?	Potential cause(s) of failure	Occurrence	Current design controls	Detection	Risk Priority Number	Recommended action(s)	Responsibility & completion date
④	⑤	⑥	⑦	⑧	⑨	⑩	⑪	⑫	⑬	⑭	⑮

Table A2.7. PFMEA worksheet

1. Level of analysis
   The analysis can be carried out at a project, product, system, subsystem or component level. It is important to be clear about the level at which the current analysis is taking place. A hierarchical organisation of analysis enables the design team to drill down to detail where appropriate.

2. Date & prepared by
   To record who was involved and when the analysis took place.

3. FMEA number & reference information
   Clear numbering is important, to enable the team to trace an analysis from system to component level. It may also be important to reference any important test results, documents or drawings here.

4. System/component/function
   The specific name/number of the element or issues under study.

5. Potential Failure Modes
   The manner in which a component, subsystem or system could possibly fail while being used. Here the design team must be creative in seeking ideas for all potential modes of failure. Ask open and general questions: How can it fail? Under what conditions? What types of use? etc.

6. Potential Effects of Failure
   For each mode of failure, what will be the likely effect? How would the failure affect different stakeholders? What will be the likely outcomes if the system or component fails? Provide as detailed a description as is necessary of the potential impact of failure. An individual failure mode may have many possible effects.

7. Severity rating
   Each failure effect can be judged for its potential seriousness. Typically, this is done by scoring the effect on a 1 to 5 (or 10) scale. This value should be discussed and negotiated by all members of the team. A team may wish to define for itself the severity to go with each score, below is a suggested scheme:

   Rating Criteria

   5 (9-10) With potential safety risk or legal problems - potential loss of life or major dissatisfaction
   4 (7-8) High potential customer dissatisfaction - serious injury or significant mission disruption
   3 (5-6) Medium potential customer dissatisfaction - potential small injury, mission inconvenience / delay
   2 (3-4) The customer may notice the potential failure and may be a little dissatisfied - annoyance
   1 (1-2) The customer will probably not detect the failure – undetectable

Critical?
A column is provided to enable the rapid identification of potentially critical failures which must be addressed (e.g. safety issues, sales issues etc.)

Potential Cause/Mechanisms of Failure
Each failure mode will have an underlying root cause. Thus, it is important to spend time to establish the potential root causes or mechanisms of failure, by asking '*what is the likely cause of the failure mode?*' Possible causes could include: Wrong tolerances, poor alignment, operator error, component missing, fatigue, defective components, maintenance required, environment ... etc.

Occurrence Ranking
It is also necessary to consider the likelihood of the potential failure occurring. Here, a 'probability' assessment is made by the team and scored on a 1 to 5 (or 10) scale. Possible occurrence ratings (you can define them in other ways) are shown below:

Rating Criteria

5 (9-10) Very high probability of occurrence
4 (7-8) High probability of occurrence
3 (5-6) Moderate probability of occurrence
2 (3-4) Low probability of occurrence
1 (1-2) Remote probability of occurrence

This section is critical in the FMEA procedure and each of the responses categorised as very high or high should be considered and addressed.

11. Current design controls
Are there any design controls that aim to reduce or eliminate the potential failure? These could include labels, barriers, instructions or total redesigns. Other controls could include prototyping, evaluation or possibly market surveys.

12. Detection rating
The final rating aims to establish how 'detectable' the potential fault will be. Will it be instantly noticeable or will it not be apparent. In addition, how likely is it that the controls listed will enable the detection of the potential failure? Suggested ratings on a scale of 1 to 5 (or 10):

Rating Criteria

5 (9 or 10) Zero probability of detecting the potential failure cause
4 (7 or 8) Close to zero probability of detecting potential failure cause
3 (4, 5 or 6) Not likely to detect potential failure cause
2 (2 or 3) Good chance of detecting potential failure cause
1 (1) Almost certain to identify potential failure cause

If the FMEA is being carried out at a 'project' level, then it can be beneficial to consider this value as 'react-ability'. Will it be possible to react to the failure rapidly enough to reduce its impact sufficiently?

13. Risk Priority Number (RPN)
It is likely that the team will have identified many possible failure modes and effects. Each one needs to be assigned a 'Risk Priority Number' to enable the prioritisation of mitigating action. The RPN is simply the product of the severity, occurrence and detection ratings:

RPN = Severity rating x Occurrence rating x Detection rating

- perhaps more easily remembered as:

RPN= S*O*D

The RPN value gives an indicator of the design risk and generally, the items with the highest RPN and severity ratings should be given first consideration.

14. Recommended actions
Follow up is essential and actions to reduce the impact or likelihood are essential. These actions should be specific and preferably measurable. Attention should be given to actions that address the root cause and not the symptoms.

15. Responsibility
Finally, all actions should be clearly allocated (to an individual, department and/or organisation) and a clear deadline given.

16. Additional columns if wanted:
Some FMEA users add additional columns to record the actual actions taken or keep an update on the status of actions. It can also be a good idea to revise the RPN value following the corrective action. This enables full traceability between potential problems and the outcomes of actions.

Pros

- Structured and comprehensive procedure
- Part of TQM – built in policy for each company that have Quality Control Plans
- Prompts designers to be aware of potential problems and incorporate controls in the design to reduce/minimise or eliminate likelihood of occurring or when it occurred its should be contained.
- Results can be used to optimise reliability and design, incorporate "fail safe" features into the system design, obtain satisfactory operation using equipment of "low reliability", and guide in component and manufacturer selection
- It identifies weaknesses
- It identifies the significant factors which affect a product/process and the critical aspects which must be addressed;
- It defines responsibility for action
- It provides information in a very structured way on the critical factors.

Cons

- Does not model cognitive components of error mechanisms
- Some predicted failures and remedies are unlikely or lack credibility, thus posing a false economy
- Can be tedious and time-consuming for complex tasks
- Probabilities or the consequences of system failures induced by co-existing, multiple-element faults or failures within the system are not addresses or evaluated.
- Human error and hostile environments frequently are overlooked.

(J) What-if method

Overview
This is a relatively uncomplicated process **[X8]**, which considers "what-if" questions at each stage of handling or processing. The answers are to evaluate the effects of component failures or procedural errors.

For more complex situations, the "what-if" study can be organised through the use of checklists and assigning certain aspects of the process to the assessor having the greatest experience or skill in evaluating those aspects.

This process has limited applications when used on its own but is often used in conjunction with other methods.

What–If Analysis is a structured brainstorming method of determining what can go wrong and judging the likelihood and consequences of those situations occurring. The answers to these questions form the basis for making judgements regarding the acceptability of those risks and determining a recommended course of action for those risks deemed to be unacceptable. An experienced review team can effectively and productively discern major issues concerning a process or system. Led by an energetic and focused facilitator, each member of the review team participates in assessing what can go wrong based on their past experiences and knowledge of similar situations.

Team members usually include operating and maintenance personnel, design and/or operating engineers, personnel with specific skills as needed (chemist, structural engineer, radiation expert, etc.) and a safety representative. At each step in the procedure or process, What-If questions are asked and answers generated. To minimize the chances that potential problems are not overlooked, moving to recommendations is held until all of the potential hazards are identified.

The review team then makes judgments regarding the likelihood and severity of the "What-If" answers. If the risk indicated by those judgements is unacceptable then a recommendation is made by the team for further action. The completed analysis is then summarized and prioritised and responsibilities are assigned.

Procedure
The first steps in performing an effective analysis include choosing the boundaries of the review, involving the right individuals, and having the right information. The boundaries of the review may be a single piece of equipment, a collection of related equipment or an entire facility. A narrow focus results in an analysis that is more detailed and explicit in defining the hazards and specific recommended controls. As the review boundaries expand to include the equipment involved in a large complex process or even an entire facility the findings and recommendations become more overview in nature. The boundaries can include the steps in the construction of the system under review, the steps involved in the operation of the equipment or

facility or the steps required to maintain the equipment or facility. A clear definition of the boundaries of the analysis starts the review off in an effective manner.

Description of operation:	By:	Date:

What If?	Answer	Likelihood	Consequences	Recommendations

Table A2.8. What-If Analysis Form

Assembling an experienced, knowledgeable team is probably the single most important element in conducting a successful What-If analysis. Individuals experienced in the design, operation and servicing of similar equipment or facilities is essential. Their knowledge of design standards, regulatory codes, past and potential operational errors as well as maintenance difficulties brings a practical reality to the review. On the other hand, including new designers and new operators in the review team mix is an excellent learning opportunity for subjects that are not taught in design school or in operating classes.

The next most important step is gathering the necessary information. One important way to gather information on an existing process or piece of equipment is for each review team member to visit and walk through the operation. Videotapes of the operation or maintenance procedures or still photographs are important, and often under-utilized, excellent sources of information. Additionally, design documents, operational procedures, or maintenance procedures are essential information for the review team. If these documents are not available, the first recommendation for the review team becomes clear. Develop the supporting documentation! Effective reviews cannot be conducted without up-to-date reliable documentation. An experienced team can provide an overview analysis, but nuances to specific issues such as interlocks, pressure relief valves, or code requirements are not likely to be found.

Conducting the Review

Now that the team has had an opportunity to review the information package, the next step is conducting the analysis. Generally, an experienced hazards review facilitator will lead the group through a series of "What-If" questions. A focused, energetic and knowledgeable facilitator can keep the review moving productively and effectively. A scribe is usually assigned to take notes of the review. Recent advances in software as well as laptop computers can provide

on-line data collection possibilities by the scribe. That is, as hazards are identified, judgements made, and responsibilities assigned, the scribe can input the data and agreements live! Scheduling more than four hours at a time can result in the team members losing energy and eager to finish the analysis rather than probing deeper. Generally, in a well-designed system or well-operated system, the participants in the review will need to work hard to find major issues. It is the job of the facilitator to keep the effort moving productively.

1. ***Developing the "What-If" Questions*** – Using the documents available and knowledge of the review team, "What-If" questions can be formulated around human errors, process upsets, and equipment failures. These errors and failures can be considered during normal production operations, during construction, during maintenance activities, as well as during de-bugging situations. The questions could address any of the following situations:

- Failure to follow procedures or procedures followed incorrectly
- Procedures incorrect or latest procedures not used
- Operator inattentive or operator not trained
- Procedures modified due to upset
- Process conditions upsets
- Equipment failure
- Instrumentation miscalibrated
- De-bugging errors
- Utility failures such as power, steam, gas
- External influences such as weather, vandalism, fire
- Combination of events such as multiple equipment failures

Experienced personnel are knowledgeable of past failures and likely sources of errors. That experience should be used to generate "What-If" questions.

As the "What-If" questions are being generated, the facilitator should ensure that each member of the team has an opportunity to input potential errors or failures. Determining the answer to each question as it is generated creates the danger of closing too soon on all possible upsets. The facilitator needs to assess if the team has really looked at all of the possibilities before going to the next step of answering the questions. It may be necessary to break down the analysis into smaller pieces if there is danger of just developing questions and not gaining the value of having them fresh in mind to answer those questions.

2. ***Determining the Answers*** – After being assured that the review team has exhausted the most credible "What-If" scenarios, the facilitator then has the team answer the question, what would be the result of that situation occurring?

If done correctly, reviewing the potential equipment failures and human errors can point out the potentials for not only safety and health improvements but also the opportunity to minimize operating and quality problems. Including the

operators and trades personnel in the review can bring a practical reality to the conclusions that will be reached.

3.***Assessing the Risk & Making Recommendations*** – Having no definitive answers to the "What-If" questions, the next task is to make judgements regarding the likelihood and severity of that situation. In other words, what is the risk? The review team needs to make judgements regarding the level of risk and its acceptability.

The team has not only assessed the risk at each situation but has also made its recommendation. The discussion of each situation leads naturally to the recommendation. The team will then continue the review, question by question, until the entire process or operation has been analysed. At this point, the facilitator should have the team step back and review the "big picture" to determine whether they have inadvertently missed anything.

Reporting the Results

The hard work of conducting the analysis has been competed. The important work of reporting the results remains. The structure of the organization generally determines to whom and how the results are reported. Usually, the department or plant manager is the customer of the review. The leader of the review team will generate a cover memo that details the scope of the review as well as the major findings and recommendations. In some organizations, the report recommendations will also include who has been assigned the responsibility to follow up and the time frame. In other cases, a separate staff or function will review the recommendations and determine the actions required. A periodic report is then generated to summarize the present status of each of the recommendations. Those organizations that have a well-developed hazard review program require follow-up assignments based on the associated hazard levels.

Pros

- Simple to Use
- Effectively applied to a variety of processes
- No specialised tools or techniques needed
- Individuals with little hazard analysis training can participate in a full and meaningful way
- Can be applied to any phases of machine life from concept design, during debugging, during operations, or during maintenance.
- Result are immediately available and can be applied quickly

Cons

- The technique does rely heavily on the experience and intuition of the review team.
- It is somewhat more subjective than other methods, which require a more formal and systematized approach.
- If all of the appropriate What-If questions are not asked, this technique can be incomplete and miss some hazard potentials.

(K) Fault Tree Analysis (FTA)

Background

Fault tree analysis **[X9]** was developed in 1962 for the US Air Force by Bell Telephone Laboratories for use with the Minuteman system...was later adopted and extensively applied by the Boeing Company...is one of many symbolic logic analytical techniques found in the operations research discipline.

Overview

A graphic "model" of the *pathways* within a system that can lead to a *foreseeable, undesirable loss event.* The pathways interconnect contributory events and conditions, using *standard logic symbols.* Numerical probabilities of occurrence *can* be entered and propagated through the model to evaluate the probability of the foreseeable, undesirable event.

FTA is primarily a means of analysing (not identifying) hazards. This model traces the failure pathways from a predetermined, undesirable condition or event, called the TOP event, of a system to the failures or faults that could act as causal agents.

The FTA includes generating a fault tree, entering failure likelihood for each fault tree initiators, propagating failure likelihood to determine the TOP event probability, and determining cut sets and path sets.

A ***cut set*** is any group of initiators that, if they all occur, will cause the TOP event to occur.

A ***minimal cut*** is a least group of initiators that will, if they all occur, cause the TOP event to occur.

A ***path set*** is a group of fault tree initiators that, if none of them occurs, will guarantee that the TOP event cannot occur.

The probability of failure, P_F, for an event is defined as the number of failures per number of attempts. This can be expressed as:

$\mathbf{P_F = F/(S+F)}$, where F = number of failures and S = number of successes

FTAs are particularly useful for high-energy systems (ie, potentially high severity events), to ensure that an ensemble of countermeasures adequately suppresses the probability of mishaps. A FTA is a powerful diagnostic tool for analysis of complex systems and is used as an aid for design improvement.

The subjective nature of risk assessment is relegated to the lowest level (root causes of effects) rather than at the top level.

It has also been found useful in determining the cause of accidents.

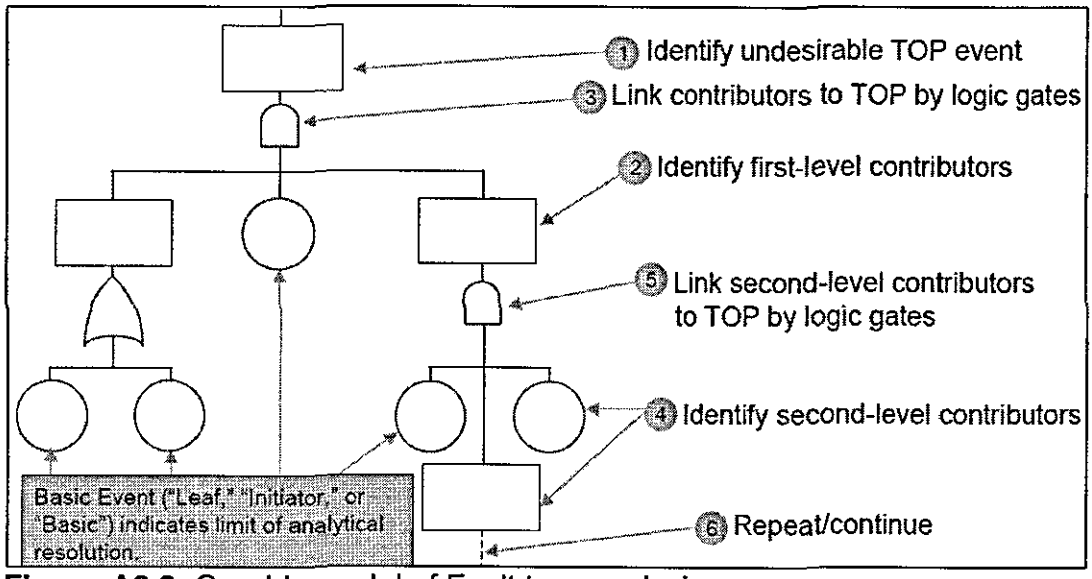


Figure A2.2. Graphic model of Fault tree analysis

Procedures

Fault Tree construction process

1. Identifying TOP Events ①

- Explore historical records (own and others)
- Look to energy sources.
- Identify potential mission failure contributors.
- Development "what-if" scenarios.
- Use "shopping lists."

2. Adding Contributors to the Tree ② **to** ⑥

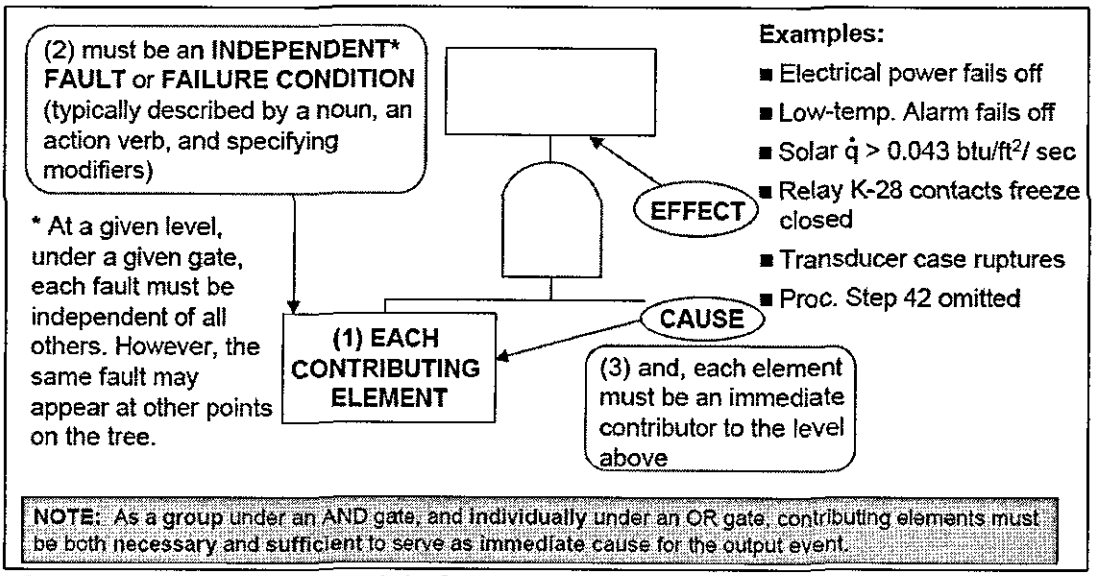


Figure A2.3. Graphic model of contributors to the Fault tree

3. Probability Determination

The probability of failure must be determined for each basic event or initiator.

Sources for these failure probabilities may be found from manufacturer's data, industry consensus standards, historical evidence (of the same or similar systems), simulation or testing, Delphi estimates and the log average method. The Delphi technique derives from the consensus of experts. The log average method is useful when the failure probability cannot be estimated but credible upper and lower boundaries can be estimated.

Probabilities must be used with caution to avoid the loss of credibility of the analysis.

Once probabilities are estimated for all basic events or initiators, they are propagated through logic gates to the intermediate events and finally the TOP event.

The probabilities of failure of independent inputs through an AND gate is the *intersection* of their respective individual probabilities.

$$P_T = P_1P_2.....P_n$$

The probabilities of failure of independent inputs through an OR (inclusive) gate is the *union* of their respective individual probabilities.

$$P_T = P_1+P_2+.....+P_n$$

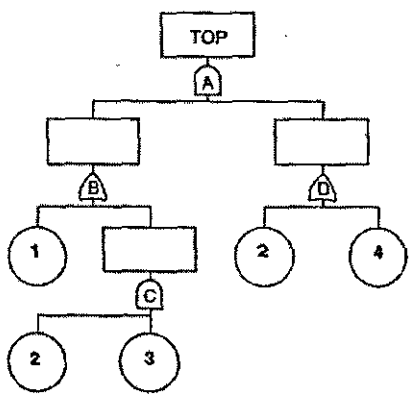
4. Identifying and assessing cut set

All cut sets and minimal cut sets are determined. Analysis of a cut set can help evaluate the probability of the TOP event, identify qualitative common cause vulnerability, and assess common cause probability. Cut sets also enable the analysis of the structural, quantitative, and item significance of the tree.

(a) Identifying

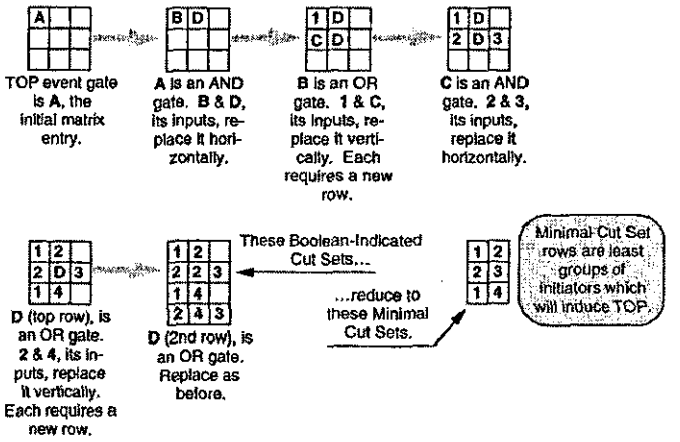
PROCEDURE:

- Assign letters to gates. (TOP gate is "A.") Do not repeat letters.
- Assign numbers to basic initiators. If a basic initiator appears more than once, represent it by the same number at each appearance.



- Construct a matrix, starting with the TOP "A" gate...

(b) Determining



(c) Assessing. The cut set probability, P_K (the probability that the cut set will induce the TOP event) is mathematically the same as the propagation through an AND gate, expressed as:

$$P_K = P_1P_2P_3P_4....P_n$$

(d) Analyse the probability of each common cause occurring, and inducing all terms within the affected cut set.

(e) Assess the structural significance of the cut sets to provide qualitative ranking of contributions to system failure. Assuming all other things are equal then:

i) A cut set with many elements indicates low vulnerability
ii) A cut set with few elements indicates high vulnerability
iii) Numerous cut sets indicates high vulnerability
iv) A cut set with a single initiator, called singleton, indicates a potential single-point failure.

(f) Assess the quantitative importance, I_K of each cut set, K. That is, determine the numerical probability that this cut set induced the TOP event, assuming it has occurred.

$$I_K = P_K/P_T$$

where P_K = probability that the cut set will occur, and
P_T = the probability if the TOP event occurring.

(g) Assess the quantitative importance, I_e, of each initiator, *e*. That is, determine the numerical probability that initiator *e* contributed to the TOP event, if it has occurred.

$$I_e = \sum_{e}^{Ne} I_{Ke}$$

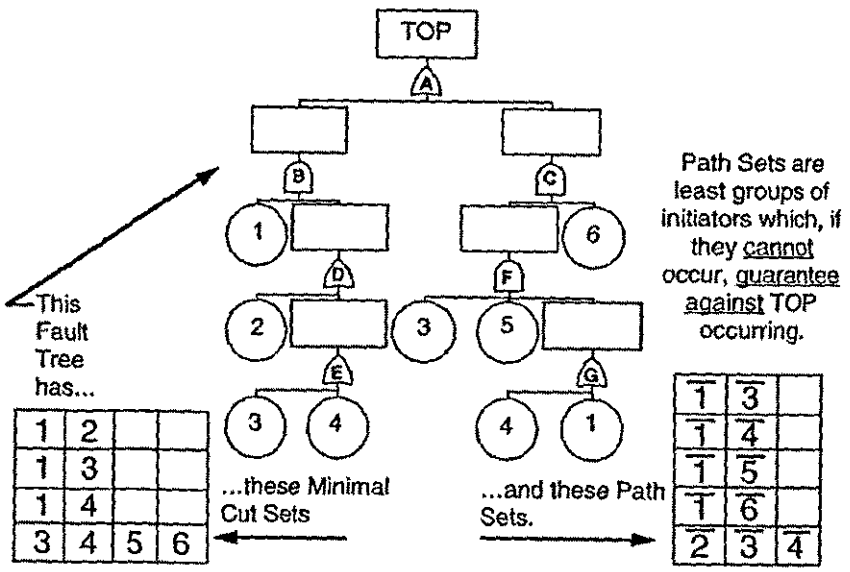
where N_e = number of minimal cut sets containing initiator *e*, and
I_{ke} = importance of the minimal cut sets containing initiator *e*.

5. Identifying path sets

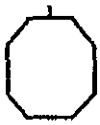
All path sets are determined.

(1) Exchange all AND gates for OR gates and all the OR gates for AND gates on the fault tree.

(2) Construct a matrix in the same manner as for cut sets. Each row of the final matrix defines a path set of the original fault tree.



Fault tree construction symbols

Symbol	Name	Description
	Event (TOP or Intermediate)*	TOP Event- This is the conceivable, undesired event to which failure paths of lower level events lead. Intermediate Event- This event describes a system condition produced by preceding events.
	Inclusive OR Gate *	An output occurs if one or more inputs exist. Any single input is necessary and sufficient to cause the output event to occur.
	Exclusive OR Gate	An output occurs if one, but only one input exists. Any single input is necessary and sufficient to cause the output event to occur.
	Mutually Exclusive OR Gate	An output occurs if one or more inputs exist. However, all other inputs are then precluded. Any single input is necessary and sufficient to cause the output event to occur.
	AND Gate *	An output occurs if all inputs exist. All inputs are necessary and sufficient to cause the output event to occur.
	Priority AND Gate	An output occurs if all inputs exist and occur in a predetermined sequence. All inputs are necessary and sufficient to cause the output event to occur.
	Basic Event *	An initiating fault or failure that is not developed further. These events determine the resolution limit of the analysis. They are also called leaves or initiators.
	INHIBIT Gate	An output occurs if a single input event occurs in presence of an enabling condition. Mathematically treated as an AND Gate.
	External Event	An event that under normal conditions is expected to occur. Probability =1.

* Most fault trees can be constructed with these four logic symbols.

Undeveloped Event — An event not further developed because of a lack of need, resources, or information.

Conditioning Event — These symbols are used to affix conditions restraints, or restrictions to other events...

Pros

- Enable assessment of probabilities of combined faults/failures with a complex system
- Single-point and common cause failures can be identified and assessed
- System vulnerability and low-payoff countermeasures are identified, thereby guiding deployment of resources for improved control of risk
- This tool can be used to reconfigure a system to reduce vulnerability

Cons

- Address only one undesirable condition or event that must be foreseen by the analyst. Thus, several or many fault tree analyses may be needed for a particular system
- The generation of an accurate probabilistic assessment may require significant time and resources. Caution must be taken not to 'overwork' determining probabilities or evaluating the system, ie, limit the size of the tree
- A fault tree is not accurate unless all significant contributors of faults or failures are taken into account.
- Events or conditions under the same logic gate must be independent of each other
- A fault tree is flawed if common causes have not been identified
- Events or conditions at any level of the tree must be independent and immediate contributors to the next level event or condition.
- Specific estimates of failure probabilities are typically difficult to find, to achieve agreement on, and to successfully use to drive conclusions. Thus failure rate of each initiator must be constant and predictable

(L) Preliminary Hazard Analysis (PHA)

Overview

A Preliminary Hazard Analysis **[X9]** produces a line item tabular of nontrivial system hazards and an assessment of their remaining risks after countermeasures have been imposed. This inventory includes qualitative, not quantitative, assessments of risks. Also often included is a tabular listing of countermeasures with a qualitative delineation of their predicted effectiveness. A PHA is an early or initial system safety study of system hazards.

A PHA's objective is to identify, for a specified system/subsystem and for its operation, the hazards, hazardous situations and events that can cause harm which could lead to an accident.

PHAs are best applied in the design and development phase but may also be applied in the concept definition phase. This tool is applied to cover whole-system and interface hazards for all mission phases.

Procedures

Procedures for performing PHAs are presented as below:

(1) Identify resources of value to be protected, such as personnel, facilities, equipment, productivity, mission or test objectives, environment, etc. These resources are potential targets.
(2) Identify and observe the levels of acceptable risk that have been predetermined and approved by management or the client. These limits may be the risk matrix boundaries defined in a risk assessment matrix.

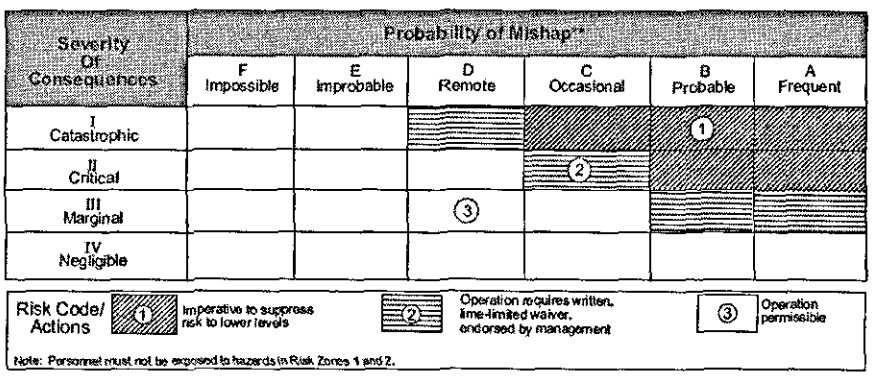


Table A2.9. Example of a Risk Assessment matrix, Sverdrup Technology Inc.1997 **[X9]**

(3) Define the extent of the system to be assessed. Define physical boundaries and operating phases (such as shakedown, start-up, standard operation, emergency shutdown, maintenance, deactivation, etc.). State other assumptions such as whether the assessment is based on an as-built or as-designed system, or whether current installed countermeasures will be considered.

(4) Detect and confirm hazards to the system. Identify the targets threatened by each hazard. A hazard is defined as an activity or circumstance posing potential loss or harm to a target and is a condition required for an undesired loss event. Hazards should be distinguished from consequences and considered in terms of a source (hazard), mechanism (process) and outcome (consequence).

A team approach to identifying hazards, such as brainstorming, is recommended over a single analyst. If schedule and resource restraints are considerations, then a proficient engineer with knowledge of the system should identify the hazards but that assessment should be reviewed by a peer. A list of proven methods for finding hazards is presented below:

- Use intuitive "engineering sense"
- Examine and inspect similar facilities or systems and interview workers assigned to those facilities or systems.
- Examine system specifications and expectations.
- Review codes, regulations, and consensus standards
- Interview current or intended system users or operators
- Consult checklists

Electrical

_____ Shock
_____ Burns
_____ Overheating
_____ *Ignition of combustibles*
_____ Inadvertent activation
_____ Power outage
_____ Distribution backfeed
_____ Unsafe failure to operate
_____ Explosion/electrical (electrostatic)
_____ Explosion/electrical (arc)

Mechanical

_____ Sharp edges/points
_____ Rotating equipment
_____ Reciprocating equipment
_____ Pinch points
_____ Lifting weights
_____ Stability/topping potential
_____ Ejected parts/fragments
_____ Crushing surfaces

Pneumatic/Hydraulic Pressure

_____ Overpressurization
_____ Pipe/vessel/duct rupture
_____ Implosion
_____ Mislocated relief device
_____ Dynamic pressure loading
_____ Relief pressure improperly set
_____ Backflow
_____ Crossflow
_____ Hydraulic ram
_____ Inadvertent release
_____ Miscalibrated relief device
_____ Blown objects
_____ Pipe/hose whip
_____ Blast

Table A2.10.a. Risk Assessment checklists (not an exhaustive list)

Human Factors (See Ergonomic)

_____ Operator error
_____ Inadvertent operation
_____ Failure to operate
_____ Operation early/late
_____ Operation out of sequence
_____ Right operation/wrong control
_____ Operated too long
_____ Operate too briefly

Ergonomic (See Human Factors)

_____ Fatigue
_____ Inaccessibility
_____ Nonexistent/inadequate "kill" switches
_____ Glare
_____ Inadequate control/readout differentiation
_____ Inappropriate control/readout location
_____ Faulty/inadequate control/readout labeling
_____ Faulty work station design
_____ Inadequate/improper illumination

Mission Phasing

_____ Transport
_____ Delivery
_____ Installation
_____ Calibration
_____ Checkout
_____ Shake down
_____ Activation
_____ Standard start
_____ Emergency start
_____ Normal operation
_____ Load change
_____ Coupling/uncoupling
_____ Stressed operation
_____ Standard shutdown
_____ Shutdown emergency
_____ Diagnosis/trouble shooting
_____ Maintenance

Common Causes

_____ Utility outages
_____ Moisture/humidity
_____ Temperature extremes
_____ Seismic disturbance/impact
_____ Vibration
_____ Flooding
_____ Dust/dirt
_____ Faulty calibration

Table A2.10.b. Risk Assessment checklists (not an exhaustive list)

- Review system safety studies from other similar systems
- Review historical documents – mishap files, near-miss reports, HSE recordable injury rates, manufacturer's reliability analyses, etc
- Consider "external influences" such as local weather, environment, or personnel tendencies
- Consider all mission phases
- Consider "common causes." A common cause is a circumstance or environmental condition that, if it exists, will induce two or more fault/failure conditions within a system
- Brainstorm – mentally develop credible problems and play "what-if" games
- Consider all energy sources. What's necessary to keep them under control; what happens if they get out of control?

(5) Assess worst-credible case (not the worst-conceivable case) severity and probability for each hazard and target combination. Keep the following considerations in mind during the evaluation:

- Remember that severity for a given hazard varies as a function of targets and operational phases.
- A probability interval must be established before probability can be determined. This interval can be in terms of time, or number of cycles or operations.

- If a short-term probability interval is used, then the assessment will underestimate the true risk unless the risk acceptance criterion is adjusted accordingly. Probability intervals expressed in hours, days, weeks, or months are too brief to be practical. The interval should depict the estimated facility, equipment, or each human operator working life span. An interval of 25 to 30 years is typically used and represents a practical value.
- The probability for a given hazard varies as a function of exposure time, target, population, and operational phase.
- Since probability is determined in a subjective manner, draw on the experience of several experts as opposed to a single analyst.

(6) Assess risk for each hazard using a risk assessment matrix. The matrix should be consistent with the established probability interval and force or fleet size for this assessment.

(7) Categorise each identified risk as acceptable or unacceptable, or develop countermeasures for the risk, if unacceptable.

(8) Select countermeasures in the following descending priority order to optimise effectiveness: (1) design change, (2) engineered safety systems (active), (3) safety devices (passive), (4) warning devices, and (5) procedures and training.

Note that this delineation, although in decreasing order of effectiveness, is also typically in decreasing order of cost and schedule impact (ie, design changes have the highest potential for cost and schedule impact). Note also that the list is in increasing order of reliance on the human operator or maintainer – to refrain from attempting to defeat the engineered safety systems, to replace the safety devices after servicing, to heed the warning devices, and to remember procedures and training. A trade study might be performed to determine a countermeasure of adequate effectiveness and minimised program impact.

(9) Re-evaluate the risk with the new countermeasure installed.

(10) If countermeasures are developed, determine whether they introduce new hazards or intolerably diminish system performance. If added hazards or degraded performance are unacceptable, determine new countermeasures and re-evaluate the risk.

Pros

- Identifies and provides a log of primary system hazards and their corresponding risks.
- Provides a logically based evaluation of a system's weak points early enough to allow design mitigation of risk rather than a procedural or inspection level approach.
- Provides information to management to make decisions to allocate resources and prioritise activities to bring risk within acceptable limits.

- Provides a relatively quick review and delineation of the most significant risks associated with a system.

Cons

- A PHA fails to assess risks of combined hazards or co-existing system failure modes. Therefore a false conclusion may be made that overall system risk is acceptable simply because each identified hazard element risk is acceptable when viewed individually.
- If inappropriate or insufficient targets or operational phases are chosen, the assessment will be flawed. While, on the other hand, if too many targets or operational phases are chosen, the effort becomes too large and costly to implement.

M) Delphi technique

This is an excellent tool **[X10]** for gaining input from recognised sources of expertise, without the need for face-to-face meetings. Such information is exchanged via email, fax, or postal mail. It provides a highly disciplined way of addressing or solving a problem. This technique takes advantage of participants' creativity as well as facilitating effects of group involvement and interaction. It can be time consuming and the information gained is only as good as the selection of the experts.

Background

The Delphi technique was developed by the RAND Corporation in the late 1960's as a forecasting methodology. It was a tool in which a group of experts could come to some consensus of opinion when the decisive factors were subjective, and not knowledge-based.

Delphi is particularly appropriate when decision-making is required in a political or emotional environment, or when the decisions affect strong factions with opposing preferences. The tool works formally or informally, in large or small contexts, and reaps the benefits of group decision making while insulating the process from the limitations of group decision-making; eg, over-dominant group members, political lobbying, or "bandwagonism".

Delphi has the added advantage that it works as an informal, subjective model when the decisions are based on opinion, and can be directly converted to a formal model, when the data is more knowledge-based.

Description

The Delphi technique uses a highly structured and focused questionnaire approach in order to establish a consensus opinion from 'experts'. Recognising that these experts may be geographically dispersed, it was designed to be conducted by post, although this does not preclude its use in face-to-face interviews.

Method
The method is iterative and first aims to obtain a broad range of opinions from the target group.

The results of the initial survey are collated, summarised and then form the basis of a second, follow-on questionnaire. Results from the second questionnaire inform a third and final questionnaire.

The aim is to progressively clarify and expand on issues, identify areas of agreement or disagreement and begin to establish priorities.

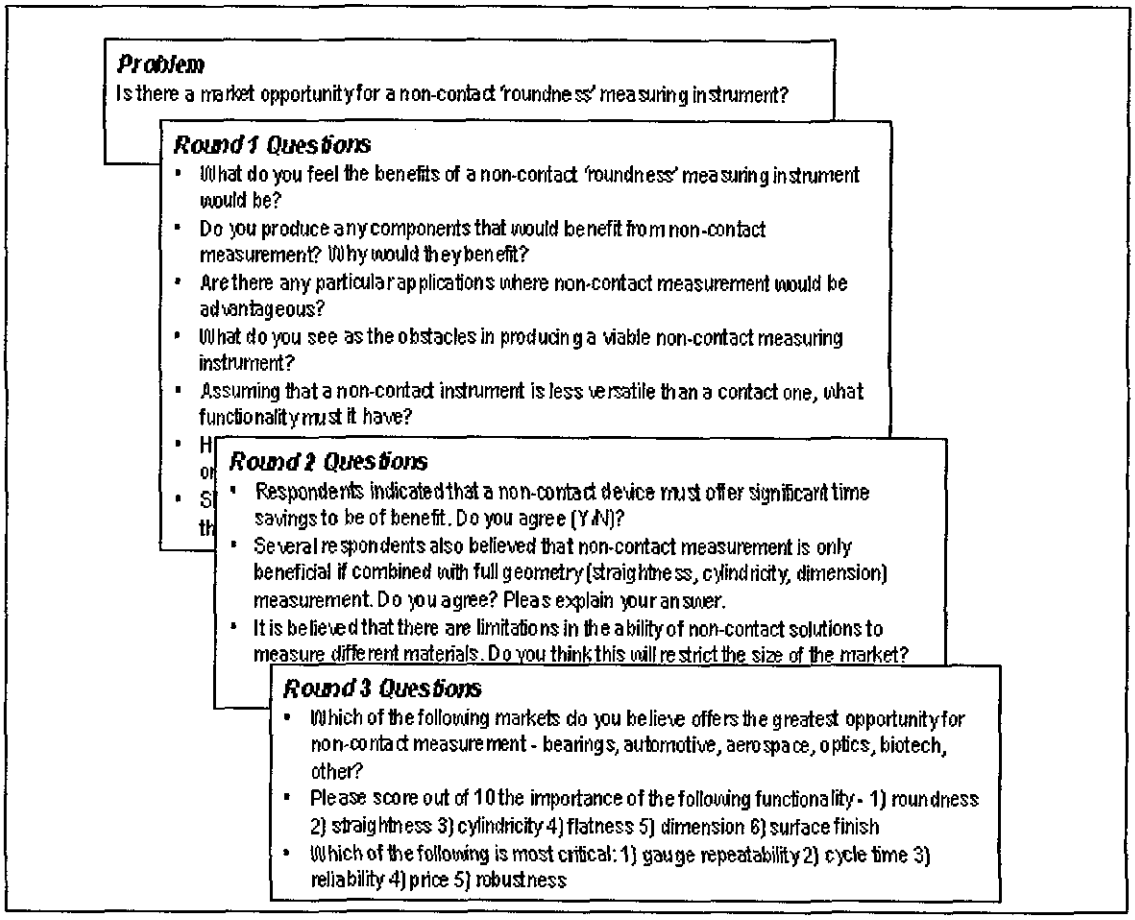


Figure A2.4. Examples of iterative process of Delphi Technique **[X9]**

A) Identify experts

Pick a facilitation leader.
Select a person that can facilitate and is an expert in research data collection. The Delphi technique requires a facilitator in order to organise requests for information, information received, and to be responsible for communication with the participants.

Select a panel of experts.
The panellists should have an intimate knowledge of a project, or be familiar with experiential criteria that would allow them to prioritise the projects effectively. In this case, the department managers or project leaders are appropriate.

B) Define the problem

In a brainstorming session, build a list of criteria that all think appropriate to the project at hand. Input from non-panellists is welcome. At this point, there are no "correct" criteria. However, technical merit and cost are two primary criteria; secondary criteria may be project-specific.

C) Round one questions
General questions to gain a broad understanding of the views of the experts relating to the problem. Responses should be collated and summarised.

For each response, the panel ranks it as 1 (very important), 2 (somewhat important), or 3 (not important). Each panellist ranks the list individually and anonymously if the environment is charged politically or emotionally.

In most cases, the panellists list strengths and weaknesses associated with each response.

Place the criteria in rank order and show the (anonymous) results to the panel. Discuss reasons for items with high ranking.

D) Round two questions
Based on the responses to the first questions, these questions should dig more deeply into the topic to clarify specific issues. Again, collate and summarise the results.

The ranking results do not have to be in complete agreement but have a consensus such that all can live with the outcome. Two passes are often enough, but four are frequently performed for maximum benefit. In one variation, general input is allowed after the second ranking in hopes that more information from outsiders will introduce new ideas or new criteria, or improve the list.

E) Round three questions
The final questionnaire that aims to focus on supporting decision-making.

Eventually the results will stabilize: projects will come to a consensus, or some will remain in the outlier range. Not everyone may be persuaded to rank the same way, but discussion is unnecessary when the opinions stay fixed. Present the ranking table to the decision makers, with the various preferences as options, for their final decision.

The conclusion may occur in one of two ways:

• If dominant, highly evaluated ideas emerge via consensus, the exercise is declared finished. The end product is a list of ideas with their associated strengths and weaknesses.

• A formal assessment of the group's opinions of the merits of the ideas is conducted. There are a number of ways to conduct a formal evaluation. In one method, a questionnaire is prepared that lists all the ideas and participants are asked to rate each one on a scale. For example, a 7-point scale could be used that ranges from 0 (no potential for dealing with the issue) through 7 (very high potential for dealing with the issue). If this approach is used, participants send the rating forms to the Facilitator, who then compiles the results and rank-orders the ideas based on the evaluations.

A second approach for evaluating the ideas is that which is used in the Nominal Group Technique for "voting." With this approach, each member is asked to identify the top five ideas and assign five points to the most promising idea, 4 points to the next most promising, and 3, 2, and 1 points to the third, fourth, and fifth-best ideas. These votes are returned to the facilitator, who tallies the results and prepares a report. The report notes the rank order of the ideas based on the total number of points received and indicates the number of people who voted for each idea

Pros

- Informal, based on subjective opinions
- Highly disciplined method of addressing a problem
- Ideal for decision-making that is required where there are strong opinions among the panel
- Highly structured approach under supervision of a facilitator
- Does not required face-to-face meetings
- Answers kept anonymously

Cons

- Can be time consuming
- Require panels of experts, having only a few expert may not be enough
- Dependant on the quality of the experts

N) Event Tree Analysis - ETA

Overview

An event tree **[X9]** is a visual representation of all the events that can occur in a system. As the number of events increases, the picture fans out like the branches of a tree.

Event trees can be used to analyse systems in which all components are continuously operating, or for systems in which some or all of the components are in standby mode – those that involve sequential operational logic and switching. The starting point (referred to as the initiating event) disrupts normal system operation. The event tree displays the sequences of events involving success and/or failure of the system components.
In the case of standby systems and in particular, safety and mission-oriented systems, the event tree is used to identify the various possible outcomes of the system following a given initiating event which is generally an unsatisfactory operating event or situation. In the case of continuously operated systems, these events can occur (ie, components can fail) in any arbitrary order. In the event tree analysis, the components can be considered in any order since they do not operate chronologically with respect to each other.

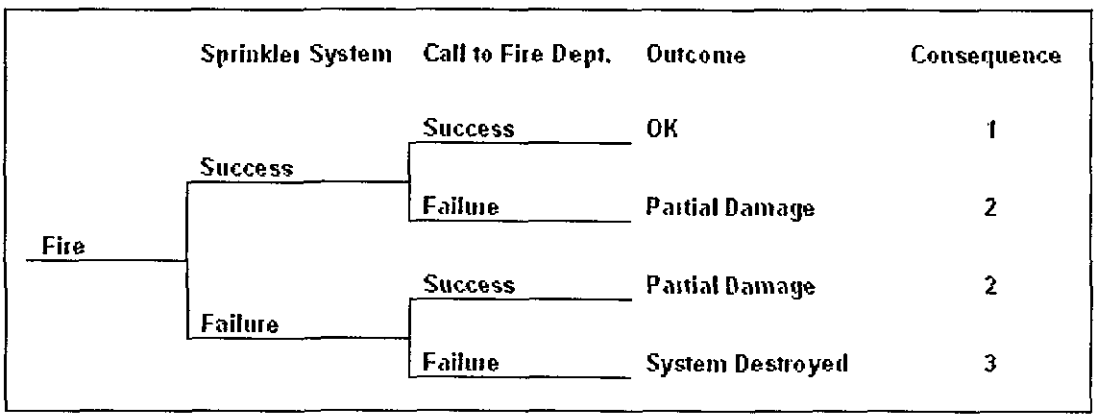


Figure A2.5. Example of Event Tree analysis

This event tree was constructed to analyse the possible outcomes of a system fire. The system has two components designed to handle this event: a sprinkler system and an automated call to the fire department. If the fire department is not notified, the fire will be mostly contained by the sprinkler system. If the sprinkler system fails as well, the system will be destroyed. The goal of an event tree is to determine the probability of an event based on the outcomes of each event in the chronological sequence of events leading up to it. By analysing all possible outcomes, you can determine the percentage of outcomes that lead to the desired result.

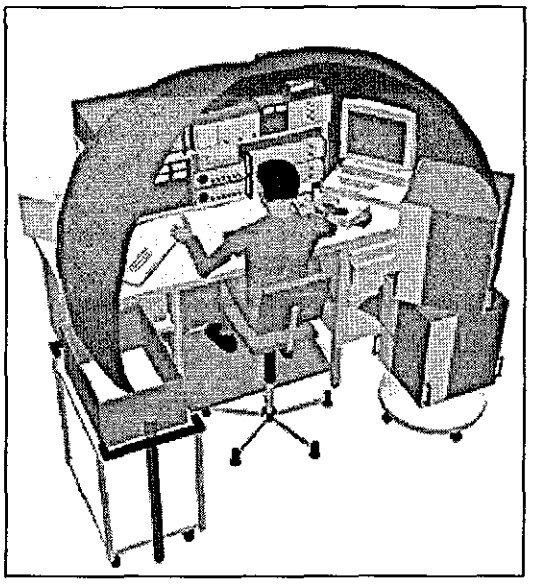
O) CAD based simulations

Overview

We cannot imagine modern work planning today without the use of efficient computer-aided planning tools. Even in our increasingly high-tech production world, workplaces in production and assembly are still planned and realized by people and, above all, for people. Today, more than ever before, the decisive criteria are productivity. **[X4]**

The application offers opportunities for analyses enabling the planner to trace

and avoid problems in an early stage, thus being able to design in an optimal way the work sequences at mainly manual workplaces.



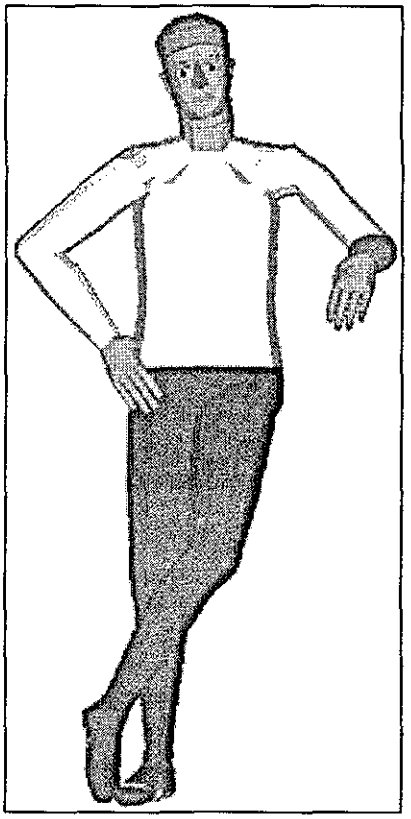


Figure A2.6. Examples of CAD simulations

CAD Simulations

3D analysis is essential where people are required to carry out complex tasks.

The medium of computer graphics provides an excellent forum for all members of the design team. Simulation software allows the user to visualise and evaluate the work and the workplace before it is built. The user can simulate the situation of the actual job. The most advanced systems are called Virtual Reality (VR) applications.

Simulation software typically allows the user to see the workplace through a mannequin's eyes, and various analyses can be done, such as biomechanical, anthropometric, angular, postural, vision, and reach analyses. The 'mannequin' program can represent a sample of the population by modifying anthropometric variables and degrees of freedom for the mannequin.

Simulation makes it easy for the designer to get a realistic overview of the content and form of the object being designed. In this way, CAD simulation and animation provide a tool to support participation in the design process. Potential operators can imagine the system more easily through a simulation

model rather than an abstract engineering drawing. Thus, it is a better basis for true participation (Mattila, 1996). **[X4]**

3D-based systems are becoming more sophisticated with their simulation capability and therefore, more accurate and reliable ergonomic analyses can be achieved in product design and in the design of production facilities.

Human model and human movement simulation systems have so far only managed to establish themselves in very few sectors of industry, such as aerospace and automotive industries. One reason for this lies in the special skills needed to use these systems. Another is the fact that even large companies are sometimes put off by the high costs of the necessary hard- and software.

Potential users frequently reject simulation technologies because those responsible for taking the purchase decision are not convinced that the relatively high costs involved yield adequate benefits, especially over the long term. Apart from the cost of acquisition and training, companies have to justify the use of personnel resources and may have difficulty in quantifying potential improvements in planning quality and its long-term positive effects on product quality and worker health.

At present, there are two possible identified areas in which simulation technologies can benefit profits. Firstly, the decision makers in industry and society in general are becoming increasingly aware of the long-term significance and long-term advantages of systematic health risk prevention at work and of the significance of good workplace design in achievement of this. Secondly, there is a massive pressure to integrate the planning tools used in industry. The different planning tools currently being used in industrial engineering are rarely fully compatible with each other and communication between them is generally poor and unsatisfactory. Demand is now growing for large-scale networked scenarios that will enable industry to maintain high quality standards, despite ever-shorter product life cycles and increasingly keen competition.

One of the key objectives of these scenarios is to create a continuous data flow starting at the product design stage continuing through cost calculations and work system, design to production planning and manufacture. Information available at one industrial location has to be accessible on demand at other locations with a minimum of effort.

This type of scenario would make the use of human movement simulation systems more attractive in a couple respects:

- Reduced effort involved in modelling a simulation environment if product data, resources and workplace layouts are directly available and do not have to be acquired or remodelled at considerable expense.
- Produce far more meaningful long-term forecasts of the potential risk of musculoskeletal disease due higher performance simulations.

Here below are few CAD based simulations

ENVISION/ERGO™

ENVISION/ERGO is a human motion and task analysis tool to rapidly evaluate multiple scenarios. In ENVISION/ERGO, human motion is rapidly prototyped or "captured" into the virtual environment, enabling quick and precise analysis of reach, lift, posture, cycle time, visibility and motion. Analysis capabilities include range of motion, NIOSH lifting guidelines, Garg energy expenditure, upper limb repetitive motion assessment, and Methods Time Measurement (MTM-UAS).

SAMMIE

The SAMMIE system is a computer-based tool that is invaluable to the designers of most products or services that are used by people. The system offers the following advantages:

- 3D analysis of fit, reach, vision and posture.
- reduced timescale.
- early input of ergonomics expertise.
- rapid interactive design.
- improved communication.
- cost effective ergonomics.

Figure A2.7. Example of lifting analysis in SAMMIE **[X10]**

SAMMIE can assist the workplace designer in the assessment of two-handed manual lifting tasks using the Revised NIOSH Lifting Equation.

VR

The use of a ***Virtual Reality*** environment in ergonomics can evaluate a design through virtual mock-ups, which is much less costly than traditional mock-ups. These VR simulations have industrial applications either in the design (for example, a car dashboard) or in the manufacturing processes (to evaluate safety, operability or maintainability of a production line). All applications share the need for an articulated virtual manikin controlled by a set of motion capture devices placed on a human subject. These applications

allow a "virtual immersion" where the goal is to recreate the "look and feel" of a complete environment with accuracy.

(P) NIOSH 81 and 91

The National Institute for Occupational Safety and Health (NIOSH) **[X3]** first developed an equation in 1981 to assist safety and health practitioners evaluate lifting demands in the sagittal plane (NIOSH 81). It was widely used because it provided an empirical method for computing a weight limit for manual lifting. This limit proved useful for identifying certain lifting jobs that posed a risk to the musculoskeletal system for developing lifting-related low back pain. The 1981 equation could only be applied to a limited number of lifting tasks, namely sagittal lifting tasks. So this equation was revised and expanded in 1991 to apply to a larger percentage of lifting tasks (NIOSH 91).

NIOSH 91 lifting equation provides methods for evaluating asymmetrical lifting tasks, objects with less than optimal hand-container couplings, and offers new procedures for evaluating a larger range of work durations and lifting frequencies than the earlier equation.

The lifting equation is a tool for assessing the physical stress of two-handed manual lifting tasks, and

- Lifting/lowering with one hand
- Lifting/lowering for over 8 hours
- Lifting/lowering while seated or kneeling
- Lifting/lowering in a restricted work space
- Lifting/lowering unstable objects
- Lifting/lowering while carrying, pushing or pulling
- Lifting/lowering with wheelbarrows or shovels
- Lifting/lowering with high speed motion (faster than about 30 inches/second)
- Lifting/lowering with unreasonable foot/floor coupling (<0.4 coefficient of fraction between the sole and the floor)
- Lifting/lowering in an unfavourable environment (ie, temperature significantly outside 66-79°F (19-26°C) range; relative humidity outside 35-50% range)

Procedures for analysing lifting jobs

Prior to the assessment, the analyst must determine:

1. if the job should be analysed as a single-task or multi-task manual lifting job, and
2. if significant control is required at the destination of the lift.

A single-task manual lifting job is defined as a lifting job in which the task variables do not significantly vary from task to task, or only one task is of interest (eg, worst case analysis).

On the other hand, multi-task manual lifting jobs, which are defined as jobs in which there are significant differences in task variables between tasks, one more difficult to analyse because each task must be analysed separately. Therefore, a specialised procedure is used to analyse multi-task manual lifting jobs.

When significant control of an object is required at the destination of a lift, the worker must apply a significant upward force to decelerate the object. Depending upon the velocity of the lift, this deceleration force may be as great as the force required to lift the object at the origin. Therefore, to insure that the appropriate RWL is computed for a lift that requires significant control at the destination of the lift, and the lower of the two values is used to assess the overall lift. The latter procedure is required if:

1. the worker has to re-grasp the load near the destination of the lift,
2. the worker has to momentarily hold the object at the destination, or
3. the worker has to position or guide the load at the destination.

The purpose of calculating the RWL at both the origin and destination of the lift is to identify the most stressful location of the lift.

Multi-task procedure

Many of the lifting jobs in the workplace have multiple lifting activities and therefore could be analyse as either a single or a multi-task lifting job. When detailed information is needed, however, to specify engineering modifications, then the multi-task approach should be used. On the other hand, the multi-task procedure is more complicated than the single-task procedure, and requires a greater understanding of assessment terminology and mathematical concepts. Therefore, the decision to use the single or multi-task approach should be used on:

1. the need for detailed information about all facets of the multi-task lifting job,
2. the need for accuracy and completeness of data in performing the analysis, and
3. the analyst's level of understanding of the assessment procedures.

Q) Rapid Entire Body Assessment - REBA

REBA **[X12]** was proposed by Hignett and McAtamney as a means to assess posture for risk of work-related musculoskeletal disorders (WRMSDs).

Consider the critical tasks of a job. For each task, assess the posture factors by assigning a score to each region. The following data sheet provides a format for this process. Areas on the data sheet with a light gray background are for data entry.

Procedure

Score the Group A (Trunk, Neck and Legs) postures and the Group B (Upper Arms, Lower Arms, and Wrists) postures for left and right. For each region, there is a posture scoring scale plus adjustment notes for additional considerations. Then score the Load/Force and Coupling factors. Finally, score the Activity.

Rapid Entire Body Assessment (REBA) Date: / /

Task	Analyst

Group A			Group B		
Posture/Range	**Score**	**Total**	**Posture/Range**	**Score**	**Total: Left and Right**
Trunk			**Upper Arms (Shoulders)**		L R
Upright	1	If back is twisted or tilted to side: +1	Flexion: 0-20° Extension: 0-20°	1	Arm Abducted / Rotated: +1 Shoulder Raised: +1 Arm Supported: -1
Flexion: 0-20° Extension: 0-20°	2		Flexion: 20-45° Extension: >20°	2	
Flexion: 20-60° Extension: >20°	3		Flexion: 45-90°	3	
Flexion: >60°	4		Flexion: >90°	4	
Neck			**Lower Arms (Elbows)**		L R
Flexion: 0-20°	1	If neck is twisted or tilted to side: +1	Flexion: 60-100°	1	No Adjustments
Flexion: >20° Extension: >20°	2		Flexion: <60° Flexion: >100°	2	
Legs			**Wrists**		L R
Bilateral Wt Bearing; Walk; Sit	1	Knee(s) Flexion 30-60°: +1 Knee(s) Flexion >60°: +2	Flexion: 0-15° Extension: 0-15°	1	Wrist Deviated / Twisted: +1
Unilateral Wt Bearing; Unstable	2		Flexion: >15° Extension: >15°	2	
Score from Table A			**Score from Table B**		L R
Load / Force			**Coupling**		L R
< 5 kg < 11 lb	0	Shock or Rapid Buildup: +1	Good	0	No Adjustments
5 - 10 kg 11 - 22 lb	1		Fair	1	
> 10 kg > 22 lb	2		Poor	2	
Score A [Table A + Load/Force Score]			Unacceptable	3	Left Right
Activity			**Score B** [Table B + Coupling Score]		L R
One or more body parts are static for longer than 1 minute	+1		**Score C (from Table C)**		L R
Repeat small range motions, more than 4 per minute	+1		**Activity Score**		L R
Rapid large changes in posture or unstable base	+1		**REBA Score** [Score C + Activity Score]		L R

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Figure A2.8. Rapid Entire Body Assessment data sheet

Find the scores from Table A for the Group A posture scores and from Table B for the Group B posture scores. The tables follow the data collection sheet. Score A is the sum of the Table A score and the Load/Force score. Score B is the sum of the Table B score and the Coupling score for each hand.

Score C is read from Table C, by entering it with the Score A and the Score B.

Table A

		Trunk				
		1	2	3	4	5
Neck = 1	Legs					
	1	1	2	2	3	4
	2	2	3	4	5	6
	3	3	4	5	6	7
	4	4	5	6	7	8
Neck = 2	Legs					
	1	1	3	4	5	6
	2	2	4	5	6	7
	3	3	5	6	7	8
	4	4	6	7	8	9
Neck = 3	Legs					
	1	3	4	5	6	7
	2	3	5	6	7	8
	3	5	6	7	8	9
	4	6	7	8	9	9

Table B

		Upper Arm					
		1	2	3	4	5	6
Lower Arm = 1	Wrist						
	1	1	1	3	4	6	7
	2	2	2	4	5	7	8
	3	2	3	5	5	8	8
Lower Arm = 2	Wrist						
	1	1	2	4	5	7	8
	2	2	3	5	6	8	9
	3	3	4	5	7	8	9

Table C

		Score A											
		1	2	3	4	5	6	7	8	9	10	11	12
Score B	1	1	1	2	3	4	6	7	8	9	10	11	12
	2	1	2	3	4	4	6	7	8	9	10	11	12
	3	1	2	3	4	4	6	7	8	9	10	11	12
	4	2	3	3	4	5	7	8	9	10	11	11	12
	5	3	4	4	5	6	8	9	10	10	11	12	12
	6	3	4	5	6	7	8	9	10	10	11	12	12
	7	4	5	6	7	8	9	9	10	11	11	12	12
	8	5	6	7	8	8	9	10	10	11	12	12	12
	9	6	6	7	8	9	10	10	10	11	12	12	12
	10	7	7	8	9	9	10	11	11	12	12	12	12
	11	7	7	8	9	9	10	11	11	12	12	12	12
	12	7	8	8	9	9	10	11	11	12	12	12	12

REBA Decision

REBA Score	Risk Level
1	Negligible
2 - 3	Low
4 - 7	Medium
8 - 10	High
11 - 15	Very High

Table A2.11. Score tables for Rapid Entire Body Assessment data sheet

The REBA score is the sum of the Score C and the Activity score. The degree of risk is found in the REBA Decision table.

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APPENDIX 3

GLOSSARY OF TERMS

APPENDIX 3 - GLOSSARY OF TERMS

Administrative control - Procedures and methods, set up by the employer, that significantly reduce exposure to risk factors by altering the way in which work is performed; examples include employee rotation, job task enlargement, and adjustment of work pace.

Aetiology – the study of the causes of diseases

Anthropometry- Anthropometry is the branch of the human sciences that deals with body measurements.

American National Standards Institute, ANSI. A private, non-profit membership organization that coordinates voluntary standards activities. ANSI assists with standards-developers and standards users from the private sector and government to reach agreement on the need for standards and establish priorities.

Awkward posture -Posture is the position of the body while performing work activities. Awkward posture is associated with an increased risk for injury. It is generally considered that the more a joint deviates from the neutral (natural) position, the greater the risk of injury.
Specific postures have been associated with injury. For example:
Wrist

- Flexion/extension (bending up and down)
- Ulnar/radial deviation (side bending)

Shoulder

- Abduction/flexion (upper arm positioned out to the side or above shoulder level)
- Hands at or above shoulder height

Neck (cervical spine)

- flexion/extension or bending the neck forward and to the back
- side bending as when holding a telephone receiver on the shoulder

Low back

- Bending at the waist, twisting

Conformity assessment, CA procedure is the collective term used for a number of techniques (testing, inspection and certification) used to determine if a product, system, process (including design) or a person's competence etc. meets a defined specification.

Contact stress. Pressing the body against hard or sharp edges can result in placing too much pressure on nerves, tendons and blood vessels. For example, using the palm of your hand as a hammer can increase your risk of suffering an MSD.

Cumulative trauma disorders, CTD a term used for injuries that occur over a period because of repeated trauma or exposure to a specific body part,

such as the back, hand, wrist and forearm. Muscles and joints are stressed, tendons are inflamed, nerves pinched or the flow of blood is restricted. Common occupational induced disorders in this class include carpal tunnel syndrome, epicondylitis (tennis elbow), tendinitis, tenosynovitis, synovitis, stenosing, and tenosynovitis of the finger, De Quervain's Syndrome, and low back pain.

Derating – The practice of limiting the stresses on operators to levels well within their specified or proven capabilities in an effort to improve safety and health

Duration - Duration is the length of exposure to a risk factor. It can be measured as the minutes or hours per day the worker is exposed to a risk. Duration can also be viewed as the years of exposure to a risk factor. In general, the greater the duration of exposure to a risk factor, the greater the degree of risk. However, specific duration guidelines have not been established for risk factors such as force, posture and repetition.

Engineering control - Physical changes to jobs that control exposure to risk. Engineering controls act on the source of the hazard and control employee exposure to the hazard without relying on the employee to take self-protective action or intervention. Examples include: changing the handle angle of a tool, using a lighter weight part, and providing a chair that has adjustability.

Ergonomics - The science of work. Ergonomics removes barriers to quality, productivity, and safe human performance by fitting products, tasks and environments to people.

Ergonomic program - A systematic process for anticipating, identifying, analysing and controlling ergonomic risk factors.

Forceful Exertions. Force is the amount of physical effort to perform a task (such as heavy lifting) or to maintain control of equipment or tools. The amount of force depends on the type of grip, the weight of an object, body posture, the type of activity and the duration of the task. High force has been associated with Work Related Musculoskeletal Disorders at the shoulder/neck, the low back and the forearm/wrist/hand.

Human Factors - A term synonymous with 'ergonomics', is the branch of this science that began in the US and focuses on cognitive performance of humans.

Lighting - The level of illumination in the workplace. Poor lighting can lead to visual symptoms of eyestrain, eye focusing breakdown, eye coordination abnormalities, and eye fatigue while performing select activities such as video display terminal tasks.

Manual material handling - Lifting, carrying, and moving materials without mechanical aide.

Motion: velocity/acceleration - Velocity/ acceleration is the speed of body part motion and the rate of change of speed of body part motion, respectively. It is generally regarded that increased acceleration leads to increased risk of injury.

Musculoskeletal disorders, MSDs - Injuries and disorders of the muscles, nerves, tendons, ligaments, joints, cartilage and spinal disc; examples include carpal tunnel syndrome, rotator cuff tendonitis, and tension neck syndrome.

Myalgic – pain in a muscle or a group of muscles.

Myopathy –any disease affecting muscles or muscle tissue.

National Institute of Occupational Safety and Health. NIOSH is the institution that provides scientific data upon which OSHA makes recommendations.

Neuropathy –any disease of the nervous system

Occupational biomechanics - Occupational biomechanics is a science concerned with the mechanical behaviour of musculoskeletal tissues when physical work is performed.

Occupational illness - Any abnormal condition or disorder, other than one resulting from an occupational injury caused by exposure to factors associated with employment. It includes acute and chronic illnesses or disease which may be caused by inhalation, absorption, ingestion or direct contact. The broad categories of occupational illnesses are skin diseases and disorders, dust diseases of the lungs, respiratory condition due to toxic agents, poisoning (systemic effects of toxic materials), disorders due to physical agents other than toxic materials, and disorders from repeated trauma.

Occupational injury - Any injury such as a cut, fracture, sprain, amputation, etc., which results from a work-related event or from a single instantaneous exposure in the work environment. Examples of injuries or disorders that can be work related include:

- Carpal tunnel syndrome (CTS)
- Rotator cuff syndrome
- De Quervain's disease
- Trigger finger
- Sciatica
- *Epicondylitis*
- Tendinitis
- Raynaud's phenomenon
- Low back pain

Occupational Safety and Health Administration. (OSHA) The mission of the Occupational Safety and Health Administration is to save lives, prevent

injuries and protect the health of America's workers. To accomplish this, federal and state governments must work in partnership with the more than 100 million working men and women and their six and a half million employers who are covered by the Occupational Safety and Health Act of 1970.

Pathogen – any agent that can cause disease

Pathogenesis – the origin, development and resultant effects of a disease.

Pathological – relating to, involving, or caused by disease

Pathology – the manifestations of disease, especially changes occurring in tissues or organs

Proactive maintenance (Preventive and Predictive)

- Preventive maintenance are all actions performed in an attempt to retain a machine in specified condition by providing systematic inspection, detection, and prevention of initial hazards.
- Predictive maintenance techniques are used to detect potential hazards so that action can be taken to avoid the consequences which could occur if machinery function continues to deteriorate.

Recovery time - Recovery time is the length of rest between exertions. Short work pauses can reduce discomfort. Inadequate rest periods between exertions can decrease performance. As the duration of the uninterrupted work increases, so does the amount of recovery time needed.

Repetition - Repetition is the number of a similar exertions performed during a task. A warehouse worker may lift three boxes per minute from the floor to a countertop; an assembly worker may make 20 units per hour. Repetitive motion has been associated with injury and worker discomfort. Generally, the greater the number of repetitions, the greater the degree of risk. However, there is no specific repetition limit or threshold value (cycles/unit of time, movements/unit of time) associated with injury.

Risk factor - Actions in the workplace, workplace conditions, or a combination thereof, that may cause or aggravate a Work Related Musculoskeletal Disorders; examples include forceful exertion, awkward postures, repetitive exertion, and environmental factors such as temperature.

Risk Levels, as defined by Pilz Automation Technology (www.pilz.com)

Negligible – No action required

Low – Prompt action required analysing existing controls as soon as possible. Develop contingency plans to cope with risk.

High – Urgent action required analysing existing controls urgently to determine what action is required to reduce the risk to an acceptable level.

Unacceptable – Highest priority for immediate action to reduce risk to an acceptable level. If the risk constitutes a *"Serious and Imminent Danger"* after considering the existing controls, implement withdrawal procedures.

Segmental vibration (Hand-arm vibration) - Vibration applied to the hand/arms through a tool or piece of equipment. This can cause a reduction in blood flow to the hands/fingers (Raynaud's disease or vibration white finger). Also, it can interfere with sensory receptor feedback leading to increased handgrip force to hold the tool. Further, a strong association has been reported between carpal tunnel syndrome and segmental vibration.

Tennis elbow – a painful inflammation of the elbow caused by over-exertion in playing tennis or similar activities

Tenosynovitis – painful swelling and inflammation of tendons, usually of the wrist, often the result by repetition movements.

Vibrations - operating vibrating tools such as sanders, grinders, chippers, routers, drills and other saws can lead to nerve damage.

Whole body vibration - Exposure of the whole body to vibration (usually through the feet/buttocks when riding in a vehicle). Whole body vibration may increase the risk for injury, including low back pain and internal organ disruption.

Work related musculoskeletal disorders - Injuries and disorders of the muscles, nerves, tendons, ligaments, joints, cartilage and spinal disc due to physical work activities or workplace conditions in the job. Examples include: carpal tunnel syndrome related to long term computer data entry, rotator cuff tendinitis from repeat overhead reaching, and tension neck syndrome associated with long term cervical spine flexion.

Work related musculoskeletal disorder hazard - Workplace conditions or physical work activities that cause or are reasonably likely to cause or contribute to a work related musculoskeletal disorder.