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AN EXTENDED EVALUATION OF THE HUMAN COMPUTER INTERFACE IN THE WARATAH 234 HARVESTING MACHINE

Project Report 92
2000

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Leading Edge Forestry Solutions

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EXECUTIVE SUMMARY

The purpose of the evaluation was to continue to evaluate the human computer interface of the Waratah mechanised harvesting machine. This report builds on the findings of the initial evaluation that was conducted on the interface, the purpose of which being to identify problems with the interface and develop solutions for them.

A summary of the initial evaluation is provided which outlines the methodology employed and the outcomes obtained. An interview was conducted with personnel from Waratah General Engineering, to assess the perceived importance of the recommended solutions and the perceived benefit associated with their implementation. In general, there appeared to be a good awareness of the importance of the problems that were identified during the initial evaluation. There was also an appreciation of the benefits that can be obtained from implementing the recommended solutions, particularly in relation to recommendations associated with the graphics display module, the hand controls, the language used in the interface user manual and the remote support and training associated with the interface. The results were encouraging, as they indicated that the people involved in the manufacture of the interface may eventually adhere to the recommendations made in the initial evaluation.

Attention is then given to a range of other factors identified during the initial evaluation that required more assessment. The prevalence of upper body discomfort problems and occupational overuse injuries associated with machine use is discussed, and the results of a body part discomfort survey are presented. The results indicate that mechanised harvester operators are suffering from a range of musculoskeletal discomforts. A number of preventative measures are then outlined, including ergonomic design considerations and changes in workplace practices.

The evaluation then outlines a range of other ergonomic factors associated with the mechanised harvesting task that may contribute to decreased operator performance levels. These include the cognitive load, repetitive nature, noise, vibration, light

intensity, postural discomfort and psychosocial factors associated with the mechanised harvesting task. A range of techniques designed to minimise the effects of these factors are then outlined. The importance of interface related training is also emphasised.

The benefits that are associated with the implementation of ergonomic recommendations are also discussed. These include increased productivity, a reduction of minor injuries, lowered injury and accident rates, increased job satisfaction and subsequently decreased absenteeism and turnover. The need for continued evaluation and cost benefit analyses is also emphasised. Finally, examples of some of the ergonomic resources that are designed to empower the manufacturer are provided. These include a range of ergonomic and human factors related software, computer programmes and world wide web information.

INTRODUCTION

The increase in the use of mechanised forestry systems is widespread. Although the majority of New Zealand forests are still harvested by motor-manual operations (Parker & Gellerstedt 1998), mechanised harvesting systems are increasing. As such, the influence of this machinery on worker performance and wellbeing within the forestry industry in New Zealand and elsewhere is continuing to increase (Guimier 1999), as is the need to critically assess the quality of the machinery.

A number of machine evaluations have been conducted in New Zealand (McConchie & Evanson 1996). One of the more recent involved the evaluation of the human computer interface in the Waratah 234 harvesting machine (Smith & O'Rorke 1999a). The purpose of the evaluation was to identify any problems that may be occurring with the interface and to develop solutions to the problems. The current evaluation is an extension of that initial evaluation.

Although the use of mechanised harvesters have been found to improve forest work productivity (Axelsson 1998), there are still a number of concerns about the quality of machine based processing (Cossens 1991). In particular, Evanson (1995) has outlined a number of the aspects of quality that have been of concern. These include;

- Accuracy of length measurement.
- Delimbing quality.
- End checking or splitting.
- Log surface impacts by harvester rollers.
- Ability to achieve optimum value recovery.

In addition to this, Evanson and McConchie (1996) have argued that 'Mechanised processing systems have had to demonstrate that they can match or exceed the log-quality standards achieved by manual processing' (pg 41). Evanson (1995) has also argued that the lack of performance in relation to these aspects is at least partly responsible for the reluctance to implement more mechanised systems. Improvements to the performance of mechanised processing systems can be approached from two main areas. The first is an attempt to fit the 'person' to the 'machine'. This approach involves attempting to identify the type of individual who is most suited to the harvesting task and has been partly addressed in a recent report (Smith & O'Rorke 1999b). The continuation of such an approach is currently being implemented. The second approach is to fit the 'machine' to the 'person', and it is this aspect of the performance improvement process that is under consideration in the current report.

Adherence to the recommendations made in this and the initial evaluation are expected to positively influence the performance of the machine operator by improving the level of fit between the man and the machine. This in turn will reflect positively on the potential of mechanised processing systems to demonstrate that they can indeed match and even exceed the log-quality standards achieved by manual processing.

THE ERGONOMIC PROCESS

Kilbom & Petersson (1999) have outlined a model of the ergonomic process which provides a useful framework with which to view the interface evaluation process (Figure 1). In this model, there are six core elements or stages that a successful ergonomic process will need to progress through.

1. The first of these involves the organisation of the ergonomic process. This involves obtaining management commitment to the process and establishing the necessary lines of communication and relationships that will be needed to carry out the process.

2. The next stage involves identifying the specific problem or problem areas that need to be considered. It is this second stage that constituted the major objective of the initial evaluation.

3. The third stage involves carefully analysing and examining the nature of the problems that are identified.

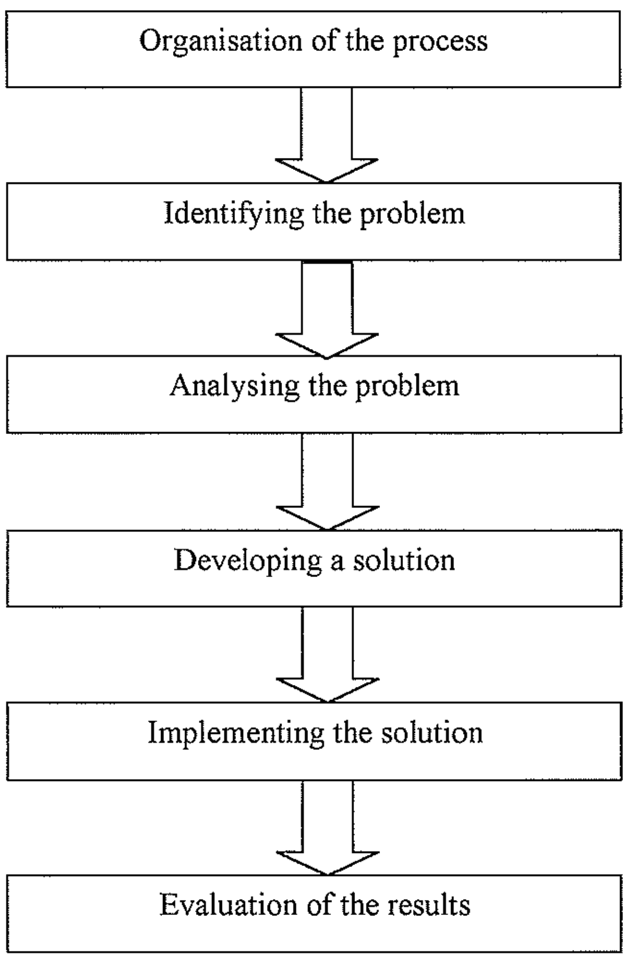


Figure 1. Stages in the ergonomic process

4. The fourth stage involves developing a range of pragmatic solutions to the problems that are identified during stages two and three.

5. The fifth stage involves the implementation of these solutions. This is often the most critical stage in the ergonomics process and requires the investment of time and concentrated effort on the part of product manufacturers and product users

alike. Involved in this stage is the need to obtain the support of and 'buy in' from all of the people who will be affected by the implementation of the changes.

6. The final stage of the process is to evaluate the results of implementing the solutions. This stage should ideally involve some form of cost-benefit analysis of the changes in financial terms. A range of other criteria should also be considered during the evaluation process. Areas may include productivity levels and productivity quality, employee safety and accident rates, turnover rates, absenteeism and job satisfaction levels. This stage in the ergonomic process often yields a wealth of information and will more then likely identify areas that need further consideration.

The first four stages in this six-stage process have already been accomplished through the initial evaluation (Smith & O'Rorke 1999a). The implementation stage and the evaluation of the results stage is yet to be conducted and until these are done the full ergonomic process, and the benefits it can yield remains largely incomplete and unfulfilled. It is at both of these stages that commitment on the part of the product manufacturer is most needed.

Human computer interaction evaluation

When we talk about the 'interface', we are referring to the 'point of contact' between the user and the technology under consideration (Noyes & Cook 1999). In relation to the mechanised harvesting machine, the point of contact refers primarily to the hand controls which are utilised during the operation of the machine and the graphics display module that is associated with the Waratah group of harvesting machines. A graphical depiction may help us to understand what is referred to by the term 'interface' (see Figure 2).

Like the hardware characteristics that need to be assessed during an evaluation, there is also the question of how the information is presented on the interface display and this reflects the software considerations that need to be taken into account. In addition to this, the reference materials and user support systems that are associated with an interface also need to be considered as does the training that is provided on how to make use of the interface.

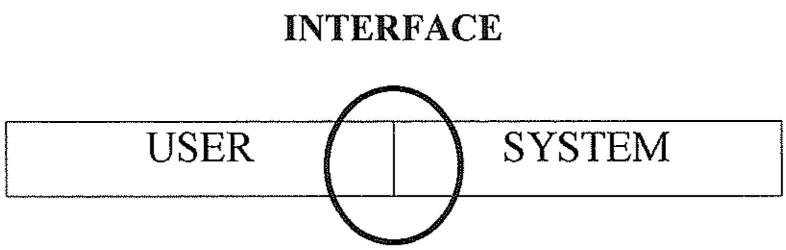


Figure 2. Representation of the interface between a system and it user

Arguably the most important perspective that needs to be considered when it comes to the evaluation of a human computer interface is the perspective of the people who will be making use of the interface. Soloway & Pryor (1996) have asserted that the needs and abilities of the users should be the primary driving force of software design and Helander (1991) has argued that one of the primary reasons for conducting an interface evaluation is to assess whether or not a system meets the needs of its users. In addition to this, Weimer (1995) has argued that all research in the area of human computer interaction should be devoted ultimately to improving the working conditions for the user or operator, and as such it is important that computer systems are designed from a user-centred perspective. As such the initial evaluation relied heavily on the perspectives of the harvester operators.

THE INITIAL EVALUATION

A number of user-centred design values and principles were taken into consideration during the initial evaluation. The key concepts of utility and useability provided the core evaluative framework (Sutcliffe 1995). Utility referring to how well the interface helps the operator to complete their given tasks and how well the interface matches what the operators need it to do and how they understand how the task should be done. Useability referring to how easy the interface it is to operate, how easy it is for operators to learn the system's functions and how much help or support is provided with the interface (Kalawsky 1999). In addition to the key factors of utility and useability, a number of principles or guidelines that have been established in the literature for good quality interface design were considered. These included the principles of; naturalness, consistency, non-redundancy, supportiveness and flexibility (Macaulay 1995). These principles provided overall guidance during the evaluation process and served as a set of criteria against which the Waratah interface was evaluated.

Areas of the interface that were evaluated

1. The first area that was evaluated was the software utilised in the interface design. A number of software considerations were taken into account. These generally related to the type of information that is presented to the operators and how that information is presented.

2. The second area that was considered was the hardware used in the interface. The hardware aspect of the evaluation included the size, shape and placement of the input devices, the hand controls and arm rests and the characteristics of the graphic display module's location and design.

3. The third area of consideration was the presentation of reference materials, user manuals, user guides and on-line help systems.

4. The fourth area of investigation was directed towards evaluating the quality of the training that is associated with the Waratah interface.

Methodology employed in the initial evaluation

The initial evaluation utilised five major methodological approaches to identify the problems or areas that could be improved with the interface. These included;

1. Extensive observation of and interaction with the interface.

2. The development and distribution of a questionnaire designed to probe the operators' subjective perceptions of the interface.

3. A comprehensive job analysis on ten current operators in order to determine the specific functions and tasks that the controller was involved in performing.

4. A comparison of all aspects of the interface to the standards, guidelines and recommendations established in the human computer interaction and ergonomic literature.

5. A specific human computer interaction interview with three operators to more closely examine user perceptions of the interface.

Outcomes of the initial evaluation

The problems identified during the evaluation and their subsequent solutions were compiled into tables according to the key principles of human computer interaction design and included in the appendix of the first evaluation report. In total, 32 problem areas were identified (see Appendix A). A number of recommended solutions were developed for each of the problems (see Table 1). A total of thirteen problems were identified that conflicted with general ergonomic principles, three problems that conflicted with the naturalness principle, one problem that conflicted with the consistency principle, four that conflicted with the non-redundancy principle, nine that conflicted with the supportiveness principle and two that were in conflict with the flexibility principle.

Principle Breached	*Number of problems*	*Number of recommended solutions*
General ergonomic	13	20
Naturalness	3	6
Consistency	1	1
Non-redundancy	4	6
Supportiveness	9	11
Flexibility	2	1
Total	**32**	**45**

Table 1- Number of problems identified and recommended solutions by ergonomic principle breached.

Implementation of the outcomes from the initial evaluation

The implementation of the recommended solutions to the problems that were identified during the initial evaluation could not be implemented overnight. Instead, the recommendations will need to be included in future interface designs and implemented when and where possible and appropriate. Waratah have committed to improving their interface and adhering to ergonomic and human computer interface guidelines more rigorously in the future. They have acted in accordance with this commitment by looking to employ an ergonomics specialist to join their research and development team.

Interviews with Waratah personnel

Interviews were conducted with two of the personnel from Waratah general engineering, the manufacturers of the Waratah group of harvesting machines. The interviews were designed to gain some indication of the level of support for the recommended solutions that were outlined in the evaluation report. Two questions were asked of each manager in relation to each of the identified problems and the recommended solutions (see Appendix A).

Importance of the problem and the recommended solution

The first question asked of each manager was associated with the perceived importance of the identified problem and its recommended solution. Each manager was asked to rate on a five-point scale how important they believed that the problem was. To answer the importance questions, the managers were asked to consider the type of problem that was identified and how it may negatively impact on the operators performance, comfort, health and safety. They were instructed to respond with a 1 if they were unsure, 2 if they believed that the problem was very unimportant, 3 if they thought that the problem was unimportant, 4 if they thought it was important and 5 if they thought that the problem was very important.

1	2	3	4	5
Unsure	Very Unimportant	Unimportant	Important	Very Important

Benefit associated with implementing the solution

Each manger was also asked to indicate on a five-point scale the degree of benefit they believed would be associated with the implementation of each recommended solution. To answer the benefit scale, the managers were asked to consider the level of benefit that may be associated with implementing the solution in terms of operator performance, comfort, health and safety. They were instructed to answer with a 1 if they were unsure, 2 if they thought that the solution would yield no benefit, 3 if they though it would yield a small benefit, 4 if they thought that it would yield a large benefit and 5 if a very large benefit.

1	2	3	4	5
Unsure	No Benefit	Small Benefit	Large Benefit	Very Large Benefit

Once each manger was interviewed and their ratings for the questions obtained, a composite score relating to each of the recommended solutions was calculated. This was done by taking the mean response from across the two responses. This provided some indication of how the people involved in the design of the Waratah interface viewed the solutions in terms of their importance and their subsequent benefit. The results of this exercise are presented in the following table (Table 2).

Problem Identified	Recommended Solution	Importance Rating	Benefit Rating
Font used in the display too small given the viewing distance.	Increase the font size used in the display by ½ mm.	3.5	3.5
Soft key functions and titles include upper and lower case type.	Adjust to include all upper case (this is not so much a problem but an improvement)	2.5	2
Dust collects in the corners of the display, obscuring visibility.	Include a flat face screen. Remove the edge running around the outside of the screen.	2	2
Display position A (between operators legs); -Beyond the recommended viewing distance -Below the recommended horizontal line of vision -Requires operators to lean forward which leads to postural difficulties.	Include an adjustable stand, move the display to position B (mounted on right hand side of cab), include an alternative input device.	2.5	3.5
Position B (mounted on right hand side of cab) beyond recommended viewing distance.	Include an adjustable mount for the display.	4	2.5
As viewing distance improves the viewing angle becomes more of a problem.	Custom design mounts for cab specifications.	3.5	3
Unable to adjust the height of the display.	Include an adjustable stand or mount.	2	3.5
Glare (reflections in the screen) obscures vision and can cause visual problems.	Encourage operators to clean their screens more often. Include an anti-glare filter.	4	3

	Remove high gloss finish from the display and replace with a more neutral density. Shade/tint/filter cab windows. Provide more adequate sun visors in cab.		
Large round scroll button requires very precise activations.	Enlarge button or alternatively split scroll functions up into four separate buttons. Have an alternative input device.	3.5	4
Differences in viewing distance between display and tree being processed can lead to visual fatigue.	Minimise by; Reducing glare Including an adjustable monitor position Encourage operators to take small rest breaks and refocus eyes	4	3.5
Activation buttons on the hand controls contain hard, sharp edges.	Replace with buttons with smooth, rounded edges.	3.5	3
Motor and de-limbing controls on the top of the joysticks cause sore thumbs.	Include soft padded cover on tops of joysticks.	4.5	4
The fixed position of the control buttons forces operator's hands into cramped positions.	Make the button panels easily adjustable to accommodate individual characteristics.	4.5	4
Many of the arm-rests used in conjunction with the harvesting task do not support the operators arms correctly.	Height and length adjustable arm rests need to be included in the cabs. More research needed into Waratah's responsibility.	2.5	2.5
Some of the words and terms used in the display are foreign to operators.	Liase more closely with operators to identify problem terms and words and then develop alternatives. Include a glossary of definitions in the user manual for the more difficult terms. Have an instructional period clarifying any unclear terms.	2.5	4
Operators believed the 'copying cutting lists' instructions in the user manual was unnecessarily complex.	Reword the paragraph. Conduct a training course which clarifies ambiguous terms.	2.5	2.5

	Provide examples and samples in the manual.		
Operators believed the 'bark-offset' formula was too complicated.	Same as above.	3.5	3.5
Soft key functions change depending on what screen the operators are on.	Have an alternative input device.	3	2
The order of functions in the main menu conflicts with the frequency of use principle.	Adjust the menu order to the order outlined in the LIRO report.	3.5	3.5
Large scroll button takes too long to scroll down through menus and lists.	Assign numbers to menu options and assign to the keypad. Incorporate display functions into the keypad.	3.5	3.5
Operators forced to turn on lights at night to see species panel.	Illuminate buttons on keypad for night work.	4	2.5
Input of cutting instructions far too time consuming.	Utilise modem capabilities. Incorporate an attachable keyboard or remote control. Incorporate buttons on display into the keypad	4	2
Measuring wheel deteriorates corrupting the accuracy of measurements.	Include a prompt for measuring wheel checks every 6 months or so depending on the conditions to which exposed.	4.5	3
Operators working long hours without any rest breaks.	Interface should prompt for rest breaks and micro pauses.	3.5	2.5
Interface takes a while to boot up without any message informing the operator.	Provide notification to the operators that the interface has responded to the start up in the form of a message.	4	3
Operators occasionally activate wrong button at night because they cannot see the panel.	Illuminate buttons for night work.	4	3
No authorship is attributed to the logrite controller manual.	Attribute name of developer to the manual.	2.5	1.5
On-line help system is currently unavailable.	Develop on-line help system and make it available to operators adhering to the	1	2.5

	recommendations presented in this report.		
There is a lack of standardised training for operators.	Develop a standardised training program for use of the controller and interface. Inform contractors of its availability and the benefits associated with such training. Develop and make further use of the interface simulator.	2.5	3
Updates of manual coming out.	Include a 'changes to version page' in new versions.	2.5	2.5
Remote service support and fault diagnosis and remote software support and upgrades unavailable.	Implement and utilise modem capabilities.	4	3.5
Interface is not very sympathetic to left-handed operators.	Same as above.	3.5	3.5

Table 2- Outcome of interviews with Waratah personnel.

Discussion of the interview findings

Generally, the responses to the interface interview indicate that Waratah are interested in the findings from the initial evaluation and are aware of the importance of the problems that were identified and the benefits associated with implementing the recommended solutions. In particular there appears to be a good appreciation of the importance of a number of the problems identified during the evaluation. These include the problems associated with the font size used in the display, the viewing distance and viewing angle of the display, the glare related problems, a number of the problems associated with the hand controls and the controller buttons, the problems associated with some of the terms and words used in the display and interface user manual, the problems associated with night operation, the inputting of cutting instructions, some of the recommended prompts, and the need for remote service support and fault diagnosis.

Similarly, there appears to be a good appreciation of the benefits that can be obtained from implementing the recommended solutions. In particular, Waratah personnel believed some benefits would be obtained from implementing the recommendations associated with the font size used, the display mount and position, those associated with compensating for the glare related effects, improving the hand controls and the controller buttons, improving the language used in the display and the user manual, and improving the remote support and fault diagnosis associated with the interface and the training associated with the interface. Large benefits in particular were perceived to be associated with improving the hand controls and the words and terms used in the interface.

The results to the interview provide encouraging signs as they indicate that the people involved in the manufacture of the Waratah interface are aware of the problems associated with their product and some of the ways that the problems can be solved. They are also encouraging as they indicate that the manufacturers may be interested in eventually implementing the recommendations and as such the full ergonomic process can be completed. The general lack of appreciation of the training related issues was however disappointing, as it indicates a lack of understanding of the importance of such factors on the performance of the mechanised harvesting task.

In addition to the problems identified during the initial evaluation, there were also a number of other areas associated with the interface that required further analysis. In particular some of the issues associated with occupational overuse and musculoskeletal problems, and how the interface may be contributing to this needed to be addressed. Similarly, training issues, user support systems and other more general ergonomic considerations needed to be emphasised.

AREAS IDENTIFIED DURING THE INITIAL EVALUATION THAT REQUIRED FURTHER RESEARCH

Body part discomfort survey

A body part discomfort survey was administered to nine Waratah harvester operators (Appendix B). The survey was developed by Straker, Stevenson & Twomey (1997) and required the operators to indicate on a scale ranging from 'no discomfort' to 'extreme discomfort' the discomfort levels associated with 13 different body part locations. In addition to the body part discomfort map, a section was included which asked operators their age, the number of months they had been operating the Waratah and the average number of hours a day spent operating.

Results & Discussion

Five of the operators invited to participate in the study returned completed questionnaires. The age of the operators ranged from 36 to 43 years with an average of 39.6 years. The total number of months the respondents had been operating the Waratah ranged from 19 to 96 months with an average of 44.6 or just over three and a half years. The average number of hours a day spent operating the harvester ranged from 6 through to 10 hours with an average of 9 hours across the five operators.

All of the operators who responded to the questionnaire reported that they were suffering from some form of physical discomfort (see Table 3). A number of operators reported experiencing discomfort in more then one area of their body. One operator in particular reported suffering from physical discomfort in his head and neck, shoulders and arms, elbows and forearms and wrist, hand and fingers. Most of the operators reported experiencing only average levels of discomfort, although extreme levels of discomfort were reported in relation to the fingers, wrist and hand.

Type of discomfort	*Number of operators*	*Average discomfort*	*Extreme discomfort*
Lower Back	2	2	
Fingers	3	2	1
Wrist & Hand	2	1	1
Head & Neck	1	1	
Shoulder & Arm	1	1	
Elbow & Forearm	1		1

Table 3- Types of discomfort experienced by mechanised harvester operators.

Although the sample used in the body part discomfort survey was small, the responses are consistent with similar types of research conducted in forestry (Ponten 1988, Byers 1997, Axelsson 1998, Cummins 1998), and indicate that machine operators are suffering from a range of physical discomforts, particularly in relation to the upper body. It is difficult to attribute the source of these ills to any one particular factor associated with the mechanised harvesting position. More then likely there are a combination of factors that are contributing to the body part discomfort of operators. As such, a range of interventions will need to be developed to help reduce discomfort levels and subsequently improve operator performance. The recommendations made in the initial evaluation and during the current evaluation are designed to accomplish this.

Upper body discomfort in forestry

Upper body discomfort appears to be a significant problem in the forestry industry and one that is likely to continue to increase with the greater reliance on mechanised equipment. The intense mental and physical nature of the harvesting task has already been documented (Byers 1997, Sullman & Kirk 1998), with operators involved in repetitive short-cycle movements for a large proportion of the working day. Hansson (1990) has indicated that the arms and hands of operators are engaged between 50-90% of the time during the working day. This ratio is consistent with the findings of the job analysis that was conducted (Smith & O'Rorke 1999b), where operators estimated their fingers to be active 95% of their operating time. Ponten (1988) has assessed over a thousand forestry machine operators and found that 44% of operators under the age of 25 reported health related symptoms in the neck and shoulders and 60% of operators between the age of 45 and 55 reported similar symptoms.

Although the increase in mechanisation has greatly reduced the number of accidents associated with forestry work, the technology has however introduced many health related problems of a different kind. In particular, repetitive strain injuries and occupational overuse afflictions are an area of major concern. Axelsson (1998) has indicated that as many as 50% of logging machine operators in Sweden have symptoms of repetitive stain injuries. Byers (1997) found that 43% of the operators surveyed in New Zealand reported experiencing pain all of the time, the majority of this pain associated with the wrists and hands. She also found that only 26% of the operators had received any training from the machine manufacturer. It also appeared as if those who had not undergone training were more likely to experience symptoms of pain. This finding is likely to be particularly true when the training that is associated with a machine includes sessions on operator health, wellbeing and ergonomics training as has already been recommended in the initial evaluation.

It is highly likely that the hand controls that are included in the Waratah group of harvesting machines are contributing to these uncomfortable working conditions. Some of the problems identified during the initial evaluation reflect this possibility. As such, this section of the report focuses on hand controls, providing recommendations on their design in an attempt to decrease musculoskelatal disorders and complaints associated with the operation of the Waratah harvesting machine.

Occupational overuse injury

There are a large variety of musculoskeletal problems that are associated with working in industry related occupations. Muggleton, Allen & Chappell (1999) have provided a taxonomy of the disorders that are related to occupational overuse in industry. These include:

<u>Vibration induced whitefinger or hand-arm vibration syndrome.</u>

Occurs in workers exposed to vibrating equipment.

<u>Nerve compression disorders.</u>

Occurs when repeated and continued compression is located at the shoulder, the elbow and the wrist. Chances of this are high in the Waratah as there is focussed compression on the elbow due to poor arm rest design (Smith & O'Rorke 1999a). There are a number of variants of nerve compression disorders. These include:

- Carpal tunnel syndrome- Compression in the median nerve in the carpal tunnel of the wrist resulting in pain, tingling and/or paralysis of fingers.

- Cubital tunnel syndrome- Involves entrapment of the ulnar nerve at the elbow. Tingling and numbness occur as a result.

- Pronator teres syndrome- Involves entrapment of the median nerve at the elbow. Symptoms include aching and discomfort in the forearm and weakness and numbness in the hand.

- Thoracic outlet syndrome- Involves compression of the brachial plexus in the neck and shoulder region. Produces pain and muscle spasms in the neck and shoulders. The strength of the wrist may also be weakened.

<u>Tendon and tendon related disorders including tendinitis</u>

Involves inflammation of the tendons. Associated with frequent or repeated movements of the hand and wrist. Again, chances of this are high in the harvesting task, as the operators are required to use their hand and wrists in operation of the machine controls for a very large proportion of their working day (Smith & O'Rorke 1999b).

- Dr Quervains disease- Caused by stenosis of the thumb abducters. Pain and swelling occurs at the base of the thumb.

- Trigger finger- Swollen tendon sheath resulting in the tendon being locked, such that attempts to move the finger cause a snapping or jerking movement (Freivalds 1999). Occurs most frequently in the middle finger.

- Rotator cuff syndrome- The tendons that rotate the shoulder joint become swollen. Results in reduced muscle power.

Other disorders

Includes other diseases related to the hand and arm.

- Cramp of the hand or forearm- Relates specifically to repetitive movements. Characterised by spasms and pain in the hand or forearm when in the process of completing a frequently repeated act.

- Subcutaneous cellulitis of the elbow- Refers to trauma around the elbow area. Symptoms include pain and swelling.

- Subcutaneous cellulitis of the hand- Involves bruising and weakening of the hand. Symptoms include pain, loss of function and swelling.

It is obvious from an analysis of the above taxonomy that the development of any one of these disorders would prove very costly in relation to performance on the mechanised harvesting task in terms of operator speed, accuracy, sick leave, absenteeism and turnover. Unfortunately, there are a number of factors associated with the mechanised harvesting task (Smith & O'Rorke 1999a, Smith & O'Rorke 1999b) that have been found to influence the development of the aforementioned and similar physical disorders. What follows is an overview of some of the problem areas or risk factors that have been found to contribute to the development of the disorders. Viikari-Juntura (1999) has outlined nine work related risk factors that may be observed.

Occupational risk factors

Heavy physical work

Involves manual handling of heavy loads and also elevated postures of the arm.

Manual handling

Involves manually manipulating work related objects.

Elevated postures of the arm

Involves prolonged elevated arm postures.

Nonneutral trunk postures

This involves postures of the torso, neck and limbs which are not natural to the worker.

Static postures

This involves static exertion of the arms and shoulders.

Repetitive work

Involves highly repetitive, usually short cycle work physical movements. A typical pattern is where the fingers need to perform quick and repetitive movements.

Lack of pauses

Involves a poorly designed pause or rest break schedule. The frequency, duration and quality of work pauses are all important considerations to take into account when looking to reduce work related physical disorders.

Vibration

Involves prolonged exposure to vibrating tools or equipment.

Work organisational factors

This includes work organisation factors such as work load, deadline work, work duration or shift length and also psychosocial factors such as work relationships and job satisfaction.

Having outlined some of the musculoskeletal problems that can occur in industry related contexts and some of the factors that appear to contribute to these problems, we will now focus on ways in which the chances of these problems occurring can be reduced. In addition to the solutions outlined in the initial evaluation, the preventative measures listed below are designed to reduce the likelihood of operators experiencing occupational overuse injuries and related problems.

Preventative Measures

Ergonomic design considerations

- The use of curved handles has been found to reduce awkward wrist and postural positions (Johnson 1993). This can help to reduce a number of the postural problems previously mentioned and can also allow for a more even displacement of pressure on the hand and fingers.

- Handle straps have also been found to be useful in reducing load related strain associated with hand control use (Johnson 1993).

- A custom-mountable handgrip can help to alleviate some of the problems associated with different hand and reach requirements (Fransson & Winkel 1991, Oh & Radwin 1993).

- Reduce grip forces- Andris (1999) has asserted that when the index finger is used extensively for operating as it is with the harvesting machine, the symptoms of trigger finger are sure to develop. He asserts that to help minimise this, trigger forces should be kept low (below 10 N) to reduce the load on the index finger.

Finger strip controls are also very effective at reducing the chances of trigger finger.

Changes in workplace practices

- Attempts should be made at reducing the task frequency and repetition associated with the harvesting task. The applicability of job rotation systems could also be assessed, although this may be difficult due to the unique skills and abilities that are required of operators (Carson 1993, Cullum & Molloy 1994).

- Operators should be encouraged to take rest breaks, preferably for five minutes every hour spent operating. During these breaks, operators should take the time to get out of the machine and stretch their fingers, hands and arms. They could take this opportunity to conduct mechanical or hydraulic checks of the machine. Byers and Skerten (1996) have outlined a range of stretches that operators could be encouraged to perform.

- Operators should be encouraged to take brief micropauses. Occupational Safety and Health guidelines (1996) for work involving visual display units suggest that they should be taken frequently (5-10 seconds every three minutes) for the greatest effect. The similarities between the repetitive nature of the harvesting task and keyboard based work would justify similar recommendations being made for the mechanised harvesting task.

- Biofeedback measures have been found to be useful in reducing physical problems in the workplace (Thomas & Vaidya 1993). Biofeedback provides the operator with information about their own operating style and the effect that this is having on different parts of their anatomy. They can then assess their own physiological state and adjust their operating accordingly. It can also provide a good indication of when a rest pause is required.

HAND CONTROLS

There are also a number of useful guidelines associated with hand control design that are available in the ergonomic literature. Such guidelines provide a set of useful criteria against which prospective hand control designs can be compared to. Ivergard (1999) has provided the following list:

Guidelines for control design

- The maximum strength, speed, precision, or body movement required to operate a control must not exceed the ability of any possible operator.
- The number of controls available for operation should be kept to a minimum.
- Control movements that are natural to the user are best and least tiring.
- Control movements should be as short as possible.
- The controls should have enough resistance to prevent their accidental activation.
- The controls must give feedback so that the operator knows when it has been activated.
- The controls must be designed so that the hand/foot does not slip off or lose its grip.

Small control levers

Research has indicated that the use of small control levers that are primarily operated by the fingers as opposed to the more conventional larger hand controls that are operated with the whole hand and require extensive arm movements can have a number of benefits. Initial studies conducted using simulators and real life harvesters and forwarders found that the mini levers reduced muscle constriction without impacting on productivity levels (Jonsson, Brundin, Hagner, Coggman & Sondell 1984, Harstela 1990). Waratah could assess the possibility of implementing small control levers into the design of their interface.

Asikainen and Harstela (1993) compared small sized mini levers to conventional levers in a forestry machine. It was found that mini levers did not influence the time consumption on the task, but did decrease muscle constriction in the trapezius muscle, and resulted in improved performance when damage inflicted on remaining trees was the criteria. Askainen & Harstela have argued that this last finding is due to the suitability of the muscles and joints in the hands and fingers for executing the short fast and precise movements that are associated with mini levers. They concluded by stating that the implementation of mini levers, coupled with well designed arm rests and the practice of ergonomic exercises, particularly in relation to the fingers may lead to a number of positive experiences for machine operators.

OTHER ERGONOMIC FACTORS IN THE MECHANISED HARVESTING TASK THAT MAY CONTRIBUTE TO DECREASED PERFORMANCE LEVELS.

There are a number of other work related factors that have been identified as being related to the mechanised harvesting task during the job analysis that was conducted (Smith & O'Rorke 1999b), that have unfortunately been found to have a negative influence on the performance of workers. What follows is an outline of these factors and a number of recommendations that are designed to alleviate the potential negative effect on operator performance that they can have.

High levels of cognitive load

Research conducted in New Zealand has indicated that the mental workload associated with the mechanised harvesting task can reach very high levels (Smith &

O'Rorke 1999b), comparable to those of air traffic controllers and higher than those of commercial airline pilots (Sullman & Gellerstedt 1997, Sullman & Kirk 1998). A number of studies have indicated that high levels of cognitive load decreases cognitive performance and subsequently task performance (Rasmussen 1986).

How to decrease cognitive load

One way of reducing cognitive load or alternatively, assisting the worker who has to bear it, is to reduce the information processing rate by increasing automation. Another more innovative solution involves improving the degree of congruence or similarity between the operator's natural movements and the actions of the machine. Branczyk (1996) argues that the position of the controls and the resulting machine movements are often incongruent in that the activation of the controls seldom resemble the effect that they have on the machine. This lack of similarity increases mental stress for the machine operator, as they have to translate the desired effect on the machine to the cause brought about by the operation of the machine controls. He argues that new technologies in the area of machine controls and steering parts that increase the similarity between the operator's movements, and the subsequent effect on the machine movements, will help to reduce mental load and improve performance.

Repetitive tasks

The mechanised harvesting task involves the performance of highly repetitive tasks, particularly in relation to the use of the hand controls which require repeated short cycle movements. The Position Analysis Questionnaire procedure used in the job analysis process (Smith & O'Rorke 1999b) indicated exposure to repetitive activities to be in the 98th percentile. Research has demonstrated that continual exposure to repetitive tasks can decrease cognitive performance (Grandjean 1979).

How to decrease repetitive tasks

This is difficult to achieve given the nature of the harvesting task. However, small rest breaks as are recommended by Occupational Safety and Health Guidelines (1996), and also in the initial evaluation (Smith & O'Rorke 1999a). Rest breaks can help reduce the monotony associated with repetitive tasks. As was mentioned earlier, job rotation systems could also be assessed but there may be difficulties associated with their implementation.

Noise

The job analysis also indicated that harvesting operators are exposed to noisy working conditions for the majority of the working day. This is due to the prevalence of large, noisy machinery within the working environment. Continual exposure to noise in the working environment can lead to decreases in performance (Broadbent 1958, Jerison 1959). Exposure to noise can have a number of other negative effects in relation to work performance. These include; masking or blocking out important work related auditory signals such as inter-operator communications or process related cues, noise induced hearing loss and reduced job satisfaction (Casali & Robinson 1999).

How to decrease noise

A relatively simple way to reduce noise levels within the working environment is to provide operators with ear protection equipment. Examples of this are hearing muffs, earplugs and ear canal caps. However, the effect that these interventions have on the operator's ability to pick up important work related cues would need to be assessed. A noise related training programme could also be implemented. This training should outline the negative effects of hearing loss and recommend the use of hearing protection devices. Noise Reduction can also be achieved through a number of design considerations. These include making use of silencers on exhaust functions and insulating the machine cab with reflective or absorptive materials (Casali & Robinson 1999).

Vibration

Operators are also exposed to vibrating equipment for the majority of their working day. Aside from the effect that continual exposure to vibration can have on the musculoskeletal system and motor control, vibration has also been found to negatively influence cognitive performance (Grether 1971). Vibration can also have negative effects on operator performance by inhibiting the ability to focus visually on the tree being processed. Oborne (1995) has argued that an object can only be perceived clearly if it is able to project a stable image onto the retina. Vibration decreases the likelihood of this occurring, and usually produces an overlapping and confused image.

How to decrease vibration

Vibration can be eliminated through good quality machine, cab and interior design, especially in relation to the seat and hand controls. Awkward operating postures which have been found to influence vibration related problems should also be eliminated through cab layout design (Pope & McIntyre 1999). Frequent rest breaks can also decrease the problems associated with exposure to vibration.

Light intensity and glare

Light intensity and glare related effects appear to be a problem associated with the mechanised harvesting task in particular (Smith & O'Rorke 1999a), and machine operators in general (Byers 1997). This is due to the fact that operators are located in a cab which is enclosed by windows and the fact that they are working in outdoor conditions, invariably in direct sunlight. In addition to this, the computer display associated with the Waratah interface reflects light and can produce glare effects and glare related problems. Light intensity and glare effects have been found to negatively influence cognitive performance through increasing levels of fatigue and can also influence musculoskeletal problems (Aronoff & Kaplan 1995).

How to decrease light intensity and glare

The use of glare filters on the logrite controller screen will help to reduce glare related problems. In addition to this, the sun visors provided in cabs should be assessed and improved if necessary and operators should be encouraged to keep their screens and windows clean. Byers (1997) has also suggested that turning on the machines external lights can help alleviate the high contrast between looking into areas of sun and areas of shade in the work environment.

Psychosocial factors

The International Labour Office (ILO 1986) defines psychosocial work factors as 'the interactions between and among the work environment, job content, organisational conditions and workers' capacities, needs, culture, personal extra-job considerations that may through perceptions and experience, influence health, work performance and job satisfaction'. A number of psychosocial factors that have been found to reduce health, performance and job satisfaction appear to be evident in the mechanised harvesting task (Smith & O'Rorke 1999b). These include high levels of work pressure, high levels of cognitive demands, repetitiveness, low levels of control over the work environment, low levels of control over work pace, computer related problems, and role conflict and ambiguity (Carayon & Lim 1999).

How to improve psychosocial factors

The specific way that psychosocial work factors will need to be improved will depend upon the specific psychosocial problem. The following table (Table 4) provides some examples of the more common psychosocial problems as well as the ways in which the problems can be addressed.

Psychosocial Problem	***Solution to Psychosocial Problem***
Repetitiveness of work tasks	• Implement job rotation. • Job enrichment programmes. • Increase the training and perceived skill levels associated with the harvesting position.
A lack of job control	• Allow operators to determine their work schedule in accordance with crew policy and production requirements (Carayon & Lim 1999). • Allow operators to provide input into the crew decision making.
Social interactions	• Encourage discussion at smoko and break times • Implement a performance review system. • The supervisor should appear to be interested in the operators work, problems and requests.

Table 4- Types of psychosocial problems and recommended solutions.

TRAINING

Numerous articles have outlined the need for improved approaches to harvester training (Garland 1990, Byers 1995, Parker, Kirk & Sullman 1996, Kirk, Byers, Parker & Sullman 1997, Sullman & Evanson 1998, Cummins 1998, Smith & O'Rorke 1999a, Smith & O'Rorke 1999c, Gellerstedt & Dahlin 1999). Guimer (1999) has argued that the increasing constraints and operational demands in the forest as well as increasingly complex machinery will further accentuate the need for improved approaches to operator training. During the course of the initial evaluation, the lack of standardised training provided for operators was widespread. The need for standardised training is imperative, if the harvesting machine is going to be utilised to its full capacity. Until such training procedures are properly developed and implemented, the full potential of the interface and the machine will not be realised, and many of the problems associated with the quality of mechanised processing and value recovery are likely to continue.

Industry related training

Training in industry has been defined as "a set of planned activities on the part of an organisation to increase the job knowledge and skills or to modify the attitudes and social behaviour of its members in ways consistent with the goals of the organisation and the requirements of the job" Landy (1989). This definition has three noteworthy components:

- By "planned activities" we mean that training is a systematic and intentional process, not random or haphazard.

- "Modify the attitudes and behaviour," means that training is designed to alter behaviour (directly or indirectly). People should do things differently after training.

- Finally, "with the goals of the organisation" refers to why training is conducted in the first place: its purpose is to alter people's behaviour in a way that will contribute to organisational effectiveness. Fortunately, in most cases the change in behaviour also contributes to the individual's effectiveness at work, so people are rarely trained against their will.

Any behaviour that has been learned is a skill. Within the area of training, the learning process is task oriented, it enhances skills. Training therefore, is directed toward enhancing a specific skill, which in turn enhances a person's proficiency or capacity in performing a certain task. Skills become the "target areas" of training, especially personnel training. In industry, training enhances three broad classes of skills; Motor skills refer to the manipulation of the physical environment based on certain patterns of bodily movements. Cognitive skills relate to the acquisition of mental or attitudinal factors. Interpersonal skills refer to enhancing interactions with other people. Though all three types of skills are the focus of personnel training, their relative importance depends on the nature of the job. Machine operators will need to be trained in relation to all three of these skill areas.

Training can contribute to organisational goals in a number of ways:

- Reducing labour costs by decreasing the amount of time it takes to perform tasks involved in producing goods or services.

- Reducing the time needed to bring the inexperienced employee to an acceptable level of job proficiency.

- Reducing the costs of materials and supplies by reducing losses due to excess waste and the production of defective products.

- Reducing the costs associated with personnel activities such as reflected turnover, absenteeism, accidents, grievances, and complaints.

- Reducing the costs associated with efficiently servicing customers by improving the flow of goods or services from the company to the consumer.

- Reducing the stress that is associated with learning a new task.

The first step in the design of a training program is to identify what the specific training needs are, or in other words, identifying what gap exists between what the workers are capable of and what the task or tasks requires of them. After determining the training needs and translating them into objectives, the next step is to design a training program to meet these objectives. There are many different training methods available. They can be classified in a number of ways, though probably the best way is according to where the training takes place.

On-site training methods include on the job training, vestibule training, job rotation, and apprentice training. Off-site training methods include: lectures, audio-visual material, conferences such as this one, programmed instruction, computer assisted instruction, simulation exercises and role-playing. The use of harvester simulators has already been discussed in the initial evaluation (Smith & O'Rorke 1999a).

During the course of the initial evaluation it became apparent that there were a number of training related needs, particularly in relation to the use of the human computer interface. Unfortunately, no formal training program is currently available and many operators reported being trained by someone from there own gang who themselves were not completely capable. This led to a number of problems as many of the new operators stumbled through their use of the interface. In addition to this, many operators were not aware of the many functions that the interface provided for them and this deficit meant that many of the machine capabilities were not used. A formalised, thorough training program for Waratah operators is essential.

BENEFITS THAT CAN BE EXPECTED FROM THE IMPLEMENTATION OF THE RECOMMENDED SOLUTIONS

When it comes to implementing the recommendations that are made in the area of ergonomics and human computer interaction, there are a number of barriers that exist (McLean & Rickards 1998). Generally, organisations tend to focus on the short-term costs associated with such an implementation rather then the benefits, which are usually more long term. However, everybody stands to gain from improved working conditions. The employee stands to gain from having an improved working environment, with its decreased likelihood of workplace injury. The employer stands to gain from increased productivity that results from improved workplaces and employee morale. Even government stands to gain with savings on sickness benefit, and unemployment payments.

Although implementing the recommendations made in this and the initial evaluation would involve investments in relation to time, energy and money, a number of benefits can be expected from such implementations that make the process economically worthwhile. McLean & Rickards (1998) suggest that these include increased productivity, fewer errors, a reduction of minor injuries, lowered injury and accident rates, increased employee job satisfaction and a subsequent decrease in absenteeism and turnover.

All of these things are going to be positive from the perspective of the manufacturer as they help to make their product look good. When operators perform well, contractors are going to attribute much of this to the machine. On the other hand, when there are repeated injuries occurring from operating the machine, which result in absenteeism, turnover and subsequent operational down-time, the Waratah will be viewed in a negative way.

EMPOWERING THE MANUFACTURER

Ergonomic software, computer programmes

There are a number of programmes, software packages and computer aided tools available that provide practitioners and designers with up to date ergonomic related knowledge. The information is designed to empower and equip those who are involved in the design of equipment, to implement and adhere to ergonomic guidelines during the design of their product. Jarvinen and Lu (1999) have outlined a number of examples of these types of programmes. These include:

ErgoSHAPE	
Developer	Institute of Occupational Health, Ergonomics Unit, Topeliuksenkatu 41 a A, 00250 Helsinki, Finland.
System Requirements	IBM-compatible PC, AutoCAD of designer software.
Description	ErgoShape is a human modelling system. The programme contains male and female anthropometric dimensions, biomechanical calculations, recommendation charts and text files that contain ergonomic guidelines.

ErgoMost	
Developer	H.B. Maynard and company. www.hbmaynard.com
System Requirements	IBM- compatible PC, 486 33 MHz or higher, 8 MB RAM, Windows 3.1 or higher.
Description	Ergomost assesses the risk factors associated with repetitive motion activities. The package focuses on ways to improve the workplace to reduce stress and enhance motion efficiency. Twelve different body parts are evaluated and a variety of report options are available.

PeopleSize	
Developer	Friendly Systems Ltd., 443 Walton Lane, Loughborough, LE12 8JX, England.
System Requirements	Windows 3.1 or higher, 2 MB RAM, 1.5 MB free disk space, mouse.
Description	Database that consists of validated human dimensions that are relevant to equipment design.

WorkSmart Stretch Software	
Developer	Ergodyne Corporation, 1410 Energy Park Dr., STE 1, St Paul, MN 55108-9950.
System Requirements	386 IBM compatible PC, windows 3.1 or higher, mouse.
Description	The WorkSmart software reminds operators about taking a rest break every 50 minutes while they are working. Demonstrations and instructions for exercises related to four body areas are provided. The break can be rescheduled.

World Wide Web information

In addition to the aforementioned programmes, there are also a number of useful ergonomic sites available on the world wide web. For an example of the enormous amount of ergonomic related information on the internet, the authors entered the term 'ergonomics' into three different well known search engines. The results are summarised in Table 5. In addition to this, to aid in the search for ergonomic information on the internet, we have also provided a list of useful web sites. This list is by no means meant to be exhaustive, but merely an indication of the types of useful resources that are easily accessible for ergonomics guidance on the internet.

Search engine	*Number of web pages matching search criteria- ergonomics*
www.altavista.com	201,175
www.alltheweb.com	137,402
www.northernlight.com	239,014

Table 5- Number of ergonomic web pages as identified by three search engines.

- www.usernomics.com

Provides a very good starting place from which to locate information on ergonomics and human factors. The site has links to almost every topic in the field.

- www.ergonomics.org.uk

Web site of the ergonomics society of the United Kingdom. For professionals using information about people to design for comfort, efficiency and user safety.

- www.ergonomics.ucla.edu

Offers ergonomic information including general workplace ergonomics, computer related ergonomics and body mechanics.

- www.hfes.org

Promotes the discovery and exchange of knowledge concerning human characteristics that are applicable to the design of systems and devices.

- www.ergonomics.com.au

Provides advice on ergonomic and safety topics plus a wide range of links to ergonomic services in Australia.

- www.ergonomics.org.au

The website of the ergonomic society of Australia. Aims to advance the science of ergonomics by promoting education and research in ergonomics and the application of its principles.

- www.ergoweb.com

Provides an extensive collection of ergonomic standards, guidelines, reference materials, case studies, anthropometric data and other ergonomic resources.

- www.iea.me.tut.fi/

Website of the international ergonomics association. Represents the association of ergonomics and human factors societies around the world. Provides a range of ergonomic related information and includes the IEA Journal of Ergonomics.

REFERENCES

Andris, F. (1999). Ergonomics of hand tools. In W Karwowski & W. S. Marras (Eds.), *The Occupational Ergonomics Handbook* (pp. 461-478). Florida: CRC Press.

Aronoff, S., & Kaplan, A. (1995). *Total Workplace Performance- rethinking the office environment.* Ottawa: WDL Publications.

Asikainen, A., & Harstela, P. (1993). Influence of small control levers of grapple loader on muscle strain, productivity and control errors. *Journal of Forest Engineering, 5*, 23-28.

Axelsson, S. (1998). The mechanisation of logging operations in Sweeden and its effect on occupational safety and health. *Journal of Forest Engineering, 9*, 25-31.

Blache, K. M. (1987). *Postural discomfort evaluation of production workers- Trends in Ergonomics/human factors IV.* North Holland: Elsevier Science Publishers.

Branczyk, C. (1996). What makes loader handling so difficult? *Journal of Forest Engineering, 7*, 67-72.

Broadbent, D.E.. (1958). Effects of noise on an intellectual task. *Journal of the Acoustical Society of America, 30*, 824-827.

Byers, J. S. (1995). *Mechanisation in the Forest Industry.* Proceedings of the 6th Conference of the Ergonomics Society. Palmerston North, New Zealand.

Byers, J. S. (1997). Operator health- A survey of feller-buncher operators. LIRO Report, Vol. 22, No. 17.

Byers, J. S. & Skerten, R. (1996). Techniques for reducing injuries in machine operators. LIRO Report, Vol. 21, No. 23.

Carayon, P. & Lim, S. (1999). Psychosocial work factors. In W Karwowski & W. S. Marras (Eds.), *The Occupational Ergonomics Handbook* (pp 275-283). Florida: CRC Press.

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

Casali, J. G. & Robinson, G. S. (1999). Noise in industry: Auditory effects, measurement, regulations, and management. In W Karwowski & W. S. Marras (Eds.), *The Occupational Ergonomics Handbook* (pp 1661-1692). Florida: CRC Press.

Cossens, P. (1991). Operator log making ability on a mechanised processor. LIRA Report, Vol. 16, No. 14.

Cullum, D. E. & Molloy, C. J. (1994). Occupation and the carpal tunnel syndrome. *The Medical Journal of Australia, 161*, 552-554.

Cummins, T. (1998). Factors affecting logmaking from the cab- A study of mechanised logmakers. LIRO Project Report, No. 70.

Evanson, T. (1995). A survey of the quality of mechanised log-making in New Zealand. LIRO Report, Vol. 20, No. 6.

Evanson, T., & McConchie, M. (1996). Productivity measurements of two Waratah 234 hydraulic tree harvesters in radiata pine in New Zealand. *Journal of Forest Engineering, 7*, 41-52.

Fransson, C. & Winkel, J. (1991). Hand strength: the influence of grip span and grip type. *Ergonomics, 34*, 881-892.

Freivalds, A. (1999). Ergonomics of hand tools. In W. Karwowski & W. S. Marras (Eds.), *The Occupational Ergonomics Handbook* (pp 461-478). Florida: CRC Press.

Garland, J. J. (1990). Assessing gains from woodsworker training. *International Journal of Industrial Ergonomics, 5*, 227-242.

Gellerstedt, S. & Dahlin, B. (1999). Cut-to-length: The next decade. *Journal of Forest Engineering, 10*, 17-25.

Grandjean, E (1979). *Psychological and physiological reactions associated with repetitive tasks.* Proceedings of the Human Factors Society, 23rd annual meeting.

Grether, W. F. (1971). Vibration and human performance. *Human Factors, 13*, 203-216.

Guimer, D. Y. (1999). Canadian forestry operations in the next century. *Journal of Forest Engineering, 10*. 7-12.

Hansson, J. E. (1990). Ergonomic design of large machines. *International journal of industrial ergonomics, 5*, 255-266.

Harstela, P. (1990). Work postures and strain of workers in Nordic forest work: a selective review. *International Journal of Industrial Ergonomics, 5*, 219-226.

Helander, M (ed). (1991). *Handbook of Human-Computer Interaction.* (2nd Ed.), New York: Elsevier Publishing.

ILO (1986). *Psychosocial Factors at Work: Recognition and Control*. Geneva: International Labour Office.

Ivergard, T (1999). Design of information devices and controls. In W. Karwowski & W. S. Marras (Eds.), *The Occupational Ergonomics Handbook* (pp 97-139). Florida: CRC Press.

Jarvinen, J. & Lu, H. (1999). A guide to computer software for ergonomics. In W. Karwowski & W. S. Marras (Eds.), *The Occupational Ergonomics Handbook* (pp 501-509). Florida: CRC Press.

Jerison, H. J. (1959). Effects of noise on human performance. *Journal of Applied Psychology, 43*, 96-101.

Johnson, S. L. (1993). Ergonomic hand tool design. *Occupational Diseases of the Hand, 9*, 299-311.

Jonsson, B., Brundin, L., Hagner, I., Coggman, I., & Sondell, J. (1984). Operating a forwarder: an electromyographic study. *Biomechanics, IX-B*, 21-26.

Kalawsky, R. S. (1999). VRUSE- A computerised diagnostic tool: For useability evaluation of virtual/synthetic environment systems. *Applied Ergonomics, 30,* 11-25.

Kilbom, A., & Petersson, N, F. (1999). Elements of the ergonomic process. In W. Karwowski & W. S. Marras (Eds.), *The Occupational Ergonomics Handbook* (pp 1575-1581). Florida: CRC Press.

Kirk, P, M., Byers, J. S., Parker, R. J., & Sullman, M. S. (1997). Mechanisation developments within the New Zealand forest industry- The human factors. *Journal of Forest Engineering, 2,* 75-80.

Landy F, J. (1989). *Psychology of Work Behaviour.(*4th ed), California: Brooks/Cole.

Macaulay, L. (1995). *Human-computer interaction for software designers*. London: International Thomson Publishing Inc.

McConchie, M., & Evanson, T. (1996). Logging Industry Research Organisation. Mechanisation Research Review, New Zealand.

McLean, L., & Rickards, J. (1998). Ergonomics codes of practice: The challenge of implementation in Canadian workplaces. *Journal of Forest Engineering, 9*, 55-64.

Muggleton, J. M., Allen, R., & Chappell, P. H. (1999). Hand and arm injuries associated with repetitive manual work in industry: a review of disorders, risk factors and preventive measures. *Ergonomics, 42*, 714-739.

Noyes, & Cook (1999) *Interface Technology- the leading edge*. Philadelphia: Research Studies Press.

Oborne, D. J. (1995). The physical environment: Vibration and Noise. In, *Ergonomics at work* (pp. 268-317). New York: Wiley.

Occupational Safety and Health, Department of Labour (1996). Approved code of practice for the use of Visual display units in the place of work.

Oh, S. & Radwin, R. G. (1993). Pistol grip power tool handle and trigger size effects on grip exertions and operator preference. *Human Factors, 35*, 551-369.

Parker, R., & Gellerstedt, S. (1998). *Ergonomic assessment of forest harvesting machines*. The 8th conference of the New Zealand Ergonomic Society. Rotorua, New Zealand.

Parker, R., Kirk, & Sullman, M. (1996). Learning curves of mechanised harvester and forward operators. LIRO Report, Vol. 21, No. 29.

Ponten, B. (1988). The health and work of forest employees- results from studies made in collaboration with 24 occupational health services during 1980-1987. The Swedish University of Agricultural Sciences, Department of Occupational Efficiency, No. 125, Garpenberg (English Summary).

Pope, M. H. & McIntyre, D. R. (1999). Perspective on Industrial low back pain. In W. Karwowski & W. S. Marras (Eds.), *The Occupational Ergonomics Handbook* (pp 1007-1036). Florida: CRC Press.

Rasmussen, J., (1986). *Information processing and man-machine interaction*. New York: North-Holland Publishers.

Smith, M., & O'Rorke (1999a). An evaluation of the human computer interface in the Waratah 234 harvesting machine. LIRO Project Report. Vol. 86.

Smith, M., & O'Rorke (1999b). A task analysis of mechanical tree harvesting to identify aptitudes necessary to successfully do the job. LIRO Project Report. Vol. 87.

Smith, M., & O'Rorke (1999c). *A practical solution- Methods to improve human performance*. Paper presented at a LIRO conference, Rotorua, New Zealand.

Soloway, E. & Pryor, A. (1996). The next generation in human-computer interaction. *Communications of the ACM, 39*, 16-18.

Straker, L. M., Stevenson, M. G., & Twomey, L. T. (1997). A comparison of single and combination manual handling tasks risk assessment: 2. Discomfort, rating of perceived exertion and heart rate measures. *Ergonomics, 40*, 656-669.

Sullman, M., & Evanson, T. (1998). Machine operator training: Can we afford not to? LIRO Technical Note, No. 37.

Sullman, M. & Gellerstedt, S. (1997). The mental workloads of mechanised harvesting. *New Zealand Forestry, 42*, 48.

Sullman, M., & Kirk, P. (1998). Mental workload of mechanised processing with a single grip harvester. LIRO Report, Vol. 23, No. 17.

Sutcliffe, A. G. (1995). *Human- Computer Interface Design* (2nd Ed.), London: Macmillian Press Ltd.

Thomas, R. E., & Vaidya, S. C. (1993). The effects of biofeedback on carpal tunnel syndrome. *Ergonomics, 36*, 353-361.

Viikari-Juntura, E (1999). Occupational risk factors for shoulder disorders. In W. Karwowski & W. S. Marras (Eds.), *The Occupational Ergonomics Handbook* (pp 833-849). Florida: CRC Press.

Weimer, J. (1995). *Research Techniques in Human Engineering*. New Jersey: Prentice Hall.

Wells, R. (1999). Integrated analysis of upper extremity disorders. In W. Karwowski & W. S. Marras (Eds.), *The Occupational Ergonomics Handbook* (pp 775-794). Florida: CRC Press.

APPENDIX A: WARATAH INTERFACE INTERVIEW

LIRO Ltd has been conducting research on the human computer interface of the Waratah harvesting machine. When I say interface I am referring to the computer display, the hand controls, and the things associated with these things such as the training and the user manual. The purpose of the research was to identify any aspects of the interface that could be improved. To conduct the evaluation we consulted with harvester operators, conducted field measurements and observations and compared the interface with ergonomic research literature. This questionnaire is an extension of that initial research.

In this questionnaire you will be presented with a list of the problems that were identified during the course on the evaluation. You will also be presented with the recommended solutions to these problems. This is then followed by two columns. The first is an '*importance*' column which is designed to assess how important you believe the problem and the solution is to the development of the waratah interface. The second is a '*benefit*' column which is designed to assess the level of benefit that you believe implementing the solution will yield. To answer these things please use the following scales;

Importance Scale

To answer the importance questions, consider the type of problem that was identified and how it may negatively impact on the operators performance, comfort, health and safety. Respond with a 1 if you are unsure, 2 if you think that the problem is very unimportant, 3 is you think it is unimportant, 4 if you think it is important and 5 if you think that the problem is very important.

1	2	3	4	5
Unsure	Very Unimportant	Unimportant	Important	Very Important

Benefit Scale

To answer the benefit scale, consider the level of benefit that may be associated with implementing the solution in terms of operator performance, comfort, health and safety. Answer with a 1 if you are unsure, 2 if you think the solution would yield no benefit, 3 if a small benefit, 4 If you think it will yield a large benefit and 5 if a very large benefit.

1	2	3	4	5
Unsure	No Benefit	Small Benefit	Large Benefit	Very Large Benefit

What follows is an example of the type of responses we are looking for.

Example

In the following example, the problem that was identified was that the buttons on the hand controls contained hard, sharp edges. It is recommended that these are replaced with buttons with smooth, rounded edges. I have given this problem and solution an importance rating of 4 indicating that I think it is an important problem, and a benefit rating of 4 indicating that I think that the solution will yield a large benefit in terms of operator performance and comfort.

Problem Identified	Recommended Solution	Importance Rating	Benefit Rating
Activation buttons on the hand controls contain hard, sharp edges.	Replace with buttons with smooth, rounded edges.	4	4

Could you please work through the rest of the questionnaire, rating the problems and the recommended solutions. We look forward to receiving your ratings. There are 32 questions in total.

Problem Identified	Recommended Solution	Importance Rating	Benefit Rating
Font used in the display too small given the viewing distance.	Increase the font size used in the display by ½ mm.		
Soft key functions and titles include upper and lower case type.	Adjust to include all upper case (this is not so much a problem but an improvement)		
Dust collects in the corners of the display, obscuring visibility.	Include a flat face screen. Remove the edge running around the outside of the screen.		
Display position A (between operators legs); -Beyond the recommended viewing distance -Below the recommended horizontal line of vision -Requires operators to lean forward which leads to postural difficulties.	Include an adjustable stand, move the display to position B (mounted on right hand side of cab), include an alternative input device.		
Position B (mounted on right hand side of cab) beyond recommended viewing distance.	Include an adjustable mount for the display.		
As viewing distance improves the viewing angle becomes more of a problem.	Custom design mounts for cab specifications.		
Unable to adjust the height of the display.	Include an adjustable stand or mount.		
Glare (reflections in the screen) obscures vision and can cause visual problems.	Encourage operators to clean their screens more often. Include an anti-glare filter. Remove high gloss finish from the display and replace with a more neutral density. Shade/tint/filter cab windows. Provide more adequate sun visors in cab.		

Large round scroll button requires very precise activations.	Enlarge button or alternatively split scroll functions up into four separate buttons. Have an alternative input device.		
Differences in viewing distance between display and tree being processed can lead to visual fatigue.	Minimise by; Reducing glare Including an adjustable monitor position Encourage operators to take small rest breaks and refocus eyes		
Activation buttons on the hand controls contain hard, sharp edges.	Replace with buttons with smooth, rounded edges.		
Motor and de-limbing controls on the top of the joysticks cause sore thumbs.	Include soft padded cover on tops of joysticks.		
The fixed position of the control buttons forces operator's hands into cramped positions.	Make the button panels easily adjustable to accommodate individual characteristics.		
Many of the arm-rests used in conjunction with the harvesting task do not support the operators arms correctly.	Height and length adjustable arm rests need to be included in the cabs. More research needed into Waratah's responsibility.		
Some of the words and terms used in the display are foreign to operators.	Liase more closely with operators to identify problem terms and words and then develop alternatives. Include a glossary of definitions in the user manual for the more difficult terms. Have an instructional period clarifying any unclear terms.		
Operators believed the 'copying cutting lists' instructions in the user manual was unnecessarily complex.	Reword the paragraph. Conduct a training course which clarifies ambiguous terms. Provide examples and samples in the manual.		
Operators believed the 'bark-offset' formula was too complicated.	Same as above.		
Soft key functions change depending on what screen the	Have an alternative input device.		

operators are on.			
The order of functions in the main menu conflicts with the frequency of use principle.	Adjust the menu order to the order outlined in the LIRO report.		
Large scroll button takes too long to scroll down through menus and lists.	Assign numbers to menu options and assign to the keypad. Incorporate display functions into the keypad.		
Operators forced to turn on lights at night to see species panel.	Illuminate buttons on keypad for night work.		
Input of cutting instructions far too time consuming.	Utilise modem capabilities. Incorporate an attachable keyboard or remote control. Incorporate buttons on display into the keypad		
Measuring wheel deteriorates corrupting the accuracy of measurements.	Include a prompt for measuring wheel checks every 6 months or so depending on the conditions to which exposed.		
Operators working long hours without any rest breaks.	Interface should prompt for rest breaks and micro pauses.		
Interface takes a while to boot up without any message informing the operator.	Provide notification to the operators that the interface has responded to the start up in the form of a message.		
Operators occasionally activate wrong button at night because they cannot see the panel.	Illuminate buttons for night work.		
No authorship is attributed to the logrite controller manual.	Attribute name of developer to the manual.		
On-line help system is currently unavailable.	Develop on-line help system and make it available to operators adhering to the recommendations presented in this report.		
There is a lack of standardised training for operators.	Develop a standardised training program for use of the controller and interface. Inform contractors of its availability and		

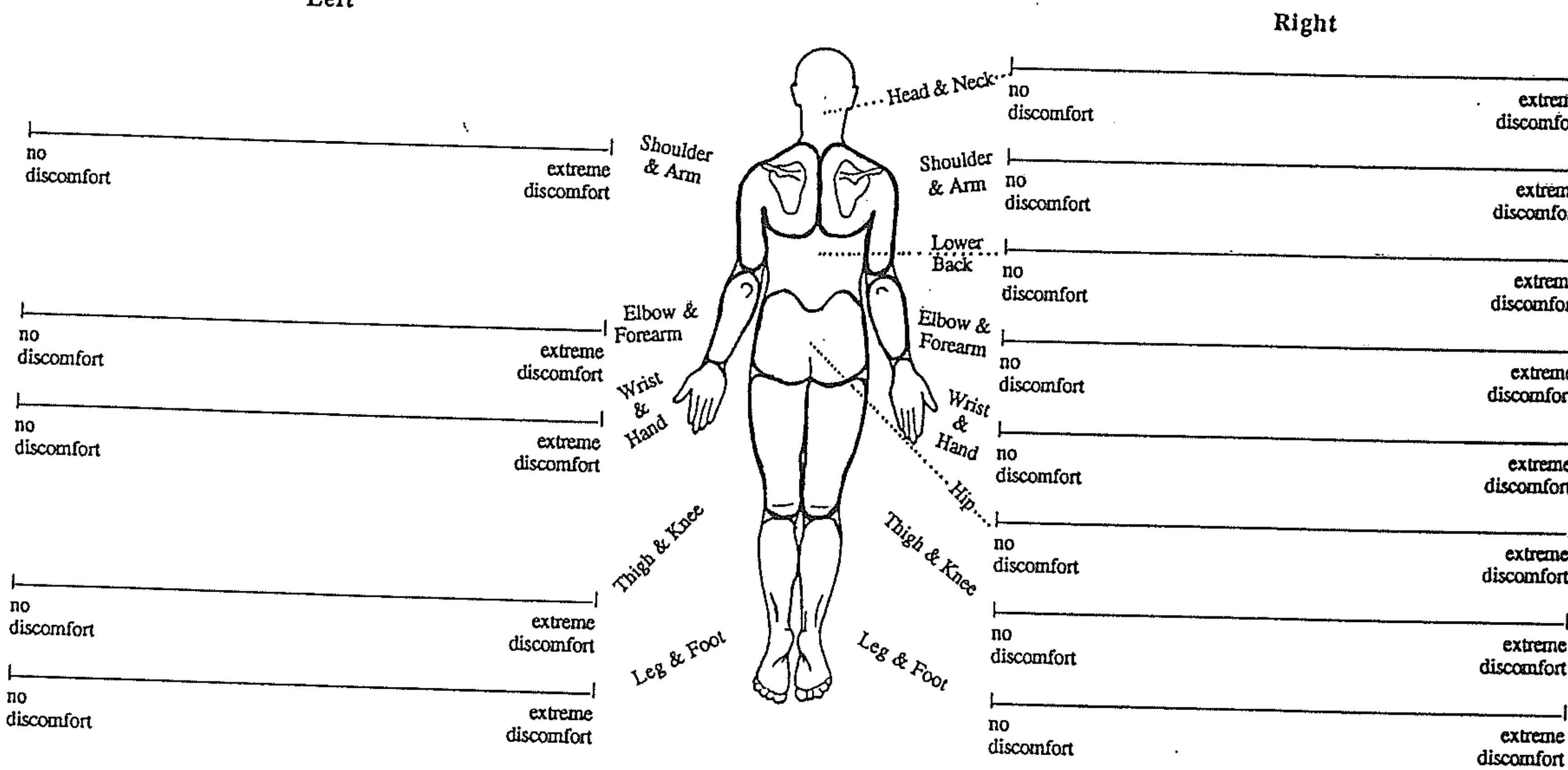
	the benefits associated with such training. Develop and make further use of the interface simulator.		
Updates of manual coming out.	Include a 'changes to version page' in new versions.		
Remote service support and fault diagnosis and remote software support and upgrades unavailable.	Implement and utilise modem capabilities.		
Interface is not very sympathetic to left-handed operators.	Same as above.		

APPENDIX B: BODY PART DISSCOMFORT MAP

Visual Analogue Discomfort Scale

Do you have any discomfort anywhere? NO ☐ YES ☐

If YES, please shade in the appropriate area(s) on the body diagram and mark on a line the *__amount__* *of discomfort you feel for* *__each__* *body part which presently feels discomfort.*



If you have any comments, please write them over the page.

Date: ☐☐☐

Subject: ☐

Condition: ☐☐☐