An Ergonomic Analysis of a Closed Circuit Television Rear Vision System for Forestry Machine Operators

A thesis in partial fulfilment of the requirements for the degree of Master of Ergonomics at Massey University

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ABSTRACT

The Bell Logger is a fast highly mobile forestry machine used in close proximity to workers on foot. It can, along with other machines, inadvertently collide with workers, other machines or logs which subsequently hit workers. To date the only successful way to prevent injury to workers on foot is to completely remove them from the work area of the Bell Logger. This is often operationally difficult and does not prevent collisions between machines or other objects. One potential solution is to improve the rear vision of the machine operator.

A literature search was carried out to review information on human vision, issues of driver vision from vehicles, epidemiology of forestry injury related to mobile machines, methods of assessing vision from vehicles and existing rear-view aids for vehicle drivers. A questionnaire was used to gather information from Bell Logger operators on their opinion of the rear view camera system. Video records of Bell Logger movements and operator head glance direction were analysed to characterise the operating environment and style without and with the rear view camera system.

Mobile machine related injuries on the skid site are a significant problem resulting in 1304 lost work days in the period 1995 to 2002. The normal operational environment of the Bell logger operator is characterised by frequent machine changes in direction (eight to 10 per minute) and frequent head movements (four to five per minute) to see if the way is clear. Results indicate that the rear vision camera system appears to have potential as a valuable addition to the Bell Logger operating under typical New Zealand forestry conditions, and it resulted in a 20% increase in Bell Logger activity.

REPORTS WRITTEN FROM THIS WORK

(Copies in Appendix 7)

1. Bentley, T.A. & Parker, R.J. 2001. Injuries to loggers during skid work: An exploratory analysis of New Zealand forest industry injury data. *Journal of Health and Safety, Australia and New Zealand* 17, 391-399.

2. Caughley, A.; Parker, R.J. & Ashby, L. 2001. *Intelligent rear vision video for forestry vehicles*. Proceedings of the 10^{th} Conference of the New Zealand Ergonomics Society. 26^{th} & 27^{th} July, 2001. Rotorua. 91-94.

3. Parker R.J. & Bentley, T. 2000. Skid work injuries 1995 – 1999. *COHFE Report* Vol. 1, No. 4.

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5. Parker, R.J.; Ashby, L.; Legg, S.L. 2002. *Evaluation of video rear vision for forestry log handling machine operators*. Proceedings of the International Seminar on New Roles of Plantation Forestry Requiring Appropriate Tending and Harvesting Operations. 29^{th} September to 5^{th} October, 2002. Tokyo. 369-375.

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CHAPTER 1 INTRODUCTION

1.1 Purpose

The Bell Logger is a fast highly mobile forestry machine (Appendix 6) used in close proximity to workers on foot. It inadvertently collides with workers, other machines or logs which subsequently hit workers. To date the only successful way to prevent injury to workers on foot is to completely remove them from the work area of the Bell Logger. This is often operationally difficult and does not prevent collisions between machines or objects. One potential solution is to improve the rear vision of the machine operator. This project evaluated a prototype rear-vision system for the Bell Logger operator.

1.2 Background

One of the single most common causes of injury to workers in logging in New Zealand is being struck by a mobile machine or a log which was struck by a mobile machine. In the period 1995 to 2002 there were 92 lost time injuries reported where injury was caused by worker/mobile machine interaction. These injuries resulted in a total of 1304 work days lost. Interventions to prevent these injuries include; training of forest workers and machine operators to develop improved situational awareness, improved design of work sites to minimise the opportunity for interaction between workers and mobile machines, the wearing of high visibility clothing and the introduction of technology to improve machine operator visibility from the cab.

This project assesses a technology intervention. The project involved the study of three Bell Logger operators under normal operational conditions. They drove an unaltered Bell Logger with the normal situation of no rear vision. The prototype rear-vision system was added to the machine and the operators were given some days to get used to the system. The operators' opinions of the rear-vision system, changes in their operating style (frequency of machine movement) and glance style (looking left or right) were measured.

1.3 Project aims

1. To review the problem of machine associated injuries on the skid site
2. To characterise the normal operational environment of the Bell Logger operator
3. To measure the effect of a prototype video rear-view system on normal Bell Logger operation.

1.4 Approach

Ergonomics takes the *system* as the unit of analysis – the person performing a task in an environment (including other people) supported by technology.

Documents relating to Bell Logger operational procedure, training material and industry guidelines were studied.

Methods used in the study included:
A semi-structured interview
Document analysis
Video measurements of behaviour (vehicle and operator movements)
Development of a rear-view camera system
Development of a data handling system
Analysis by General Linear Models
Use of guidelines on in-vehicle vision recommendations.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

The interaction between people and mobile heavy machinery is always potentially dangerous because of the great differences in momentum (the product of mass multiplied by velocity) of the person and the machine and the often poor visibility of the operator of the heavy machinery. Over the last few years the American trucking industry has experienced fewer accidents on and off highways in North America. Cates (2000) noted that although safety is improving in the industry there are still backing accidents and injuries. Injury resulting from poor visibility during backing continues to be a major problem. Cates (2000) identifies video technology as a simple, cheap and effective means to dramatically improve the rear view of truck drivers.

Video has also been identified by the mining industry, on underground vehicles and on above ground vehicles as a practical solution to poor driver visibility. However, in the forest industry video has not been used to improve driver visibility. This thesis presents the results of an evaluation of a prototype closed circuit television system which provides rear view to a forestry machine operator.

Chapter 2 introduces the industrial background to the problem of vision from mobile machines. A general introduction to the forest industry and logging is then followed by a more detailed review of skid work and associated tasks and the interaction of skid workers and mobile machines in close proximity.

Recent research on the epidemiology of skid worker injury with particular reference to worker-machine interactions is reviewed. The Bell Logger, a skid site based forestry machine with no rear vision, is then discussed. Methods used to assess vehicle operator field of view will be presented and rear-view aids for vehicle drivers are then be reviewed with particular relevance to forestry and in-vehicle closed circuit television.

2.2 Factors influencing the visual system

The main factors described are: colour, glare, illumination, contrast, aging, visual defects and fatigue.

Light source properties

The frequency transduction efficiency of the human eye is greatest under normal sunlight (a mixture of wavelengths). However if the surface is coloured (reflects a predominance of one wavelength) the object may be difficult to recognise. For example orange high visibility clothing worn in log yards appears white under orange sodium lamps and loses its high visibility properties.

Glare

Glare overloads the light adaptation mechanism of the retina and can be affected by age and nutritional factors (Coren, Ward & Enns, 1994). For example forestry machine operators often travel or visually search from deep shadow to full sunlight and back. It is difficult to maintain adequate visual sensitivity under such conditions and objects (sometimes people) are run down by the machine. Types of glare are adaptive, absolute and relative (Sanders and McCormick, 1992).

Illumination

The eye is more sensitive to change at high illumination levels so visual performance is improved by increasing illumination (Wilson and Corlett, 1995). However too much illumination (full sun and white pumice road surfaces found in many logging operations in Central North Island forests) overloads the visual system, causing glare.

Contrast

Contrast sensitivity is the ability to perceive differences in luminance and is closely linked with illumination. For example, when close behind a vehicle at night the red tail lights of that vehicle offer adequate contrast to the surrounding darkness. But when the brakes are applied the illumination of the red tail lights increases rapidly (effectively instantaneously), increasing illumination. The eye, adapted to a low level of ambient illumination, is "dazzled" and subsequent visual performance, including contrast is impaired.

Aging

There are a number of effects of aging which degrade the accurate operation of the human visual system (Coren, Ward & Enns, 1994; Sanders and McCormick, 1992): the lens hardens; muscles controlling the diameter of the pupil atrophy reducing both the speed and range of accommodation to changing illumination level; the lens thickens (continued cell growth) reducing the eyes ability to focus on near objects; the lens becomes more cloudy and yellowed reducing the amount of light reaching the retina and reducing the transmission of blue light; the intraocular fluids become cloudy, reducing light to the retina as the light is scattered and producing a "veiling luminance".

Forestry machine operators are often older members of the crew because of the logging experience required and lower physical demands of machine operating compared with other logging tasks.

Visual defects

Accuracy (performance) of the visual system is reduced: short and long sightedness; colour deficiencies; photophobia; night blindness; field defects; double vision and so on (Coran *et al.*, 1994; Sanders and McCormick, 1992; Wilson and Corlett, 1995).

Fatigue

The ciliary muscles controlling the curvature of the lens can become fatigued with extended use, e.g., focussing on close work such as inspecting the surface of a hydraulic hose for apparent leaks or the chain of a chainsaw for damage. Also the scanning speed of the eyes is reduced with fatigue. Neural satiation can occur (Coran, Ward & Enns, 1994) whereby a group of neurones in the eye become tuned to a specific spatial frequency (say, a pattern of stripes on the thread of a bolt) and fatigue to that pattern, reducing their response to that spatial frequency with time. The eye normally makes frequent small movements, called fixation restlessness, to minimise selective adaptation.

2.3 Person – machine related injury due to poor vision in other industries

In New Zealand there is no prescriptive legislation regarding visibility for the operator from the cab of forestry machines. However, in Europe such legislation exists and is useful as a guide for visibility requirements.

In the UK the European Community Machinery Directive was adopted in 1989 and implemented as the Supply of Machinery (Safety) Regulations 1992. Section 3.2.1 of the regulations states *"...Visibility from the driving position must be such that the driver can in complete safety for himself and the exposed persons, operate the machinery and its tools in their intended conditions of use. Where necessary, appropriate devices must be provided to remedy hazards due to inadequate direct vision."*

A harmonised European Standard on earthmoving vehicles has also been published – BSEN 474 Part 1: Earth Moving Machinery – Safety, Part 1 General Requirements. Section 4.7.1 states *"Operators field of view. The design and position of the operator's place shall be such that the operator has sufficient visibility in relation to the drive and work area of the machine. Aids, e.g. mirrors, ultrasonic devices, TV devices, shall be provided to remedy inadequate direct vision."*

The potential for the supplementation of direct vision or mirrors with other technology is identified in the European legislation and is presented in more detail in Section 2.8.

Mining industry

In the Canadian province of Ontario, Load-Haul Dump (LHD) equipment has been associated with approximately 160 injuries/incidents each year (Tyson, 1997). LHDs are rubber tyred vehicles with a bucket at the front. They steer by articulation in the middle and the operator sits in a low cab. Tyson (1997) states that "A significant contributing factor to many of these accidents and injuries is the restricted visibility from the operator work space". In 1994 and 1997 Coroner's Juries have recommended that the visibility from LHD operator's compartments be improved (Tyson, 1997).

Half of all mining fatalities involving LHD equipment in Ontario in the period 1986 to 1996 were the result of poor operator visibility (Table 2.1)

Table 2.1 – Injuries involving LHD equipment in Ontario mines 1986 to 1996 (from Tyson, 1997).

Type of injury	All causes	Operator visibility a significant factor
First aid	1331	37
Lost time	218	35
Fatal	10	5
Total	1559	77

The British experience is similar. In the period 1986 to 1991 in British coal mines nine miners were killed and 96 sustained major injuries in incidents directly involving LHD equipment (Rushworth, 1996). Rushworth (1996) stated "The main area of concern identified with regard to ergonomic aspects of Free Steered Vehicle (FSV - British term for LHD) design was poor driver vision".

The CSIRO (2000) reported "Two fatalities have occurred in open-cut mines in the last 10 years, as well as numerous incidents where people and small vehicles have been run over" when not seen by the drivers of large dump trucks (Figure 2.1).

Figure 2.1 – "Not seen" by driver of larger vehicle.

Aviation

Ground crew working near and under aircraft are at risk of being run over. The International Air Transport Section of the National Safety Council (ARTEX, 2003) identified 34 occasions where ground staff have been run over by the aircraft or the tug since 1968. Thirteen resulted in fatalities and 12 resulted in leg amputations. This does not include ground staff run over by service vehicles such as fuel trucks, catering trucks, luggage tugs and cars or conveyor trucks.

Transport

Injuries resulting from "not seen" events where a truck, bus or other vehicle has run over an unseen person are frequently reported in the news media and recognised as serious cause of injury or death. Children are often run over when not seen because they are smaller than adults as well as having less knowledge of the hazards of reversing vehicles. For example a four-year-old girl was backed over and killed by a bus (Rotorua Daily Post, 1993). As a result of the death the bus company installed video cameras on the rear of all its new buses at a cost $3,500 each.

Children are also killed or injured in driveways and parking lots. In the United States during the period July 2000 to June 2001 there were an estimated 9,160 non-fatal injuries to children who were left unattended around motor vehicles that were not on public roads (KIDS 'N CARS™ database cited McLouglin, Middlebrooks, Annest, Holmgreen & Dellinger, 2002). Of these, 2,767 children were treated at hospital emergency departments after being "run over/backed over" by a motor vehicle. Being "backed over" by a motor vehicle was the cause of 27 % of 78 fatal injuries to children under 14 years old killed in "non-public road" incidents identified in the United States (KIDS 'N CARS™ database). McLouglin *et al.* (2002) concluded that "Children might be protected …by commercially available vehicle enhancements, such as sensors that detect unseen obstacles behind a motor vehicle or devices that emit audible signals when a motor vehicle is in reverse." They went on to recommend that "Evaluation of such interventions should be conducted to inform policy makers about their effectiveness in reducing non traffic motor vehicle related injuries and deaths among children."

Agriculture

The National Safety Council's publication "1994 Tractor Fatality Rates" reported there were 353 tractor related deaths on farms in the United States. People being run over by tractors accounted for 26 % of fatalities. In Britian, the single most common cause of fatal injury in the agricultural sector (agriculture, forestry and fish farming) in the period 1986 to 1999 was"struck by a moving vehicle". This cause accounted for 18 % (130 deaths) of all fatalities (Health and Safety Executive, 2000).

2.4 Forestry

Forestry is recognised as a difficult and dangerous industry resulting in many injuries and fatalities every year (Gaskin and Parker, 1993; Kawachi, Marshall, Cryer, Wright, Slappendel & Laird, 1994; Myers and Fosbroke, 1994). In some ways forestry can be described as almost pre-industrial with many tasks being performed with manual labour. Animal power was introduced in the early 1800's and steam power in the 1860's. These steam driven mechanical devices were little modified in the early 1900's to run on diesel. With the development of faster, wheeled vehicles many machines were adapted or modified for use in the forest. Mechanisation has been used to reduce the physical load on people and limit their exposure to hazards (Drushka and Konttinen, 1997).

Forestry in New Zealand is a major export industry. In the year to December 2002 New Zealand exported logs and timber valued at NZ$3,709 million (New Zealand Ministry of Agriculture and Forestry, 2003). At mid-February 2002 the forest industry directly employed 25,000 people. Of these, 4,900 were engaged in logging activities in forests. It is these people who are at risk of injury while working in close proximity to mobile machinery.

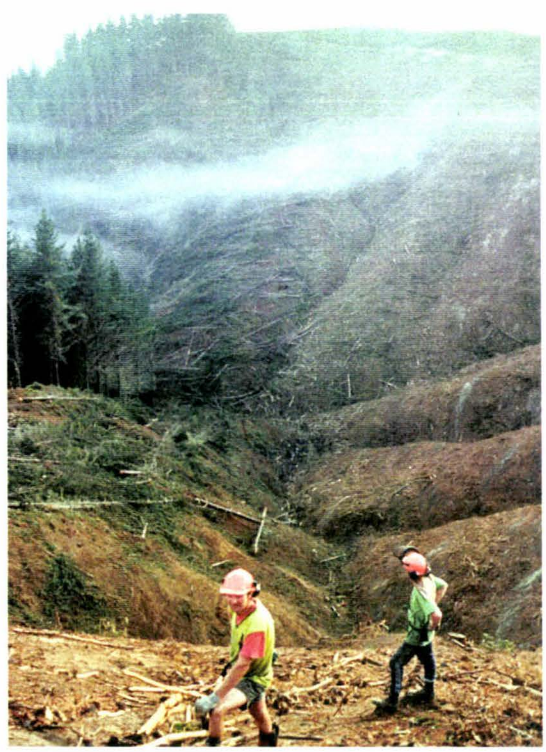


Figure 2.2 – New Zealand cable logging operation on steep slopes.

Forest harvesting can be divided into two main types, ground based logging and cable logging. Ground based logging is that used on flat land forests and slopes negotiable by wheeled vehicles, up to 18° slope and tracked vehicles, up to 22° slope (Safety and Health in Forest Operations, 1999). Large four-wheel-drive tractors or caterpillar tracked vehicles extract felled trees from the stump to the road edge where the stems (felled trees) are processed into logs.

Forests that grow on steeper terrain (Figure 2.2) must be harvested by cable logging techniques. In cable logging the trees on a hillside are first felled, then a heavy wire rope is passed across the area and anchored at the corners of the block of trees with sheaves or pulleys. The stems are attached to the wire rope and hauled from the hillside. Both types of forest harvesting result in stems being taken to a processing area or skid site.

2.4.1 Skid work

After trees are cut down (now called stems) they are moved to a flat processing area, the skid site (Figure 2.3), where they can be cut into logs. Because there are a large number of different log grades, care has to be taken to cut the stem into the correct logs or considerable value will be lost (Donovan, 1989; Parker and Cossens, 1993). This results in a concentration of people working on the skid site.

Figure 2.3 – Typical New Zealand skid site with excavator based loader (left) and Bell Logger (right).

Normal tasks include delimbing (removing branches with a chainsaw), log making - assessing the quality features of the stem such as damage, knot diameter, stem diameter (Donovan, 1989), quality control, and machine operating.

An important feature of the skid site is the close interaction between people, machines, logs and stems, and it is where most injuries occur (Bentley, Parker, Ashby, Moore and Tappin, 2002). The most common cause of injury reported was being hit by a rolling log or hit by a machine. The causes of skid site injuries will be discussed more fully in Chapter 3.

2.4.2 Human - machine interaction

On the skid site people work in close proximity to fast mobile machinery. Ideally there would be a physical separation between people and machines to eliminate the possibility of collision. In some logging operations this occurs and is called a "dephased" operation (Conway, 1982) where two skid sites operate at the same time. One has only workers on foot processing the stems into logs and the other has only machines handling the logs. However, it is often logistically more convenient for people to be working on the same skid site as machines. Workers on foot can rectify quality errors such as logs of the wrong length immediately. Machines can free chainsaws jammed in logs and move logs that are in the wrong place. Also operating two skids at the same time can be difficult if there are space limitations such as in a small forest area or where environmental constraints do not allow the building of many skid sites.

The New Zealand Health and Safety in Employment Act (1992) suggests that if at all possible, the hazardous task should be eliminated. If that is not possible then the task should be isolated, and if that cannot be achieved then risk should be reduced. Table 2.2 outlines some of the injury reduction methods that have been used in logging.

Table 2.2 – Level of protection and methods used in logging to achieve protection of workers.

Level of protection	Mechanism – forestry examples
Eliminate hazard	Mechanised processing – put the worker in a protective cab and eliminate hazards of other vehicles, rolling logs and chainsaw use.
Isolate hazard	Dephased operation – workers on foot and mobile machines (skidders and loaders) work on separate skid site preventing worker/machine interactions.
Reduce risk	Improve around vehicle vision of machine operator, workers on foot wear high visibility clothing and "safe areas" are designated which machines may not enter.

During the 1990's there had been a greater emphasis by forest companies and their customers for higher quality logs (Hipkins, 1995). This resulted in more quality control and assessment tasks being undertaken on the skid site. Most of these tasks were manual and resulted in more people sharing the skid site with mobile machines. In addition, these tasks required concentration (looking for wood quality features, recording data on code sheets or into a computer and making decisions). As a consequence the opportunity for collision between people and machines was increased.

2.5 Epidemiology

The causes of injury to skid workers in New Zealand in the most recent year, January to December 2002, are presented. Then injuries and incidents associated with mobile skid site machines and Bell Loggers are presented.

2.5.1 Skid worker injuries

In New Zealand logging during the calendar year 2002 there were 119 lost time injuries (injured person missed at least one full days work because of injury). Twenty seven percent were in skid work resulting in a total of 466 days lost. There were also 106 minor injuries reported (Parker, Ashby & Evanson, 2003). The other major causes of lost time injury were felling trees and breaking out, i.e., attaching felled trees to wire ropes for extraction (Figure 2.4).

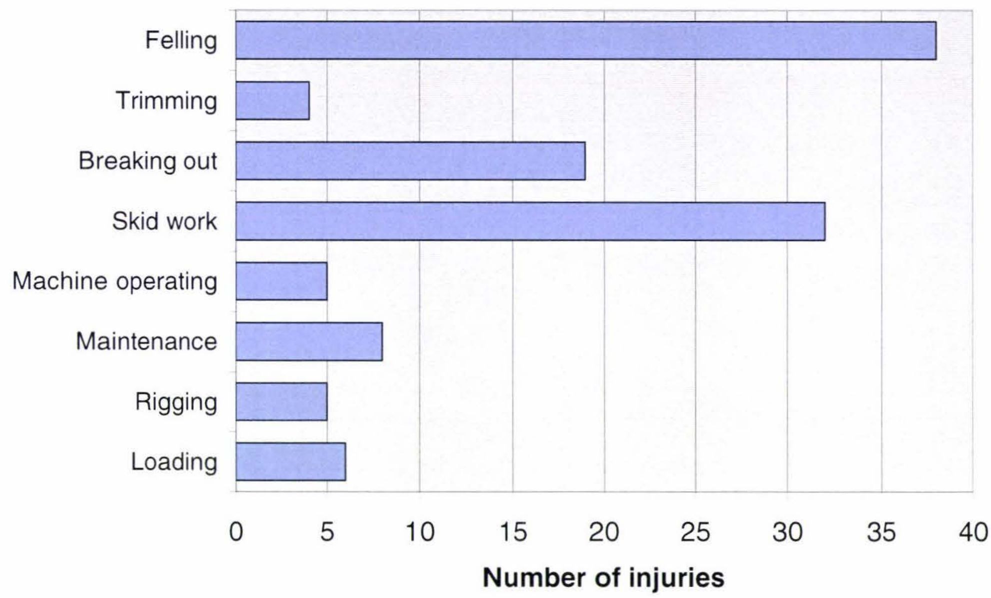


Figure 2.4 - Lost time injuries by part of logging operation in 2002.

The main causes of lost time injury to skid workers in the year 2002 were:

- Being hit by machine or by material moved by machine, nine injuries, total of 176 days lost
- Being hit by a rolling log, six injuries, total of 81 days lost
- Cut by chainsaw, five injuries, total of 31 days lost
- Being hit by a log or limb when cut under tension, four injuries, total of 129 days lost.
- Slipping or tripping over, four injuries, total of 14 days lost

The number and severity of injuries resulting from being hit by a machine or material moved by a machine highlights the need for care around machines on the skid. The most severe injuries resulted from fractures when a stem or log was moved by machine and hit the skid worker (Figure 2.5).

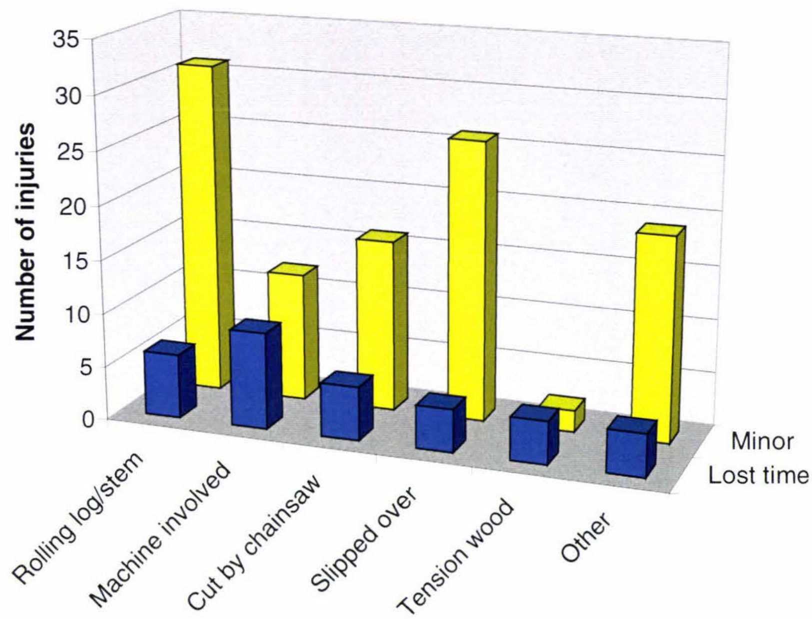


Figure 2.5 - Cause of skid work injuries by severity in 2002.

All machines working on the skid site pose a risk to the skid worker. This thesis will discuss one machine in particular, the Bell Logger (Section 2.6.2). In 2002 there was one lost time injury reported where a skid worker was struck by stem being handled by a Bell Logger. He was not seen by the Bell Logger operator and sustained a fractured foot which resulted in 36 days off work. Injuries sustained by skid workers and machine–person interactions will be discussed in more detail in Chapter 3.

2.5.2 Bell Logger

The Bell Logger is a three-wheeled, hydrostatically-powered grapple tractor originally developed for South African sugar cane harvesting (Gleason, 1985). The machine is steered by foot controls. The left foot controls the left wheel motor and the right foot, the right motor. Forward motion is initiated by pushing down with the toes of both feet. Rear motion is initiated by pushing down with the heels. The driving wheels are at the front of the machine with a smaller castor wheel at the rear (Figure 2.6). The frame shape is triangular with the boom pivot mounted above the operator's cab. Operating the Bell Logger is a visually demanding task because all the other senses are overwhelmed by the noise and vibration of the machine. The operator only has rear view by slewing the machine to the left or right (Appendix 6).

Figure 2.6 – Bell Logger forestry machine.

2.6 Assessment of vehicle operators field of view

2.6.1 Forward field of view determination

Boocock, Weyman, Corlett & Naylor (1996) describe a number of methods used to determine operator field of view. The simplest method is line of sight techniques. For example the ISO 5006-1 standard (ISO, 1991) for field of view for earth moving machinery measures the the shadows cast by two light sources in the cab of the machine, on a circle 12 m in radius placed at ground level. The distance separating shadows cast on the perimeter of the circle are used to determine the field of view.

Hella, Tisserand, Schouller & Englert (1991) and Hella, Schouller & Tisserand (1996) replaced the two light sources with a planimetric camera which produces images without distortion. They obtained quite different results from the ISO method because the photographic method took into account objects visible above ground level which was closer to the reality perceived by a machine operator.

Sanders and Kelley (1981), assessing visibility from mining vehicles, used a photographic technique but took photographs from outside the vehicle looking at the cab. An adjustable mannequin was seated in the cab to account for movements of the operator's trunk and head.

Other methods have used computer aided design (CAD) methods. Glowacki, Unger & Rossi (1992) used CAD to generate a three-dimensional model of a mining vehicle. The visibility assessment was then based on the method of Sanders and Kelley (1981). The CAD program determined if vehicle structures intersected lines of sight to the cab. The System for Aiding Man Machine Interface Evaluation (SAMMIE) was used by Boocock and Weyman, (1994) and Boocock, Weyman, Corlett & Naylor (1996) to determine the operator's field of view from an underground mining tractor or "free-steered vehicle" (FSV). Results of the study generated design improvements to FSVs to improve operator field of view. Gibson and Scott (1986) adapted SAMMIE for the design and evaluation of a prototype high-speed electric train cab windscreen.

An alternative use of SAMMIE was to generate a visibility grid (a computer representation of the view of a test subject of a visibility frame), from the drivers seat of a vehicle. The visibility frame was a 4 m x 4 m x 2 m wooden frame covered in 250 mm square grids which was placed 3.25 m in front of the vehicle to be tested (Porter and Stearn, 1986). Test subjects marked on the SAMMIE generated visibility grid any obstructions to their field of view. This data was input to SAMMIE and design recommendations made.

2.6.2 Rear field of view determination

The determination of rearward field of view via mirrors is more complex (Fowkes, 1986). Lights are sited in the cab at eye level and the reflected light from the mirrors falls on to vertical graduated test screens. The images on the screens are photographed to determine rearward field of view. Laser beams are also used to determine rear view by tracing the edge of the mirror surface and measuring the reflected ray against a test screen or ground target (Fowkes, 1986).

Fowkes (1986) describes computer simulation programs used by the vehicle industry to act as design evaluation tools before full-scale vehicles are built:

- RVM (Rear-View Mirror) by Austin Rover gives simulated test screen or mirror views closely replicating practical testing.
- FOVEA (Fields of View Evaluation and Assessment) developed by MIRA (Motor Industry Research Association, United Kingdom) provides a field of view in the form of a ground plan corresponding to the performance standards in the legislation.
- SAMMIE, the most sophisticated of the computer simulations, also allows the modelling of rear-view mirror systems in addition to forward views.

Case, Porter & Bonney (1980, pp205) used SAMMIE to determine sight lines of mirror systems for commercial vehicles. They concluded that SAMMIE allowed the rapid development of mirror views with varying eye-points, based on varied anthropometry and posture, however "final confirmation of sound ergonomics design should be made on the basis of subjective evaluation on prototype vehicles". However, the objective performance of a task such as detection of threat vehicles would be superior.

Burger and Ziedman (1987) described a preliminary methodology for evaluating the effectiveness of rear-view mirrors. It took into account characteristics of the mirror: size of field of view, radius of curvature, accommodation distance (distance from eye to the focal point or focal plane of mirror) and reflectance. The mirrors were then assessed by test subjects who estimated the successive position and relative motion of images, "threat vehicles", as seen in the mirrors.

2.7 Visual aids for vehicle operators

When a vehicle operator cannot see all around their vehicle some visual aid is required. The most common aid is a mirror and periscopes are a class of mirror. Closed circuit video is a simple solution to poor operator visibility and its uses will be detailed below.

2.7.1 Mirrors

Mirrors vary in size and shape, according to use. Mirrors can be used for rear and forward view, such as those which show the front bumper of a vehicle in relation to objects. These mirrors are often convex with a small radius of curvature (for example 200 mm) providing a wide area of view. Vehicle rear-view mirrors are either flat or convex. Convex mirrors provide a a greater field of view but objects appear further away than they really are. Subjects overestimate separation distance relative to the judgements of the same distance using a planar (flat) mirror. Work by Tait (2002) demonstrated that distance estimation error became significantly greater as the radius of curvature of a mirror decreased to 1200 mm. The same study also identified the difficulty of adjusting mirrors from the drivers seating position in heavy vehicles. This results in the mirrors not being utilised to full capacity.

The periscope is a mirror-based visual aid which has been used in land, sea and air vehicles. Baldwin (1996) describes the work of American designer and visionary Buckminster Fuller who, in the 1930's, designed a radical aerodynamic car based on a three-wheeled chassis (Figure 2.7). The Dymaxion car did not use conventional mirrors because they would create unacceptable drag. Instead, Fuller incorporated a periscope into the roof of the car which provided rear vision to the driver.

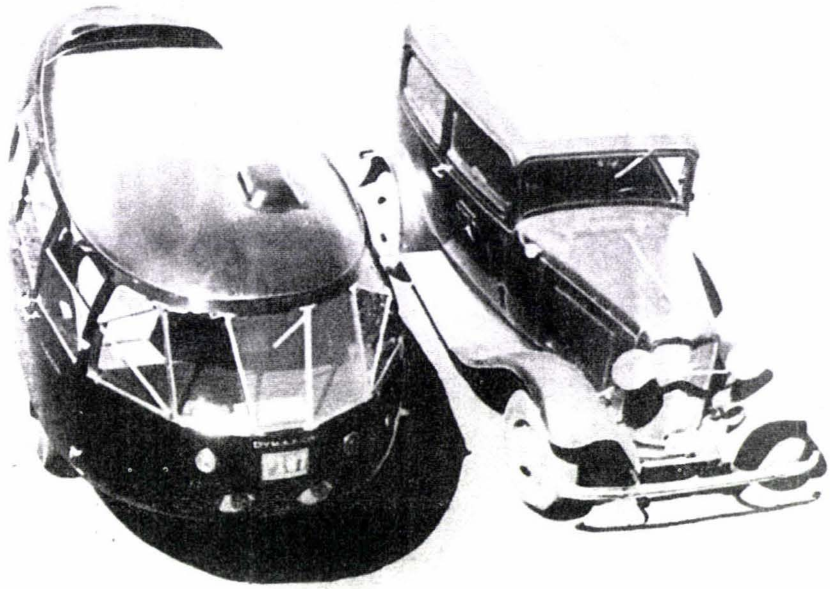


Figure 2.7 – Dymaxion car by Buckminster Fuller built in 1933 incorporating a periscope with contemporary counterpart (on right).

The military have also utilised periscopes in land vehicles to provide driver vision, both forwards and to the rear (Figure 2.8) The U2 reconnaissance aircraft developed by the Lockheed Skunk Works had a periscope which passed through the floor of the aircraft and gave the pilot a view to the ground below (Rich and Janos, 1995).

Figure 2.8 – New Zealand Army M113 vehicle with periscopes in driver's position and turret.

2.7.2 Closed circuit television cameras

Closed circuit television (CCTV) systems are commonly used on heavy vehicles. The Exploration and Mining Group of the CSIRO have developed 'Monstervision' which is has CCTV camera mounted above the rear axle of dump trucks (Figure 2.9) proving a colour image to a television monitor in the truck cab.

Figure 2.9 – Dump truck fitted with CSIRO rear-vision video camera "Eye in the Backside" system (operator cleaning camera lens).

Lee (1997), in an assessment of visibility aids for workplace vehicles, concluded that "CCTV appears set to become the norm as a vehicle visibility aid". The set up of CCTV systems is simple and a range of camera lenses allows the optimum field of view for the purpose to be determined. Other recommendations from Lee (1997) were: drivers should be alerted to the apparent distance distortions caused by "fisheye" lenses; flashing light beacons improve the visibility of vehicles viewed on a CCTV system and the CCTV system should be on at all times, not just when reversing, because the system provides greater driver situational awareness.

A CCTV system has been incorporated in Boeing aircraft because the pilot of a Boeing 777-200 or 777-300 has a blind spot in front of the aircraft (Boeing, 1998). When the aircraft is on the ground the pilot's eyes are positioned 5.9 m above the ground. A blind spot extents 14.8 m forwards from the pilot's eye position to a point on the runway surface. This creates difficulty when the aircraft is taxied or must manoeuvre with ground vehicles. One of the multifunction LCD screens in the cockpit of the Boeing 777 displays images from the "Ground Manoeuvre Camera System" (Norris, 1998). The split-screen image shows the view from three cameras, one located beneath the forward fuselage to display the nose wheel, and two display the main landing gear wheels from mountings in the leading edge of the horizontal stabiliser at the rear of the aircraft (Figure 2.10).

Figure 2.10 - Boeing 777 cockpit with ground manoeuvre camera system.

Lane change and sideswipe accidents are the areas of concern most commonly listed by heavy-vehicle drivers, according to studies conducted by the (US) National Highway Traffic Safety Administration" (Cates, 2000). Heavy highway trucks have a blind spot on the passenger's side of the cab. Video cameras are being mounted on trucks to eliminate these blind spots.

Numerous automotive closed circuit video systems are available to retro-fit to vehicles to improve operator visibility. A system available in New Zealand is detailed in Appendix 5. The practicality of incorporating "intelligence" into the vehicle video system to identify and highlight the high visibility colours worn by people working near vehicles has been investigated by the author (Caughley, Parker & Ashby, 2001).

2.7.3 Other technologies

Other technologies exist, which can provide information about objects to the rear of a vehicle. These include capacitance sensors (Buck and Aherin, 1989), ultrasonic sensors and Doppler radar (Shutske, Gilbert, Morgan & Chaplin 1997). Murphy and Morrow (1996) evaluated commercially available and prototype sensors which may reduce risk to people working around agricultural machines. They evaluated light and laser devices, mechanical devices, alert systems, radar systems, radio frequency devices, image analysis systems and combination systems. Few were found to show sufficient promise under the demanding agricultural conditions. The direct video image of rear view offers the greatest promise at this stage. Flannagan and Sivak (1993 pp 207) concluded that "…video systems … allow much greater flexibility in the selection of vantage points and display locations than is possible with mirrors or even periscope systems."

2.8 Summary

This chapter summarised the relevant literature on rear vision from mobile machines. First, aspects of human vision were outlined and the industrial background to poor vision from machines and resultant injury summarised. Forestry in New Zealand and the particular processes of harvesting, especially skid work were explained. The often dangerous interaction between people on foot and poor visibility from mobile forestry machines was discussed with particular reference to the Bell Logger machine. Methods used to assess vision from the cab of machines were summarised and existing and potential engineering solutions to poor vision from vehicles presented.

CHAPTER 3 EPIDEMIOLOGY OF INJURIES TO LOGGERS DURING SKID WORK

This chapter is an adaptation and update of a published paper (Bentley and Parker, 2001) and a report to the forest industry (Parker and Bentley, 2000). The purpose of this chapter is to provide a detailed background to the problem of skid site injuries and in particular mobile machine related injuries.

3.1 Introduction

Internationally, the injury rate in forest operations is high (Myers and Fosbroke, 1994; Parker, Bentley & Ashby, 2002). New Zealand is no exception, with highest injury incidence found in logging operations (Gaskin and Parker, 1993; Kawachi, Marshall, Cryer, Wright, Slappendel & Laird, 1994; Parker, Ashby & Evanson, 2003). During 2002, some 437 logging injuries were reported in New Zealand, 119 of which required at least one complete day away from work (Parker *et al.*, 2003). Resources to prevent injury in the New Zealand forest industry are limited, and detailed information on the types of injuries and their causes is required to target research and development efforts effectively (Parker *et al*, 2002). In New Zealand, the Forest Industry Accident Reporting Scheme (ARS) is used by the Centre for Occupational Human Factors and Ergonomics (COHFE) of the New Zealand Forest Research Institute to drive its forest industry injury prevention research and development programme. The ARS contains details of lost time, minor and near miss incidents collected over a 19-year period. The scheme receives excellent industry support in terms of data contributions from across the New Zealand industry, who in turn receive summary quarterly and annual injury reports from COHFE. The data received enable COHFE to examine trends and patterns in logging injury data, and target their wider ergonomics, safety and health work programme at key risk areas.

The present study aims to explore patterns and trends in skid site injury data over an 8-year period: 1995-2002. The specific aims of this exploratory analysis are to: identify the extent of skid site injuries and trends over an 8-

year period; determine trends in skid site injury incidence involving mobile machines and identify possible areas for preventive action.

3.2 Methods

The ARS holds information on lost time injuries, minor injuries and near miss events reported to the large majority of forest companies across New Zealand. Data on lost-time injuries occurring on skid sites were selected for the years 1995 - 2002 from the main ARS database and analysed using Microsoft Excel. Variables available for analysis are listed in Table 3.1.

Table 3.1 - Variables considered in the analysis of lost-time skid site injuries.

Variable	Example	How derived (where appropriate)
Lost time	3 days	Days absent from work following injury
Time of day injury occurred	1400 hrs	
Experience in task	15 months	Period of time employed in job
Body part injured	Foot; lower back	
Injury type	Fracture; sprain/sprain	
Injury initiating event	Slip, trip and fall; struck by; manual handling	One-line narrative text (description of injury event)
Agency	Log; branch; chainsaw; underfoot surface	One-line narrative text (description of injury event)
Injury mechanisms	'Vehicle hit log which rolled and struck logger'	One-line narrative text (description of injury event)
Vehicle involved in injury	Loader; Bell Logger	One-line narrative text (description of injury event)

Quantitative analysis methods used were simple frequency distributions and cross tabulations. Content analysis was performed on one-line narrative text describing injury circumstances to obtain information on a number of variables (Table 3.1).

3.3 Results

3.3.1 Skid site worker injuries

Of the 1302 lost-time injuries reported to the logging ARS for the period 1995 - 2002, 342 (26 %) incidents occurred on skid sites. Skid site injuries were incurred at a mean cost of 14.6 days lost per incident. This figure does not differ significantly from that for all logging injuries recorded for the same period (11.8 days). Skid site injuries accounted for one-quarter of all lost days for logging.

Table 3.2 - Distribution of lost-time skid site injuries by initiating event, agency and main injury mechanisms 1995 – 2002.

Initiating Event	n	%	Agency	n	%	Main Injury Mechanisms
Struck by/ strike against	232	68	Log	140	41	• vehicle hit log which rolled and hit logger • vehicle carrying log which hit logger • logger cut log which moved and hit logger/other logger • log being moved by hauler hit logger
			Branch	16	5	• logger hit by uncut branch carried by vehicle • logger hit by branch kicked up by vehicle wheel/chainsaw
			Vehicle	11	3	• unseen logger hit by vehicle reversing • logger hit by vehicle and fell onto saw/other object
			Other	61	17	
Other	110	32				
TOTAL	***342***	***100***				

Initiating event

Some 232 (68 %) of incidents involved the injured logger being struck by something (or in a small number of cases striking against something), reflecting the risks associated with working in a processing area in which foot workers and mobile machinery work in relatively close proximity. The agency most commonly involved in 'struck by/strike against' injuries was 'log' (140 injuries; 41 %). The majority of these incidents resulted from: a vehicle either hitting a log which then hit the logger; logs being carried by a vehicle hitting a logger working on foot; or a log moving under tension and hitting a logger after it had been cut by the logger or a colleague. The common event of a log rolling and hitting a logger's legs (from whatever cause) is in line with findings from previous research on injuries to forest workers (Kawachi *et al.*, 1991), and indicates a key area for prevention.

Further analysis revealed that loaders, skidders and Bell Loggers were the vehicles most commonly involved in striking incidents (Figure 3.1). In the majority of these cases the log that the vehicle was carrying hit a logger, or the vehicle hit a log which rolled and hit a logger. The category "Loader" included rubber tyred loaders, tracked excavator based loaders and Bell Loggers.

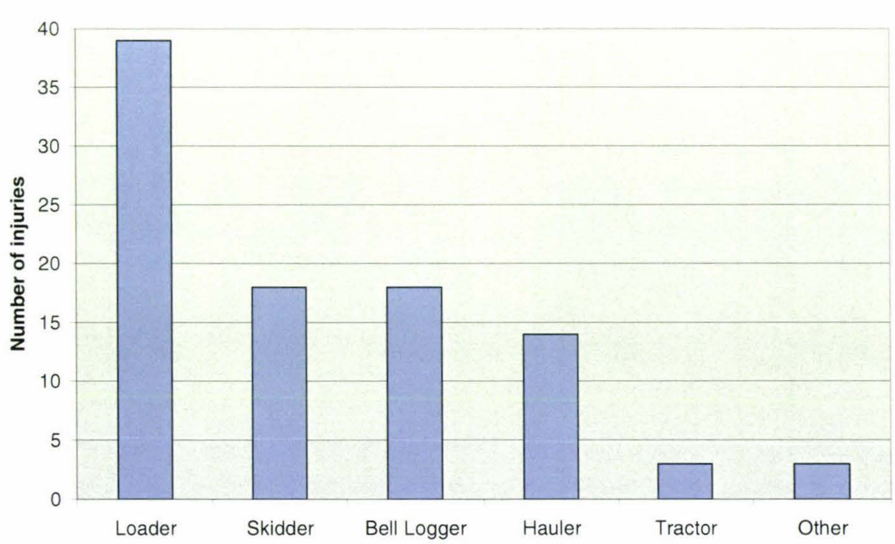


Figure 3.1 - Distribution of vehicles involved in 'struck by' lost time injuries on skid sites 1995 – 2002.

3.3.2 Skid site mobile machine related injuries

Lost time per injury

In the period January 1995 to December 2002 there were 92 lost time injuries reported to the ARS which involved worker/mobile machine interactions on the skid site. The average time off work was 14.6 days. The number of days lost ranged from one to 100 days. A total of 1304 workdays were lost in injuries where mobile skid site machines were involved. At 235 working days per year this is equivalent to 5.5 person – years lost.

Most injuries resulted in one to five days off work (Figure 3.2). However 25 % of injuries were very severe and resulted in more that 21 days off work. Most of these were fractures sustained when the skid worker was hit by a machine or material moved by a machine.

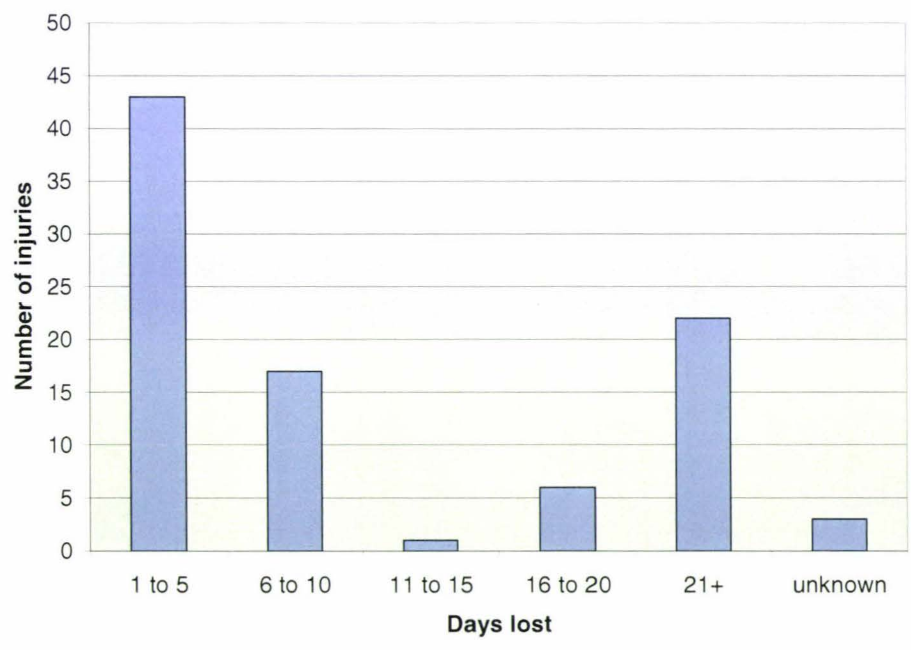


Figure 3.2 – Distribution of lost time mobile machine related injury by days off work.

Part of body injured

The greatest number of injuries (28) occurred to the lower legs (Figure 3.3). Half (14) of the injuries were fractures to the bones of the lower leg resulting in a total of 362 days lost. There were eight serious bruise injuries to the lower legs resulting in 23 days lost. The most common cause of injury was a log being moved by a machine.

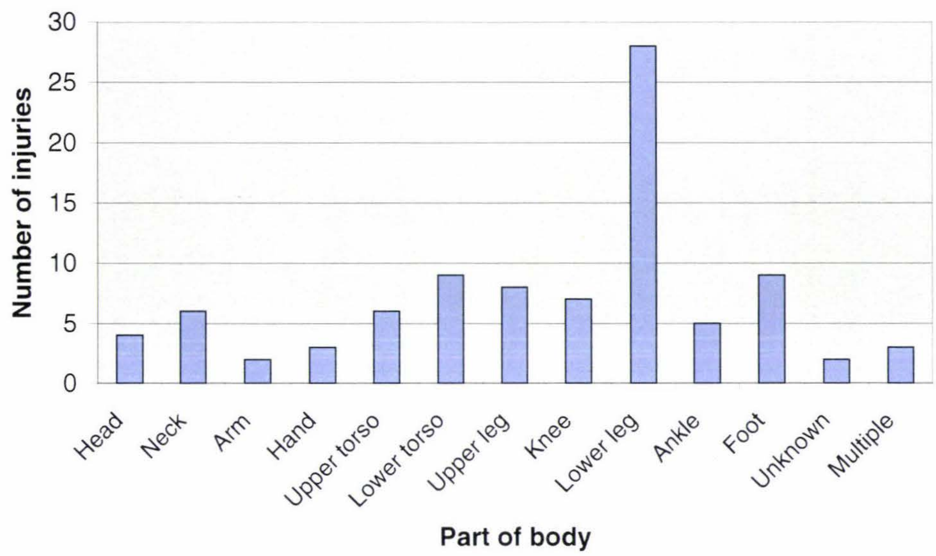


Figure 3.3 – Lost time mobile machine related injuries to skid workers by part of body.

Time of day of injury

Figure 3.4 shows the distribution of skid site injuries throughout the day, with a trend to more injuries during the eight am to nine am period. Most loggers start work at 7 am. This injury pattern differs from that identified from previous forestry research (Kirk, 1996; Parker *et al.*, 2003), where most loggers (across all logging tasks) are injured between 10 am and 11 am and between 2 pm and 3 pm. Likely explanations were being exposure (up to 10am the large majority of loggers will be working; after this time meal-breaks are taken at some point reducing the number of loggers at risk) and fatigue (the energy provided by breakfast will fuel loggers for up to four hours, so by 9 am or 10am they will be low in energy and more likely to experience fatigue). A second peak in injury incidence between 2 pm and 3 pm suggests a second energy low, coming some two to three hours after food was eaten at morning break, and supports findings from Australian logging workers compensation data (Foley, 1994). However, mobile machine initiated injuries present a different temporal pattern suggesting different causes. Generally injuries to loggers are usually a result of a chain of events initiated by the logger. However mobile machine related injuries are the result of the skid worker and the machine operator interaction. Perhaps the early peak of injuries is due to a lack of synchronisation in patterns of work between the machine operator and skid workers.

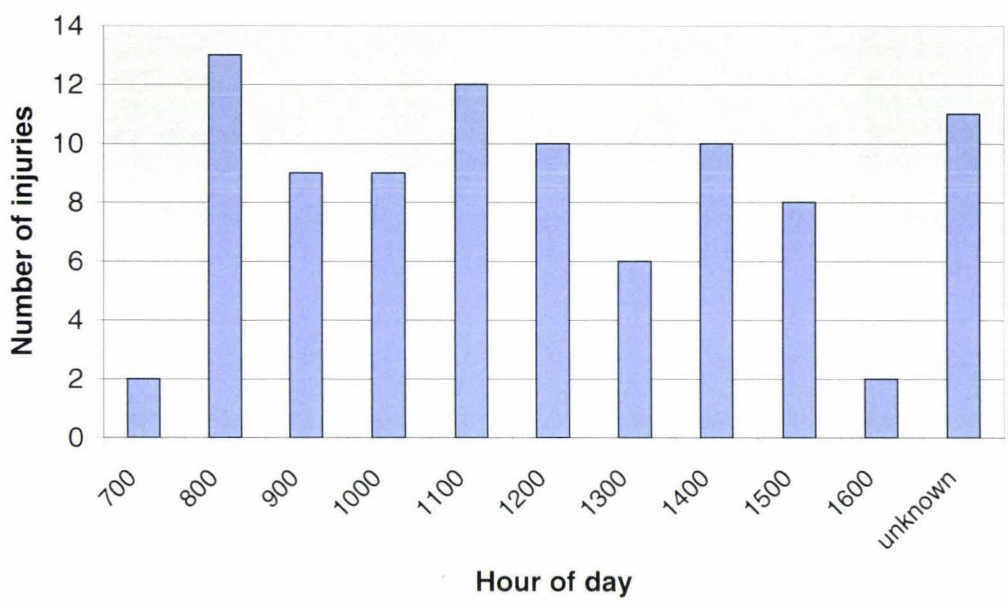


Figure 3.4 – Lost time mobile machine related injuries to skid workers by time of day.

Mobile machine initiated skid site injuries were found to occur across the working week in roughly the same pattern as that for all logging injuries (Parker *et al.*, 2002), with significantly fewer injuries being reported on Fridays (8 % of injuries) than on the other working days of the week.

Injured loggers work experience

Data for injured logger's age was not available for this analysis. Examination of experience data, however, showed 37 % of injuries occurred to skid workers in their first year of logging, with 25 % of incidents involving loggers in their first six months of employment (Table 3.3).

Table 3.3 - Distribution of skid site injuries by injured worker's experience.

Injured worker's experience	n	%
Less than 3 months	13	14
3 to 6 months	10	11
7 to 12 months	11	12
13 months to 2 years	13	14
25 months to 5 years	11	12
Over 5 years	13	14
Unknown	21	23
Total	***92***	***100***

There is no reliable data on the proportion of loggers working in these various categories of experience to determine exposure. However these figures suggest attention needs to be directed at new recruits and inexperienced loggers who are more susceptible to injury than their more experienced colleagues.

3.4 Discussion

This exploratory analysis has highlighted the significant risks of injury associated with working on skid site operations and specifically injuries sustained from interactions with mobile machines.

Training

A large proportion of injuries were sustained by loggers in the first six months of their employment (25 %). These findings suggest a considerable potential benefit to the forest industry would result from improved on-the-job training methods, and other measures to ensure new workers are brought 'up to speed' gradually, and made aware quickly of safe working methods before poor practices become part of the logger's habitual work behaviour. Further research is required to determine the specific risks faced by inexperienced logging workers, particularly those in their first few months of work, and to identify safe practices and systems to ensure these workers acquire the necessary skill and safety knowledge to allow them to work safely around mobile machines following an initial induction period.

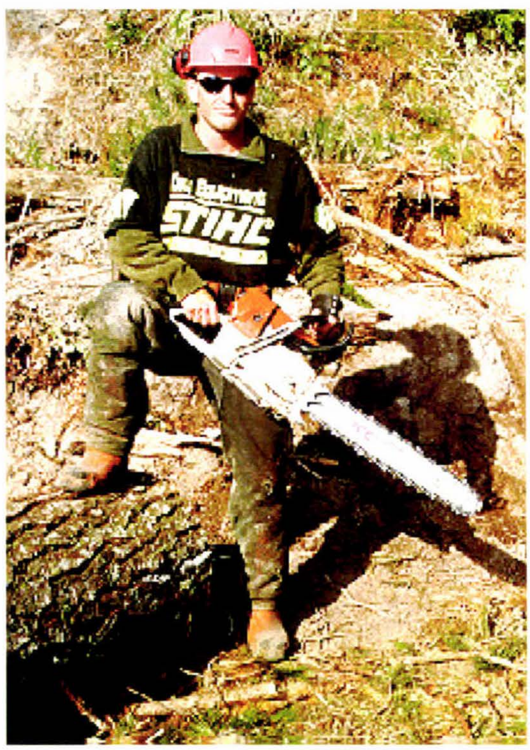


Figure 3.5 – Thirty-seven percent of injuries occur to skid workers in their first year of logging.

Skid site design

The high proportion of 'struck by' incidents indicate that it is the close and frequent interaction between vehicles, materials and humans that impact most on skid site safety. More specifically, it is the proximity between people and logs, whether stacked or being transported by loaders, that presents the greatest area of risk. Some 140 incidents involved loggers being struck by a log through one of a small number of mechanisms (Table 3.2).

Possible measures to reduce the risk of injury through the most common injury event ('struck by log'), and other incidents involving workers being struck by logs or vehicles, include skid site design/redesign. On a simplistic level, design might include repositioning log stacks so that if they become dislodged through contact with a vehicle they roll away, not towards, the location in which foot workers are stationed. More generally, forest engineers should better plan work processes with a view to producing layouts that minimise the risk of mobile machine-person, mobile machine-log and mobile machine–mobile machine contacts.

Improved operator vision

A further measure to improve safety associated with mobile machine - logs - people collisions is to design systems that improve machine operators' vision when manoeuvring on skid sites (rear vision can be extremely poor in some vehicles used on skid sites). COHFE are presently addressing this issue through the use of an in-cab closed circuit television system that provides the vehicle operator with an image to the rear of their vehicle. An analysis of the system is presented in Chapter 5. A related issue is the use of high-visibility clothing by foot workers on skid sites. The adequacy of current high-visibility clothing needs to be determined, and the possible effect of the use of high-visibility materials that are detected easily using the video technology described above or sensors should be considered.

3.5 Conclusions

The findings from this analysis are subject to a number of limitations. The absence of data for minor injuries and near-miss incidents, together with a lack of exposure data from which to determine the extent to which particular tasks, equipment and machinery and population groups are at risk on skid sites, limits the conclusions that can be drawn from this analysis. In addition, it is possible that bias and error in the data may have been introduced from interpretation during different stages of the injury reporting and analysis process. Despite these shortcomings, this study provides a useful starting point for safety work targeting skid site injury risks and particularly injuries resulting from collision between people and mobile machines or material moved by machines. Further research should consider the implications for logger safety, of increasing mechanisation and the growth in the use of 'super-skids' (larger skid site operations with more people and machines). Work needs to be done to improve the visibility of machine operators.

CHAPTER 4 VISUAL ANALYSIS OF BELL LOGGER

This chapter describes the glance direction of three Bell Logger operators working under normal operational conditions. Glance direction is analysed within the context of the direction of movement of the Bell Logger and the tasks undertaken with it, primarily picking up logs and placing them on stacks (fleeting).

4.1 Introduction

As stated earlier (Section 3.1), and restated here for continuity, forestry is recognised as a difficult and dangerous task resulting in many injuries and fatalities every year (Kawachi *et al.*, 1991). Most injuries occur during skid work where trees (now called "stems") are processed on a flat processing area, the skid site. Normal skid site processing tasks include delimbing (removing remaining branches with a chainsaw), log making (assessing the quality features of the stem such as damage, knot diameter, stem diameter (Donovan, 1989)), quality control and machine operating (sorting and moving logs to stacks and loading trucks). These activities result in one to four people, on foot, working in close proximity to heavy mobile machinery.

A machine commonly working in close proximity to skid workers is the Bell Logger (Figure 2.6). The Bell Logger is a popular machine because it is much cheaper to purchase and maintain than alternative log sorting and loading machines such as rubber tyred front-end loaders or tracked excavator based boom loaders. The three-wheeled configuration with two driving wheels in the front and a castor wheel in the rear allows the Bell Logger to manoeuvre quickly. However this quick manoeuvrability can result in collisions with people, other machines or logs.

An important feature of particular concern on skid sites is the close interaction between people, machines, logs and stems. Injuries are detailed in Section 3.3.2. The operator cannot see well due to restricted visibility from the cab. There is no rearwards vision so the Bell Logger can easily hit people or logs which can then hit people. Thus the purpose of this chapter is to investigate the visual components of the task of operating a Bell Logger on the landing.

4.2 Methods

Ergonomics takes the *system* as the unit of analysis – the person performing a task in an environment (including other people) supported by technology. The visual glancing activity of the Bell Logger operator can be understood more fully by knowing the physical environment of the operator and his machine. The work environment of the skid site is described and the tasks the operators engaged in are detailed. The machine cab, the immediate work environment of the operator, is shielded to guard against logs hitting the operator. The guarding reduces the field of view of the operator, which was measured. The glancing direction of the machine operator was recorded in conjunction with the direction of movement of the Bell Logger.

4.2.1 Bell Logger work environment and operator tasks

Work environment

The Bell Logger normally works on skid sites picking up logs, sorting them and carrying the logs to stacks. The skid site has a high concentration of people, mobile machines and obscured sight lines. The operators in this study all shared the same Bell Logger. Observations were done on a large permanent landing in Whakarewarewa Forest, near Rotorua. The skid site was 120 m by 200 m with the Bell Logger moving between the processing zone and the stacks (Figure 4.1)

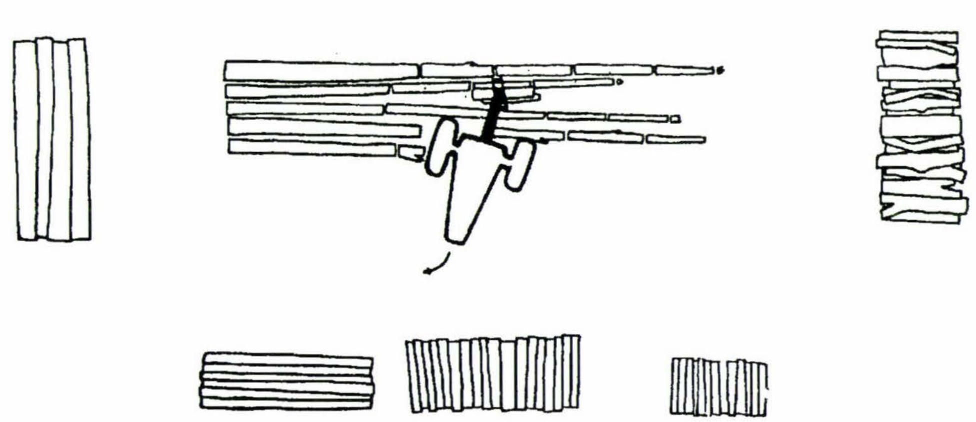


Figure 4.1 – Schematic of Bell Logger working on the skid site used in study.

Bell Logger operators

The three operators in the study worked in the same logging crew and were experienced in operating the same Bell Logger. Because they worked in the same crew they understood the normal skid site etiquette (meaning of hand signals, indications that the way is safe, response times to signals and so on) of that crew. This allowed comparisons of working style between operators to be made more easily without the variation that would exist if different crews were used.

The operators were older crew members. Operators 1, 2 and 3 had respectively 5, 1 and 1 years experience operating Bell Loggers and were respectively 48, 52 and 41 years old.

The purpose of the study was described to the operators. All operators gave informed consent (Appendix 2) to be observed and video taped while working and were aware that they could withdraw from the study at any time.

Operator tasks

The normal tasks of the Bell Logger operator are fleeting logs (positioning stems and logs for a subsequent action), removing debris from the landing and loading trucks. These tasks were recorded on video tape and transcribed with a behaviour observation programme to a computer file (Section 4.2.3). Bell operators are cautioned during training (Gleason, 1985) to "Be well aware of what is to your side, both in front and behind you before rotating. There may be a tree or even a co-worker who could be crushed as you swing around."

There is a standard operating procedure adopted by logging crews operating the Bell Logger on skid sites (Gleason, 1985). Cut logs are picked up and transported in the Bell grapple to the appropriate log stack. Two or more logs of the same type (diameter class, pruned or unpruned, knot size etc) will be accumulated in the grapple if they are of small enough diameter or weight (Appendix 6). The Bell then returns from the stack to collect more logs. The cycle of fleeting logs continues until all logs are in stacks. The operator then has time to "sweep" the skid site of debris.

4.2.2 Operator field of view

The Bell Logger cab is armoured with steel plate and wire grills (Figure 4.2), to protect the operator from logs which could slip from the grapple which is positioned directly in front of the machine.

Figure 4.2 – Forward field of view of Bell Logger operator obstructed by protective bars.

The field of view of the operator was estimated by making a montage of photographs taken of the inside of the cab from the operators eye height with an Olympus OM10 SLR camera and 50 mm lens (Roscoe and Hull, 1982). A diagram was then created of the field of view showing obstructions and openings in the armoured cage in which the operator sits (Figure 4.3). The Bell Logger cab provides 60° of view to the left or right of the principal vertical axis and 45° up and 25° down. The boom occludes 15° of horizontal view from the top to bottom of the front window. Also the protective bars on the window reduce the forward view.

The operator had no significant rear view. Although there was a small window directly behind the seat, operators could not twist sufficiently to see out of it.

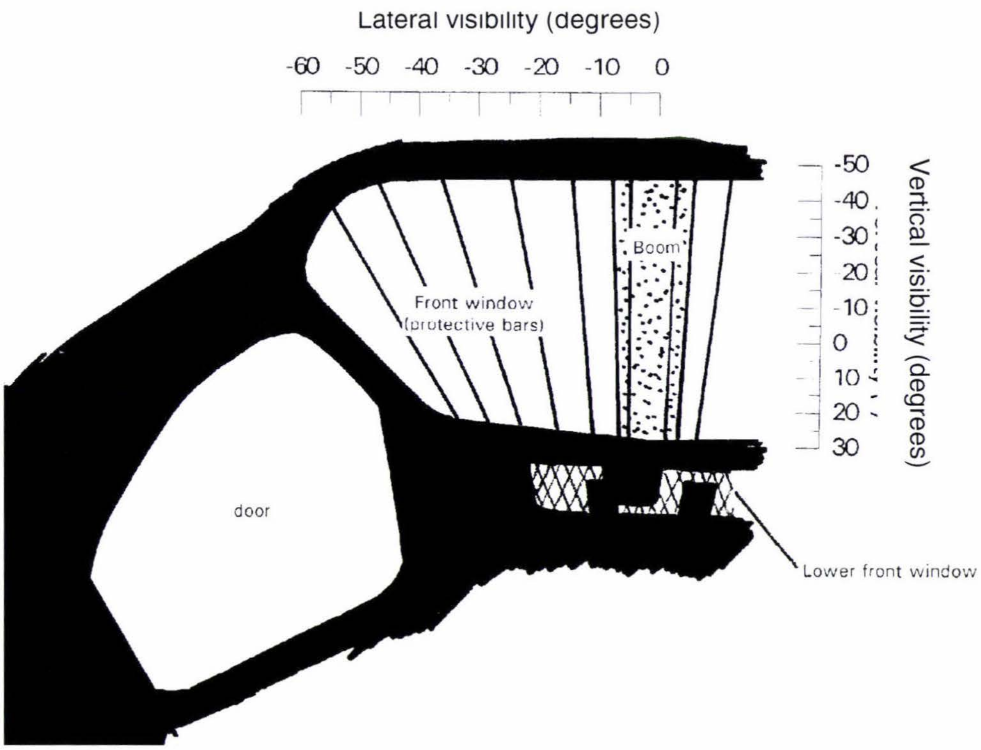


Figure 4.3 - Operator field of view from Bell Logger.

4.2.3 Activity recording

Bell Logger operator head movements (glance direction) and machine movements were recorded on video (Figure 4.4) for later analysis.

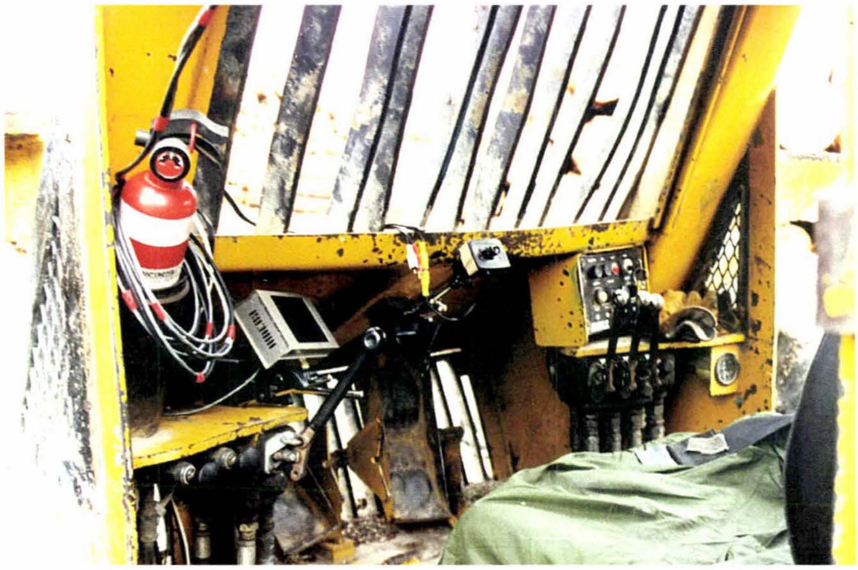


Figure 4.4 - Cab of Bell Logger with video camera used to record operator head movements (video monitor not connected).

Machine movements

A digital video camera was used to record the movements of the machine from a distance (travelling forward, travelling backward). This camera was hand held and the camera - person viewed the operation from a safe position on top of a nearby high point.

The Bell Logger was engaged in four main activities or "states" while working; fleeting, sweeping, travelling or loading. In addition the Bell Logger was occasionally delayed and sat still waiting for the way to clear or was engaged in some other activity. These activities are defined in Table 4.1.

Table 4.1 - Definition of terms used to describe Bell Logger activity on the skid site (from Spiers, 1985).

State	Definition
Fleet	Positioning logs by machine in preparation for a subsequent operation (includes stacking logs)
Sweep	Blade the surface of the landing with a blade held in the grapple and against the front of the Bell
Travel	Move from one part of the landing to another with no logs or blade in the grapple
Load	Place logs from the ground or a stock pile on to the back of a truck
Delay	Bell motionless while waiting for people or machines to move away
Other	Other activity not defined above

In addition, the direction of movement of the Bell Logger was recorded. Definitions used are defined in Table 4.2.

Table 4.2 - Definition of terms used to describe Bell Logger movements on the skid site.

Event	Definition
Forward	Bell Logger moves forward – rear castor wheel behind vertical axis
Backward	Bell Logger moves backwards – rear castor wheel in front of vertical axis
Stop	Machine motionless
Disregard	Machine not visible – obscured behind stacks of logs or behind other machines

Operator head movements

A small black and white video camera was mounted in the cab pointing directly at the operator's face to record the direction the operator glanced forward, left and right (Figure 4.4). The signal from this camera was fed into a Sony 530 digital video camera. Bell Logger operator's head movements were only recorded when the operator glanced to the left or right. These movements are defined in Table 4.3.

Table 4.3 - Definition of Bell Logger operator head movements.

Event	Definition
Left	Head rotates to the left and the left helmet-mounted ear muff is not visible – at least 42° from straight ahead
Right	Head rotates to the right and the right helmet-mounted ear muff is not visible – at least 42° from straight ahead

Head movements and machine movements were subsequently transcribed to an Excel file using the animal behaviour transcription programme EthoLog 2.2 (Ottoni, 1999). EthoLog is a computer based software programme that can be synchronised with a videotape recording. Events of interest recorded on the videotape are programmed into EthoLog as "categories" (Figure 4.5) and each category is linked to a key on the keyboard.

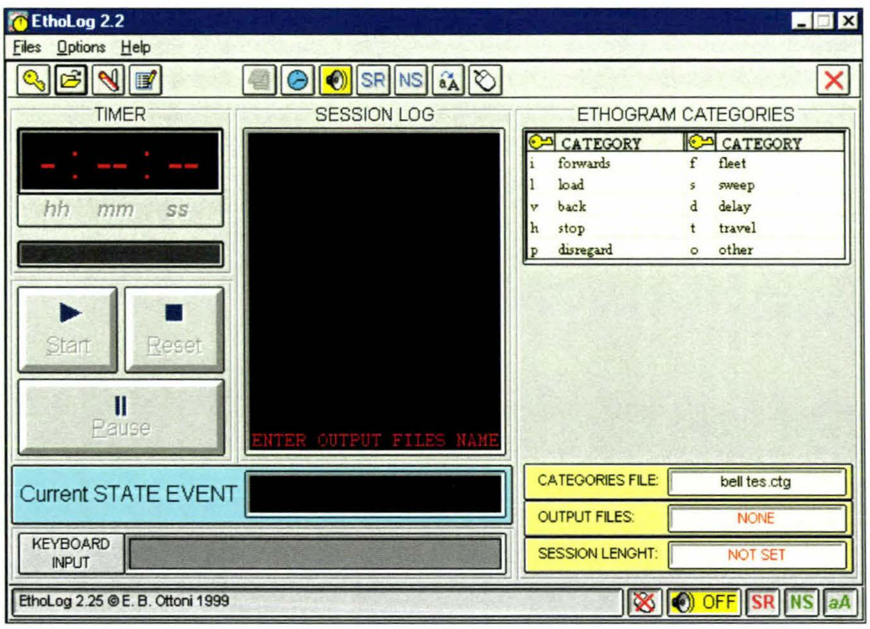


Figure 4.5 - EthoLog data input screen for Bell Logger movements.

The videotape is then viewed with EthoLog running and when an event of interest occurs, such as forwards, load, back etc, the corresponding key on the keyboard is depressed and the occurrence of the event is recorded in a file with time of occurrence generated by EthoLog. In this way data sets were generated comprising changes in direction of the Bell Logger (Table 4.4) and Bell Logger operator head movements (Table 4.5) in relation to time.

Table 4.4 - Raw data set derived from Etholog of Bell Logger movements where File *is a data set identifier,* Direction *is the direction of Bell Logger movement,* Time *is elapsed time from the start of the recording and* Etho state *is the activity the Bell Logger was engaged in at that time.*

File	Direction	TIME(s)	Etho state
C13new01	Forwards	5.24	Fleet
C13new01	Back	8.7	Fleet
C13new01	Forwards	14.23	Fleet
C13new01	Back	21.89	Fleet
C13new01	Forwards	25.2	Fleet
C13new01	Back	29.23	Fleet

Table 4.5 - Raw data set derived from Etholog of Bell Logger operator head movements where Dataset *is a data set identifier,* Leftright *is the direction the operator glanced,* Glance *is an Etholog code,* Time *is elapsed time from the start of recording,* Elapsed *is elapsed time between glances and* Corrected time *was a time to synchronise head movements with Bell Logger movements.*

Dataset	Leftright	Glance	Time	Elapsed	Corrected time
incab2	Left	1	10.33		550.33
incab2	Right	4	10.79	0.46	550.79
incab2	Right	4	13.95	3.16	553.95
incab2	Right	4	34.09	20.14	574.09

The Bell Logger movement data and the operator head movement data were synchronised because they were recorded on different cameras and in different data sets. Preliminary testing of the two cameras found no discernable differences in recording speed or clock times over one hour (the longest recording time on digital tape).

A proprietary data manipulation programme to combine and synchronise the data sets could not be found so an original programme was developed by the author and an Excel programming specialist (Falconer, *pers com.)* at the New

Zealand Forest Research Institute. The details of the programme are presented in Table 4.6 so this useful series of steps can be used in future studies.

Table 4.6 - Data manipulation required to create the final synchronised Excel 97 data set containing Bell Logger movements and operator head movements.

- Log file TIME converted to time on videotape VIDEOTIME.
- VIDEOTIME converted to a time synchronised with the other video tape SYNCHTIME.
- Bell .xls file appended to bottom of Cab .xls file
- Create OPERATOR field – *identifies operator*
- Create REAR VIEW field – *identifies rear view status (with or without rear view system)*
- Reformat DIRECTION and ETHOSTATE fields with =TRIM(D1) and COPY, VALUES – *to remove trailing blanks in data field created by Etholog programme*
- Reformat DIRECTION and ETHOSTATE fields with =PROPER(D1) and COPY, VALUES – *to ensure first letter in data fields is upper case.*
- Sort data set by SYNCHTIME field – *to interleave Bell.xls and Cab.xls files by time*
- Create TASK field by manually interpolating ETHOSTATE values – *ETHOSTATE automatically generated for Bell.xls file but not Cab.xls file*
- Create STATE field – *indicates the direction the Bell is moving at that time (forward, reverse or disregard)*

=IF(ISNA(VLOOKUP(LEFT(D3,1),$M$2:$M$5,1,FALSE)),J2,LEFT(D3,1))
using look up table (Table 4.7, "OK conditions column)

- Create ELAPSED field – *time elapsed since previous event started (duration of previous event)*

=C3-C2

- Create EVENT BEFORE field – *indicates the event which occurred immediately before the Bell moved forward or in reverse*

=IF(OR(B5="Forward",B5="Back",B5="Stop",B5="Disregard"),LEFT(B5,1)&B4,"x")

The files for each operator were then appended together to create a data set suitable for statistical analysis (Table 4.7).

Table 4.7 - Combined file used for data analysis where:

- *Operator* identifies the Bell Logger operator being observed
- *Rear view* is whether the video rear-view system is fitted (Chapter 5)
- *File* is the original data file generated in EthoLog
- *Direction* is the Bell Logger movement direction
- *Time* is the original time from EthoLog
- *Etho state* is the activity the Bell Logger was engaged in
- *Task* is a code filled in to account for gaps in the Etho state field
- *Video time* is the time code on the video tape
- *Synchronised* is a common synchronised time for both tapes – in this example one file was out of synchrony by one second
- *State* is the activity the Bell Logger was engaged in
- *Elapsed* is the time elapsed between direction (head or machine) changes
- *Event before* is the event when occurred immediately before - FRight indicates glance right then move Bell Logger forwards
- *OK conditions* is an Excel "Lookup table" to generate State codes.

Operator	Rear view	File	Direction	TIME(s)	Etho state	Task	Video time	Synchronised	State	Elapsed	Event before	OK conditions
Willy	None	W01	Left	14.72		Other	64.72	64.72	D	6.33	X	F
Willy	None	W01	Right	23.36		Other	73.36	73.36	D	8.64	x	B
Willy	None	W11nbl02	Forwards	32.79	Fleet	Fleet	76.79	77.79	F	4.43	FRight	S
Willy	None	W01	Right	34.59		Fleet	84.59	84.59	F	6.8	x	D
Willy	None	W11nbl02	Disregard	42.3	Fleet	Fleet	86.3	87.3	D	2.71	DRight	
Willy	None	W11nbl02	Back	56.78	Fleet	Fleet	100.78	101.78	B	14.48	BDisregard	
Willy	None	W11nbl02	Forwards	58.7	Fleet	Fleet	102.7	103.7	F	1.92	FBack	
Willy	None	W11nbl02	Stop	64.21	Fleet	Fleet	108.21	109.21	S	5.51	SForwards	
Willy	None	W11nbl02	Back	69.14	Fleet	Fleet	113.14	114.14	B	4.93	BStop	

4.3 Results

Results of analyses of the Bell Logger activity and operator glance direction, from the data set generated in Section 4.2.3, are presented.

4.3.1 Bell Logger movement

Time budget for Bell Logger operation

All three operators were engaged in Bell Logger fleeting (picking up logs and moving them to log stacks) for the greatest part of the observation period (Table 4.8). Other tasks were loading a truck with short (less than 3-m length) logs, stopped with operator talking to other workers, sweeping the landing of debris (branches and bark) with a blade held by the Bell Logger grapple and travelling from one side of the skid site to the other.

Table 4.8 - Total time engaged in each task (minutes).

Operator	Fleeting	Loading truck	Other	Sweeping	Travel
1	42.9	0.0	0.0	3.4	0.0
2	37.8	0.0	3.2	12.4	0.5
3	42.8	12.0	0.5	0.0	1.6

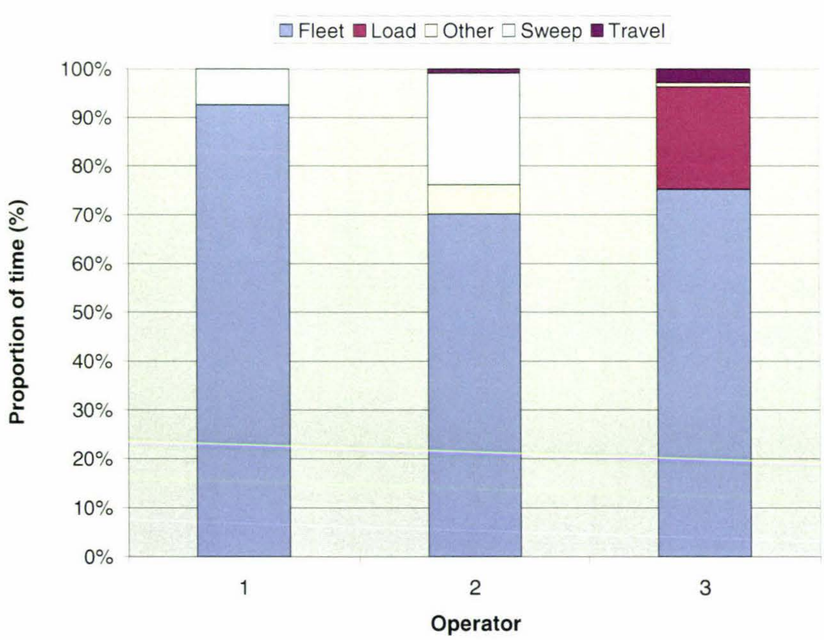


Figure 4.6 - Proportion of observation time each operator engaged in tasks.

Fleeting was the task most frequently performed by all operators (Figure 4.6). Operator 2 was engaged in sweeping because the landing had become littered with debris. Operator 3 had to load a truck with short pulp wood because no other loader could handle such short logs.

Direction of Bell Logger movement

The periods of observation for Operator 1, Operator 2 and Operator 3 were 46.4, 53.9 and 56.9 minutes respectively. Operator 1 had the greatest delay free work time with the Bell Logger motionless for only 13% of the events recorded in the observation period (Table 4.9). Operator 2 and Operator 3 had 21% and 31% respectively of the observation period motionless. All operators except Operator 3 had more movements in the forward direction. However, duration of movement (Table 4.10) indicates more time was spent moving forwards than reverse.

Table 4.9 - Total number of Bell Logger movements across all tasks.

Operator	Back	Disregard	Forward	Stop
1	216	4	224	63
2	155	10	163	94
3	220	5	210	147

Table 4.10 - Bell Logger duration of movement across all tasks (minutes).

Operator	Back	Disregard	Forward	Stop
1	16.1	1.1	24.5	4.8
2	11.3	1.8	27.2	13.4
3	14.5	1.5	27.3	13.6

Tables 4.9 and 4.10 show the gross representation of Bell Logger direction movements over all activities during the observation period. Movements that occurred just during the fleeting period are presented in the next section (Table 4.11).

Table 4.11 - Bell Logger duration of movements (seconds) during the fleeting task (CI - 95 % confidence interval).

Operator	Direction	Mean	Lower CI	Upper CI	Min.	Max.	Count
1	Forward	6.2	5.5	6.9	0.3	42.2	217
	Reverse	4.4	4.1	4.7	0.8	14	210
2	Forward	8	6.9	9.1	0.3	58.6	138
	Reverse	3.8	3.4	4.2	0.3	16.2	129
3	Forward	8.1	7.0	9.2	1.3	55.9	164
	Reverse	4.0	3.7	4.3	0.3	12.3	171

The duration of Bell Logger movements ranged from less than one second (lurch forwards or backwards) to almost one minute of sustained forward movement when repositioning the machine. All operators travelled in the forward direction for a greater period of time than in the reverse direction ($p < 0.05$). Operator 1 had a smaller mean duration of forward movements than Operator 2 or Operator 3 ($p < 0.05$). Also, Operator 1 tended to have the longest mean duration of reversing. The driving style of Operator 1 appears quite different from the other operators, e.g., he had a higher number of direction changes in the observation period.

The rate of Bell Logger movements per minute was determined. This gave a measure that reflected the forwards/backwards activity of the Bell Logger better than mean duration of movements (Figure 4.7).

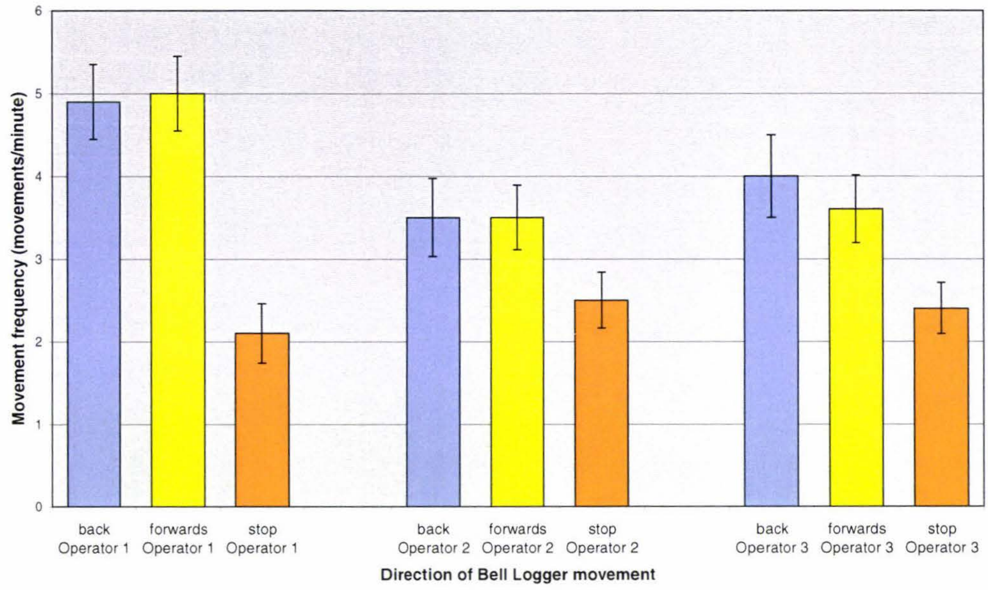


Figure 4.7 - Bell Logger movements per minute (± 95% confidence interval), for the task of fleeting, in the forward and reverse directions and stopped.

Operator 1 drove the Bell Logger both forwards and backwards significantly more frequently per minute than Operators 2 and 3 ($p < 0.05$). However there was no significant difference in the frequency of stopping between the three operators without rear vision (Figure 4.7).

4.3.2 Operator glance direction

The operators had to look from side to side frequently while driving the Bell Logger. The number of glances for each operator was measured from the video record collected from the camera which viewed the operator's face (Figure 4.4). Overall the operators glanced to the left or right approximately once every 12 seconds. Operator 1 tended to glance to the right more frequently than to the left.

Table 4.12 - Direction of glance (head movements) of Bell Logger operator across all tasks during the observation period.

Operator	Glance Left	Glance Right
1	100	133
2	123	103
3	143	94

The three operators exhibited quite different glance behaviour when examined in the context of the direction of Bell Logger movement (Table 4.13). When moving backwards, Operator 1 glanced equally to the left and right. In contrast, Operators 2 and 3 glanced more to the left. When moving forwards, Operator 1 glanced more to the right. Where as Operators 2 and 3 had a similar number of glances to the left or right.

Table 4.13 - Count of direction of glance by machine direction for fleeting task.

Operator	Direction	Back	Forward	Stop
1	Left	40	49	9
	Right	40	76	8
2	Left	30	33	9
	Right	24	37	8
3	Left	40	46	19
	Right	15	44	12

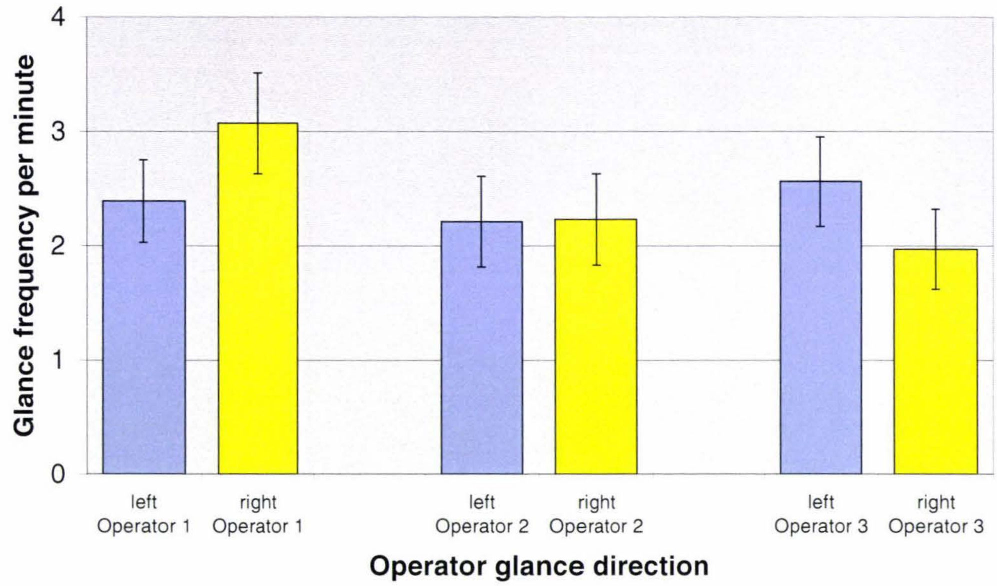


Figure 4.8 - Direction of glance (mean head movements ± 95% confidence interval) per minute of three Bell Logger operators under normal operational conditions during fleeting.

The frequency of glances per minute was calculated from the video record. All operators glanced to the left with a similar frequency. However Operator 1 glanced to the right more frequently per minute than Operators 2 and 3 ($p < 0.05$). There was no difference in the frequency with which they glanced to the left or right.

4.4 Discussion

4.4.1 Operator's field of view

The field of view of the operator was severely restricted in the forward direction and non-existent in the rear direction. Considering that a Bell Logger is traveling in reverse for approximately 50% of the time it is remarkable that more collisions do not occur. Measurements of visibility from the cab were done directly as opposed to using a computer model (eg. Boocock and Weyman, 1994; Boocock *et al.*, 1996; Giguère and Larue, 1996) or sophisticated photographic methods (eg. Hella *et al.*, 1991; Hella *et al.*, 1996). The simple aviation-based visibility method of Roscoe and Hull (1982) was adequate to characterise the Bell Logger operator's field of view.

The boom of the Bell Logger is placed directly in front of the cab (Figure 4.3) and occludes a section of forward vision of 15° horizontally and 75° vertically. SAE (1967) provides guidelines for field of view in vehicles. It suggests the optimal range of eye movement should be no more than 15° to the left or right and 15° up or down. The operator could see very little other than the boom with this range of vision. The SAE (1967) report suggests 30° in each direction is "acceptable". In this case the boom would still occlude 25 % of the forward field of view, not taking into account that occluded by the protective bars over the windows. However, the operators considered their forward vision was not hindered by the protective bars and boom structure because they could easily move the vehicle to get an unobstructed view (*Pers comm.*).

4.4.2 Activity recording

The transcription and timing tool EthoLog 2.2 was a rapid and simple method to collect head movement and machine movement information. Previously, New Zealand forest machine time studies have been completed by stop-watch or the time study programme SIWORK (Rolev, 1988).

To review, the Bell operator was normally engaged in four main tasks when working on a ground based landing. These tasks were:

- fleeting - picking up logs from where they were cut from a stem and placing them in a log stock pile,
- sweeping - attaching a blade to the front of the Bell and blading waste material, too small to pick up in the grapple, off the surface of the landing,
- travel - repositioning from one part of the landing to another and not carrying a log or having the sweeping blade attached,
- loading - placing logs on the back of a truck.

Activities on the skid site were optimised around unloading stems, processing stems into logs and storing logs as quickly as possible. The Bell Logger operator must sometimes change his pattern of work to assist in maintaining a high flow of logs through the skid site. The log flow status of the landing at the time each operator was observed is reflected in the proportion of time engaged in each task (Figure 4.6). Operator 1 was engaged in fleeting logs for 93 % of the observation period. He swept the skid site in the remaining 7 % of observation time. Sweeping is a "house keeping" task which is performed if time is available. Sweeping increases the safety of workers on the ground by removing debris which could result in a tripping hazard. Sweeping also improves productivity by removing material which may hinder the rapid pick-up of logs in the grapple. Operator 2 had considerable time to sweep the landing because the forwarder, delivering stems to the skid site, was late. Operator 3 was requested to load waste material which had been swept into a heap, into the back of a dump truck. Operator 3 had no spare time to sweep the landing. The task of fleeting occupies the greatest proportion of the Bell Logger operator's time (Figure 4.6).

4.4.3 Bell Logger movements

The direction of movement of the Bell Logger was only recorded forward and backward. In reality the machine was often turning as it reversed. But because the frequency of direction changes was so rapid, left or right turning movements of the Bell Logger could not be measured. Discussion with operators revealed that turning while reversing was used to improve the field of view to the rear, but this could not be measured.

Operators were observed for less than one hour because that was the maximum recording time on the video camera. Longer recording periods would have necessitated changing video tapes and resychronising the cameras. This would involve additional disruption and delay for the Bell operator and the logging contractor. The short distances moved when fleeting logs result in a quick cycle time of Bell Logger operations and considerable data was collected in a short time. The activities of Operators 1, 2 and 3 were recorded for 46.4, 53.9 and 56.9 minutes respectively. In these periods Operators 1, 2 and 3 had respectively 440, 318 and 430 forwards or backwards movements of the Bell Logger (Table 4.9). Operator 1, the most experienced operator, had the greatest rate of forwards and backwards movements. This study is the first, in the author's knowledge, to record the detailed movements of the Bell Logger under normal operational conditions.

Operator 1 had only 46 minutes of recording because of delays at the start of his trial period due to the unscheduled arrival of a diesel tanker and the refueling of his Bell Logger. This delay period was not included in his recording time.

Total time the Bell Logger was immobile, with the engine running, expressed as a proportion of the total observation time was 10.4 %, 24.9 % and 23.8 % for Operators 1, 2 and 3 respectively. The proportion of delays experienced by operators in the observation period are similar to those reported in the New Zealand logging literature of Bell Loggers operating on skid sites. Gleason and Stulen (1984) reported delays accounted for 12 % to 15 % of scheduled machine hours over a 69-hour study. Use of a Servis recorder (Terlesk, 1972) over a 10-week period showed machine utilisation of 78 %. Duggan (1989) reported 28 % delay time for a Bell 220 Logger sorting and stacking logs under the tower of a Madill 071 hauler.

All operators had a similar proportion of Bell Logger movements forwards and backwards. However, they differed in the number of times their machine was immobile ("Stop" in Table 4.10). This difference is due to the different work styles of the three operators. Operator 1 was the most experienced. He is also the most dexterous with the boom and grapple of the Bell Logger. Operator 1 could move forward, pick up a log and move backward without stopping. Operators 2 and 3 were less experienced. They often have to stop the forward motion of the Bell Logger while they picked up a log in the grapple (Table 4.9).

The average duration of forward and reverse movement was calculated for each operator during fleeting (Table 4.11). The shorter duration movements of Operator 1, the most experienced operator, support the observation that he can work faster and more smoothly than Operators 2 and 3.

Operator 1 moved the Bell Logger with greater frequency ($p<0.05$) compared with the other operators (Figure 4.7). However there was no difference in the frequency of stopping per minute between operators. Stopping frequency expressed as a proportion of all movements was least for Operator 1. This indicated a smoother working style without the need to stop and position the Bell Logger as frequently as Operators 2 and 3.

The results presented indicate that the Bell Logger machine is operated quickly, has a short cycle time and has frequent changes of direction and the operators varied in their speed of Bell Logger movement. Other literature on the ergonomics of reversing vehicles focuses on slower moving vehicles such as the forklift (Hella *et al.,* 1988). The Bell Logger operator must not only be capable of working at a high intensity of movement but must also be aware of other machines and people on foot working in close proximity. The operator can only use vision to locate the presence of other machines or people nearby.

The operator's other senses are overwhelmed by the working conditions inside the Bell Logger cab. It is an environment of high noise levels in the cab, 103 dBA Leq, (OSH, 1993), high vibration levels and contamination of all surfaces with an odiferous film of diesel and hydraulic oil. This work environment is similar to other diesel powered machines which have an open cab (Boocock *et al.*, 1996). The next section will examine the operator's use of vision while driving the Bell Logger utilising the recording of glancing behaviour.

4.4.4 Operator glance direction

The Bell Logger operator must look to the left and right frequently to locate hazards in his work environment. This is the first time in a logging machine, to the author's knowledge, that operator glance behaviour has been measured. Other workers have investigated head movements and eye glancing behaviour of car drivers and truck drivers (Snyder and Monty, 1986; Mollenhauer *et al.*, 1997) and head movements of fork lift operators (Hella *et al.*, 1988). Numerous other studies have used sophisticated eye tracking devices to monitor what direction the operator is looking. Since an eye tracking device was not available for this study, the direction the Bell Logger operator glanced was measured. A glance was defined as the head rotating laterally to such an extent that one of the operator's helmet-mounted ear muffs was not visible (at least 42° from straight ahead).

The three operators differed in the number (Table 4.12) and proportion of times they glanced left and right. Operator 1 glanced more to the right and Operators 2 and 3 glanced more to the left. In conversation with the operators they were unaware of any difference in glancing direction or the reason for it. It must be part of their operating style and was not related to handedness or neck injury.

The differences between operator glancing style became greater when glancing activity was examined in relation to Bell Logger movement direction (Table 4.13). During reversing Operator 1 glanced an equal number of times to the left and right. In contrast both Operators 2 and 3 glanced more frequently to the left. During forwards movement Operator 1 glanced most frequently to the right. Again Operators 2 and 3 differed from Operator 1 – now glancing a similar number of times to the left or right. The direction of glancing may be related to the preferred direction of turning the Bell Logger while moving. Unfortunately Bell Logger turning direction could not be measured in this study.

The glance rate per minute, left or right, during fleeting showed no significant differences within operators (Figure 4.8). However, Operator 1 glanced to the right more frequently ($p<0.05$) that Operators 2 or 3. The reason for this difference is unknown.

The operators worked in a very visually dynamic environment. The highest visual acuity is concentrated around the fovea and decreases toward the periphery of the retina (Flannagan and Sivak, 1993). Therefore the eyes need to move to keep the item of interest (log to be picked up, skid worker walk across path of machine) in focus. The operator can move his eyes, head or the Bell Logger. Because the Bell Logger is so manoeuvrable he can compensate for the poor field of forward view which is obscured by the boom and protective bars.

The task of Bell Logger operating in this study had to be observed and recorded under normal operational conditions. A controlled environment where the operators could fleet logs in repeatable conditions would have been ideal. However, because of the commercial pressures on logging crews disruption of normal work flow had to be minimised. Similarly, a greater number of experienced operators would strengthen the analysis. However, few crews have three experienced Bell Logger operators all regularly driving the same machine.

4.5 Conclusions

Results confirmed the task of operating a Bell Logger was very visually "busy". During fleeting, operators were glancing to the left or right on average five times per minute and changing the direction of movement of their machine seven to ten times per minute.

The three operators had different operating and visual scanning styles. All glanced frequently and they differed in the proportion of glances made to the left and right depending on the direction of travel.

Improvements to the design of the study which should be incorporated in future work include: a repeatable fleeting task, a method to record Bell Logger direction of motion and turning and operator glancing direction (without laborious manual video transcription) and of course a larger sample size of operators.

The Bell Logger is involved in collisions with people, logs and other machines (Chapter 3). Solutions to reduce injury include eliminating all workers on foot from the vicinity of the machine. However other machines and obstacles (logs, holes in the ground, banks of earth) still exist and can result in injury to the operator. Introduction of a rear-vision system would assist the operator when manoeuvring the vehicle. Closed circuit rear-view television has been successful in other vehicles (Chapter 2). The evaluation of a closed circuit rear-view television system for the Bell Logger is presented in Chapter 5.

CHAPTER 5 EVALUATION OF REAR-VIEW CAMERA SYSTEM

This chapter describes the evaluation of the effectiveness of a prototype closed circuit colour video camera system to provide rearwards vision to the operator of a forestry machine (Bell Logger) working in close proximity to other machines and workers on foot.

5.1 Introduction

The Bell Logger is a three wheeled log handling machine commonly used in logging operations (for more details refer to Section 2.5.2). Mirrors have been unsuccessful in providing rear vision for Bell Loggers because the mirrors get damaged or covered in mud in the demanding operational conditions. Vibration of the mirrors and the associated out-of-focus image has also been reported as a problem by vehicle operators in its use (pers comm.). Rushworth (1996) and Lee (1997) identified video technology as a simple, cheap and effective means to dramatically improve the view of the vehicle driver to the rear of the vehicle. In the forest industry, video has not yet been used to improve the drivers field of view.

5.2 Method

5.2.1 Study design

A closed circuit video system was fitted to a Bell Logger to provide rear vision to the operator. The same work environment was used for both the non - camera (Chapter 4) and video rear vision conditions. The work site was an active skid site where the most frequently performed task was fleeting logs. Refer to Section 4.2.1 for a detailed description. The effectiveness of the video rear-vision system was evaluated by asking the operator's opinion of the system, measuring the field of view of the system, measuring the frequency and direction of Bell Logger movements forwards and backwards and measuring the frequency and direction of operator glances without (Chapter 4) and with the rear-vision system installed.

5.2.2 Rear-vision camera system

The rear-vision camera system comprised a camera and a monitor. The camera was a 330-line reversing camera which produced a mirror image by translation about a central vertical axis. The image was colour and was collected by a 6 mm CCD sensor with 512H x 582V picture elements. The camera was mounted in a protective metal tube and bolted to a plate on the diesel tank at the rear of the Bell Logger (Figure 5.1). The monitor was a colour, 95 mm diagonal, liquid crystal display (LCD) with 290 lines and 234 x 383 elements. It was mounted in the cab on a magnetic base which was clamped to the hydraulic control plate (Figure 5.2).

Figure 5.1 - Video camera mounted in protective metal tube on the diesel tank of the Bell Logger.

Figure 5.2 - Video monitor LCD mounted in the cab of the Bell Logger with camera to record operator head movements.

Locating the video rear-vision monitor in the cab of the Bell Logger was a compromise between being easily visible yet not obscuring the view ahead, particularly the view of objects on the ground such as logs. Also the monitor had to be sufficiently shaded from bright light so it would be visible. The monitor was located 35° below and 20° left of the operator's principal line of sight, outside the optimum range (SAE, 1967) of 15° to the left or right and 15° above or below the principal line of sight. However, it was within the (SAE, 1967) 'acceptable' range of 65° below the line of sight. Physically the monitor could not be raised to more than 30° below the line of sight (Figure 5.2). Kelley and Prosin (1969) cited by Flannagan and Sivack (1993) recommend that rear images (from mirrors) are not at the same elevation as the most critical forward images to ensure a rear image is not confused as a forward image. As a guide to mirror or monitor location Morrow and Salik (1962) found a consistent deterioration of the ability to detect objects that were more than 30° from the line of sight. The prototype rear-vision system developed was within acceptable limits but the operator had to move his head, in addition to his eyes, to see the monitor.

5.2.3 Evaluation of operators' opinions

A questionnaire (Appendix 3) based on that of Mollenhauer *et al.*, (1997), who evaluated an advanced driver information system, was administered to the Bell Logger operators after they used the video rear-vision system for some days.

5.2.4 Operator field of view

The existing field of view of the operator out the side doors and the front window was not changed by the addition of the video monitor to the cab. The monitor did not obscure any windows. The field of view provided by the video rear-vision camera system to the operator was 36° vertically and 30° horizontally. The camera had no magnification. Figure 5.3 shows the colour image seen by the operator in the Bell Logger cab. Movement cues were also used by the operators to identify workers in the field of view. As usual, all workers wore high visibility clothing at all times while working on the skid site.

Figure 5.3 - Video still image from rear-view video monitor in cab of Bell Logger.

5.2.5 Activity recording and analysis

Movements of the Bell Logger and head movements of the operator were recorded in the same way as they were for the non-rear-vision camera condition (Section 4.2.3) with the addition of the head movement "glance at video monitor". A data field in the Excel database was created to identify the minute of observation in which each event occurred. In this way all data fields could be expressed as a rate per minute. All relevant data fields were checked for normality and the General Linear Models procedure of the SAS statistical package Version 8 was utilised. Type III sums of squares were used to fit the effects so that each effect was adjusted for all other effects (Freund and Littell, 1981). Therefore the operator effect has been fitted after the rear view effect, ie. the variation in "movements per minute" attributable to the operators has been fitted after the variation attributed to the rear view effect. Then the rear view effect fitted after the operator effect.

Glance direction and next Bell Logger movement

The sequence of glance direction and subsequent Bell Logger movement was investigated. The data field EVENT BEFORE was created (Table 4.6) to identify the event (known as "*previous event*") which occurred immediately before the Bell moved in the forward or reverse direction. The time elapsed between the *previous event* and the Bell moving forward or reverse was determined from the field ELAPSED (Table 5.1).

Table 5.1 - Sequence of Bell Logger movements and operator glance direction from the Excel file.

Direction	Time(s)	State	Elapsed	Event before
Forwards	14.54	F	3.13	FLeft
Back	16.95	B	2.41	BForwards
Forwards	21.01	F	4.06	FBack
Right	16.2	F	0.19	x
Back	25.14	B	3.94	BRight
Left	21.66	B	1.52	x
Forwards	29.18	F	2.52	FLeft
Back	32.04	B	2.86	BForwards
Forwards	35.6	F	3.56	FBack
Back	38.8	B	3.2	BForwards

5.3 Results

The results are a comparison of the No Rear Vision situation (none) detailed in Chapter 4 and the Rear Vision Video System Fitted (camera).

5.3.1 Questionnaire

The operators were very positive about the rear-vision video system (Figure 5.4). They thought the system useful and found it easy to get used to. Operator 1 stated he used it less going in reverse than did the other operators. None found the system distracting. All were neutral as to whether they "liked" using the camera system.

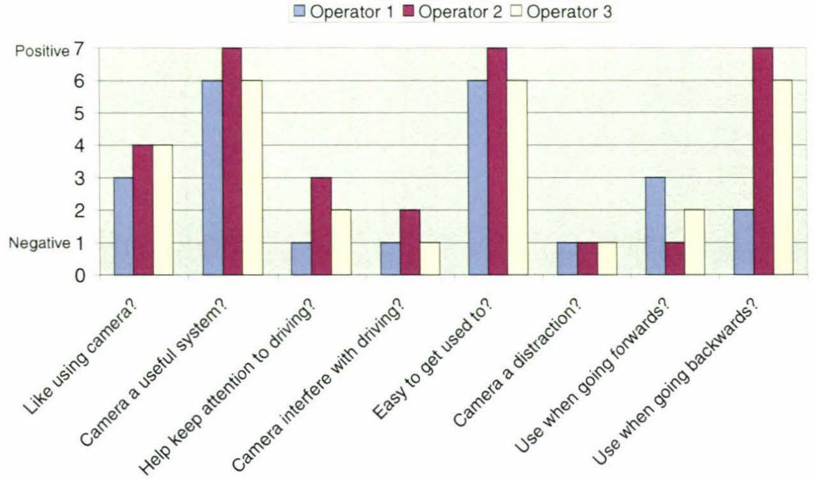


Figure 5.4 – Operator responses to the questionnaire asking their opinion of the video rear-view system.

5.3.2 Bell Logger movement

Fleeting logs was the predominant activity engaged in by the operators driving the Bell Logger.

Bell Logger time budget

Table 5.2 - Minutes engaged in each activity during observation.

Operator	Rear view	Delay	Fleet	Load	Other	Sweep	Travel	Total
1	None	0	42.9	0	0	3.4	0	46.4
	Camera	0	40.9	0	0	0	0	41.0
2	None	0	37.8	0	3.2	12.4	0.5	53.9
	Camera	0	54.6	0	0	0	1.4	56.0
3	None	0	42.8	12.0	0.5	0	1.6	56.9
	Camera	0.8	58.1	0	0.8	0	0.9	60.7

Table 5.3 - Proportion of observation time Bell Logger engaged in each activity.

Operator	Rear view	Delay	Fleet	Load	Other	Sweep	Travel	Total
1	None	0	93	0	0	7	0	100
	Camera	0	100	0	0	0	0	100
2	None	0	70	0	6	23	1	100
	Camera	0	97	0	0	0	3	100
3	None	0	75	21	1	0	3	100
	Camera	1	96	0	1	0	2	100

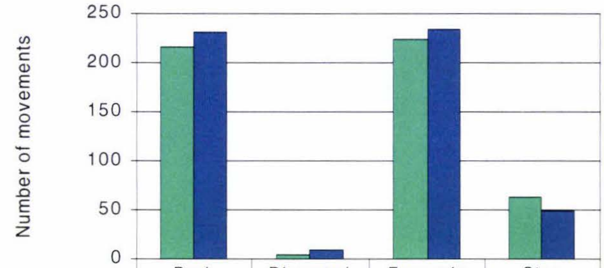
Fleeting analysis

To reiterate, fleeting is the task of picking up cut logs from the ground and carrying them to log stacks. Each stack is a particular grade of log and care must be taken not to place logs on the wrong stack. Since fleeting of logs was the main task of the Bell Logger, only data for events which occurred while the operator was fleeting logs will now be presented in the following sections. Other activities – delay, loading trucks, sweeping and travel and other are secondary activities which are not relevant to this study.

Bell Logger direction of movement while fleeting

Operator 1: No camera 42.9 minutes of observation

Camera 40.9 minutes of observation

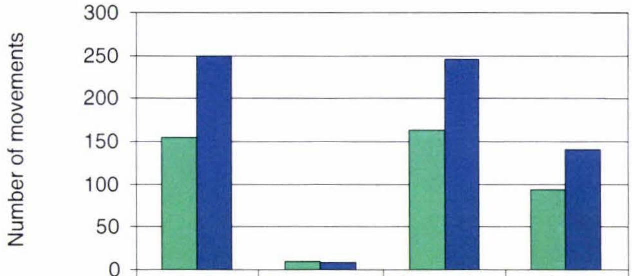


	Back	Disregard	Forwards	Stop
None	216	4	224	63
Camera	231	9	234	49

Direction of Bell Logger movement

Operator 2 No camera 37.8 minutes of observation

Camera 54.6 minutes of observation

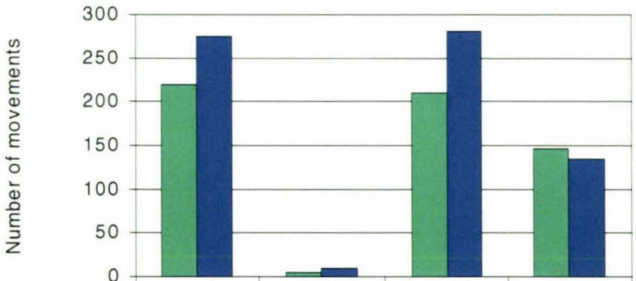


	Back	Disregard	Forwards	Stop
None	155	10	163	94
Camera	250	9	246	141

Direction of Bell Logger movement

Operator 3 No camera 42.8 minutes of observation

Camera 58.1 minutes of observation



	Back	Disregard	Forwards	Stop
None	220	5	210	147
Camera	275	10	281	134

Direction of Bell Logger movement

Figure 5.5 - Comparison of the number of Bell Logger movements without and with video rear vision for each operator during the task of fleeting.

Rate of Bell Logger movements per minute

However Figure 5.6 does not take into account the varying length of observation period between operators. Using rate of movement per minute more meaningful comparisons can be made.

Table 5.4 - Rate (per minute) of Bell Logger direction of movement.

Operator	Rear vision	Back	Disregard	Forward	Stop	Total
1	None	5.0	0.1	5.2	1.5	11.8
	Camera	5.6	0.2	5.7	1.2	12.8
2	None	4.1	0.3	4.3	2.5	11.2
	Camera	4.6	0.2	4.5	2.6	11.8
3	None	5.1	0.1	4.9	3.4	13.6
	Camera	4.7	0.2	4.8	2.3	12.0

Normal Bell Logger operation has a very fast cycle time. The Bell Logger had between 11.2 and 13.6 direction changes per minute, including stops. This equates to a direction change approximately every 5 seconds, including stops. Most cycles consisted of a forwards movement followed immediately by a reversing movement with no hesitation or "stop". Operator 1 had fewer stops per cycle than Operators 2 or Operator 3.

Table 5.5 - Least squares means (± se) of Bell movements per minute related to Bell operator and absence or presence of video rear-view system (interaction not significant at p<0.05).

Machine travel direction	Effect	Level	Movements per minute*	se	Significance
Forwards	Operator	1	5.50a	0.18	
		2	4.03b	0.17	
		3	4.09b	0.16	0.001
	Rear view	None	4.07a	0.14	
		Camera	5.01b	0.13	0.001
Backwards	Operator	1	5.39a	0.20	
		2	3.99b	0.19	
		3	4.13b	0.17	0.001
	Rear view	None	4.00a	0.16	
		Camera	5.01b	0.15	0.001

*Different letter suffixes indicate significant differences within an effect, p<0.05

Operator 1 drove the Bell Logger both forwards and backwards significantly more frequently per minute than Operators 2 and 3 ($p<0.001$, Table 5.5). However there was no significant variation in the frequency of stopping between the three operators with or without rear vision. With the rear-vision system installed all operators drove forwards and backwards more rapidly ($p<0.001$).

5.3.3 Operator glance direction for fleeting

An operator was considered to have glanced if he turned his head left or right and one of his helmet mounted ear muffs was obscured (42° from straight ahead). A glance at the rear-vision video monitor was identified by the operator peering directly at the cab mounted observation video camera which was mounted close to the monitor (Figure 5.2).

Table 5.6 - Count of the number of glances by direction for the task of fleeting.

Operator	Rear view	Left	Monitor	Right	Total
1	None	98	-	126	224
	Camera	97	66	79	242
2	None	73	-	69	142
	Camera	147	89	122	358
3	None	105	-	71	176
	Camera	184	73	130	387

Table 5.7 - Number of operator glances per minute during fleeting.

Operator	Rear view	Left	Monitor	Right	Total
1	None	2.3	-	2.9	5.2
	Camera	2.4	1.6	1.9	5.9
2	None	1.9	-	1.8	3.8
	Camera	2.7	1.6	2.2	6.6
3	None	2.5	-	1.7	4.1
	Camera	3.2	1.3	2.2	6.7

The task of operating a Bell Logger is visually demanding with the operator glancing left, right or at the monitor every 9 to 16 seconds. In a 7-hour work day the operator could move his head up to 2800 times.

Table 5.8 - Least squares means (± se) of Bell operator glances per minute related to operator and absence or presence of video rear-view system.

Glance direction	Effect	Level		Glances per minute*	se	Significance
Left	Operator	1		2.59a	0.17	
		2		2.29a	0.15	
		3		2.78a	0.15	0.06
	Rear view	None		2.26a	0.13	
		Camera		2.85b	0.12	0.001
Monitor	Operator	1		1.89a	0.39	
		2		1.68a	0.40	
		3		1.31a	0.36	ns
Right	Operator	1		2.61a	0.16	
		2		1.99b	0.15	
		3		1.88b	0.14	0.01
	Rear view	None		2.12a	0.12	
		Camera		2.20a	0.12	ns
	Interaction	Operator 1	None	2.95c	0.22	
		Operator 1	Camera	2.26b	0.24	
		Operator 2	None	1.77ab	0.23	
		Operator 2	Camera	2.22b	0.19	
		Operator 3	None	1.62a	0.21	
		Operator 3	Camera	2.13b	0.18	0.009

*Different letter suffixes indicate significant differences within an effect, $p<0.05$

There was no significant difference between operators in the frequency of glancing left or at the monitor. However, when glancing right, Operator 1 glanced more frequently ($p<0.01$) than other operators. With the rear-view system installed all operators glanced to the left more frequently than to the right ($p<0.001$, Table 5.8). There was no significant difference in the right glancing frequency with or without the rear-view system installed. The interaction between operator and rear view indicates the presence or absence of rear view resulted in a different pattern of glancing between operators. Operator 1 glanced more frequently to the right without rear vision ($p<0.05$). There was no significant difference for Operator 2. Operator 3 glanced more frequently to the right with rear vision ($p<0.05$).

5.3.4 Sequence analysis

Sequence analysis was used to understand the order of glance and Bell Logger movement events. In particular, where did the operator glance immediately before reversing.

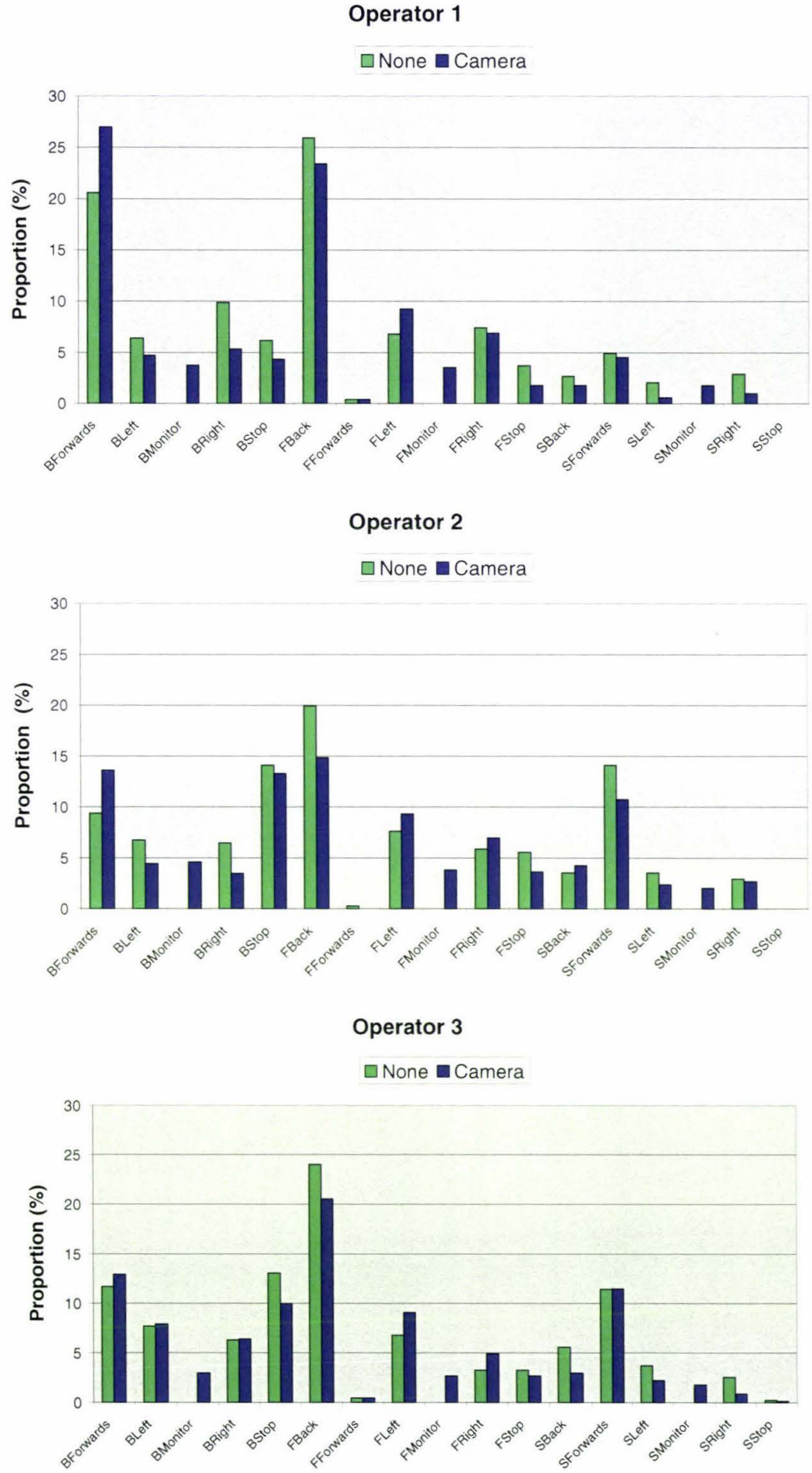


Figure 5.6 - Comparison of the proportion of each class of previous event and direction for fleeting. BForwards *means move forwards then reverse.* BLeft *means glance left then reverse.*

Operators 1 and 2 looked at the monitor before reversing (BMonitor) as frequently as they looked left (BLeft) and right (BRight) before reversing. Operators 1 and 2 tended to look left or right before reversing less when they had the camera system. Operator 3 did not reduce the proportion of glances to the left or right when using the camera compared with the non-camera condition and tended to use the monitor less.

Elapsed time between glance direction and Bell Logger movement

The time elapsed from glancing (left, right or at the monitor) and reversing the Bell Logger was measured from video records. Operators exhibited different styles in the speed of initiating a reversing manoeuvre after glancing (Figure 5.7).

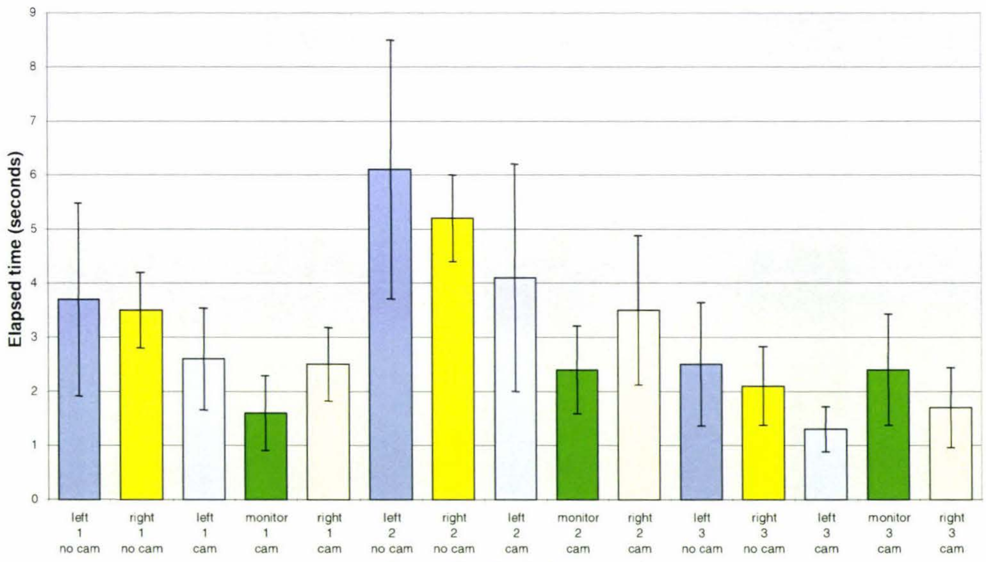


Figure 5.7 - Mean (± 95% confidence internal) elapsed time per minute between glancing left, right or at the rear-view monitor and reversing the Bell Logger with or without the rear-view video system for each operator.

For each operator there was no difference in the delay between glancing left or right and reversing. Without the rear-video system installed, Operator 3 was significantly faster at reversing after glancing left or right than Operator 2 ($p<0.05$) and tended to be faster than Operator 1.

With the rear-vision system installed there was a non-significant trend for Operators 1 and 2 to reverse sooner after glancing left or right than they did without rear vision. There was no difference between the operators in the time elapsed from glancing at the monitor and reversing.

Figure 5.8 - Skid workers in close proximity to the Bell Logger.

5.4 Discussion

5.4.1 Work environment

The work environment was unchanged from the non-camera situation. However, the other machine operators (driving trucks, loaders and utility vehicles) and skid workers on foot were aware the Bell operator now had some rear vision. There was no noticeable change in activities of these machines or workers. But their activities were not measured systematically to determine if there were changes in behaviour.

There were differences in activities between the non-camera and camera conditions. Operator 2 had a total of 12.4 minutes sweeping the skid site when the forwarder was delayed. Sweeping is done when time allows and reduces the opportunity of slip, trip and fall injuries on the landing (Parker *et al.*, 2003). Operator 3 had to load a waste-wood truck which took 12.0 minutes, as there was no other loader available that could handle short logs less than 3 m in length.

5.4.2 Questionnaire

The operators recognised the rear-view system as useful and easy to use. However, the most experienced operator stated that he did not use the camera very much when going backwards. He had a greater number of Bell Logger movements per minute than the other operators but had a non-significant trend of glancing at the monitor less than the other operators (Table 5.8). The operators did not find the monitor a distraction but this was not measured quantitatively (Jordan and Johnson, 1993).

5.4.3 Operator field of view

The field of view of the operator without the rear-view system was restricted in the forward direction and non-existent in the rear direction. The Bell Logger traveled in reverse frequently so many movements were made "blind".

The "effective field of view" of the operator was increased when using the rear-view system. When the operators glanced at the monitor they were effectively looking at a rear-view mirror.

5.4.4 Bell Logger movement

The Bell Logger was engaged in fleeting for 89 % of the total observation time. This is similar to other published Bell logger studies (Gleason and Stulen, 1984).

The raw observation data for the number of Bell Logger movements indicates that for all operators the number of forward movements is similar to the number of rear movements, within the rear-vision system case (Figure 5.5). This result is expected because the normal motion of the Bell Logger, in a cycle of picking up a log and repositioning it, is rapid forwards and backwards motions, rather than numerous forward positioning movements followed by reversal away from the log pickup point.

Table 5.4 presents Bell Logger movements as a rate per minute. In this way the effect of different observation periods is removed. The Bell Logger was moving forwards and backwards frequently, with a machine direction change approximately every five seconds when fleeting. The operators were fleeting for 89 % of the observation period. The operators confirmed (*pers comm.*) the observation period was representative of a normal day. In a seven-hour period of operation the Bell Logger would have changed direction approximately 4500 times, including stopping. At least a third of these direction changes will be in reverse where the operator risks collision with unseen objects or people.

A more systematic way to present the effects of operator and absence or presence of rear vision was to determine the variation in the rate of Bell Logger movement due to an operator effect and a rear vision effect (Table 5.5). The General Linear Models procedure of SAS was used to partition variation. The rate of forward movements per minute was significantly associated with both the operator effect and the rear vision effect. Operator 1 had a significantly higher rate of forward movements per minute than Operators 2 and 3. The presence of rear vision was associated with a significantly greater rate of forward movements. Similarly the rate of backwards movements was significantly associated with the operator effect and rear vision effect. Again Operator 1 was the fastest and rear vision was associated with more backwards movements per minute.

An unexpected result was that operators would drive forwards 20 % more frequently per minute with the rear-vision system. This may be because driving backwards is the rate-limiting step in Bell Logger operation. With a clear view behind the operator reverses more frequently which, of course, is associated with a subsequent forward movement. Results also showed a 20% increase in backwards movements with rear view from 4 reverses per minute to 5 per minute (Table 5.5).

Operator 1, the most experienced operator, changed direction more rapidly than Operators 2 and 3 ($p<0.05$) and was more "flowing" in his operation of the Bell. The only measure of this more flowing operating style is in the fewer times he bought the machine to a complete stop while fleeting (Table 5.4).

The direction of the Bell Logger was only recorded forward and backward. In reality the machine was often turning as it reversed, but because the average time between direction changes was so short, left or right turns could not be measured accurately. Discussion with operators revealed that turning while reversing was used to improve the field of view to the rear. This may be a useful measure of the change in operating style. Machines fitted with rear-vision systems may not be turned to the side as frequently. This information could be incorporated in a future study with some automation of the video transcription or the use of accelerometers

5.4.5 Operator glance direction

Raw data for the number of glances during the period of observation indicated the high level of vigilance exhibited by the operators (Table 5.6). In a total of 277 minutes of observation of fleeting the three operators glanced away from looking forwards a total of 1529 times, resulting in an average of 5.5 glances per minute. The operators had a high number of head movements although none reported pain in the neck or shoulders. A head movement was classified as a "glance" if one ear-muff was rotated from view. Each head movement was at least 42° from straight ahead to obscure the ear-muff. The variation in glancing rate between operators and the presence or absence of rear view can be seen in Table 5.7. Operators were glancing at the rear-view camera system 1.3 to 1.6 times per minute. This compares with a reversing rate of 4.6 to 5.6 times per minute when the camera system was fitted (Table 5.4). Approximately two out of every three reverse movements of the Bell Logger were undertaken without using the rear-view system. Discussion with operators revealed that they only used the camera when they were not sure what was behind the Bell Logger.

Least squares means of operator glance rate to the left, at the monitor or to the right were calculated (Table 5.8). With the rear-view system installed, two operators tended to glance to the left more frequently. This may have been because the television monitor was installed to the left of centre in the cab. It would have been convenient for the operator to look at the screen as his head moved to the left to glance out the left side door. The Bell Logger was changing direction more frequently with the rear-view system, but this is only reflected in the greater glancing frequency to the left. Glancing frequency to the right did not change significantly.

The introduction of the monitor added another place where the operator must look while working. This could be perceived as a second primary task, which is drawing his attention away from the task of looking through the front window while driving. The operator is either looking through the front window or looking at the monitor. Wickens (1980) describes this as 'resource competition' between the visual demands of the rear-vision monitor and the external driving scene. Fairclough, Ashby & Parkes (1993) assessed the 'visual cost' or 'distraction' of a symbolic in-vehicle display. They measured glance duration and glance frequency of 44 drivers with in-vehicle displays and found both were influenced by age, gender, and driving experience. They went on to describe a method to estimate the level of distraction to the driver. Unfortunately the method used only duration of glance and not frequency of glance. They concluded that glances away from the road of greater than two seconds (Zwahlen, Adams & DeBald, 1988) were unacceptable. Fairclough *et* *al.* (1993) distinguished between glance duration and glance frequency … "Average glance duration was sensitive to design. More glances do not make up for poor legibility." "Glance frequency represents the amount of visual activity in terms of visual checking behaviour. This visual checking may be carried out on the internal vehicle environment (i.e. monitoring speed via the dashboard) or the external driving environment (i.e. mirror checking)."

Location of monitor

The grapple of the boom situated 3 m in front of the operator is focused on when handling logs. The protective bars, some 40 to 50 cm in front of the operator, may also 'trap' the operator's eyes (O'Hare and Roscoe, 1990). To focus on the monitor, 35° below the line of sight and 65 cm away requires a quick change in accommodation. Seeser (1974), cited by Flannagan and Sivak (1993), suggests that loss of near accommodation with age would make it difficult for older operators to see the monitor's image clearly. Glare also may be a problem, particularly for the older operator. The eye must also adapt rapidly to the lower level of illumination of the monitor after the high levels of illumination in the outside view and vice-versa. The most experienced operator (48 years old) tended to use the rear-view camera system less (Table 5.8) and reported using the system less (Figure 5.4) than the other operators. Perhaps this was because it was difficult for him to see the image on the monitor.

5.4.6 Sequence analysis

The operator glances to ensure the way is clear before moving the Bell Logger. Using the Excel spreadsheet the event immediately before moving forwards or, more interestingly, reversing the Bell Logger can be identified, and the time elapsed between that event and moving forwards or reversing calculated.

The events and proportion of times that each type of event occurred immediately before reversing are presented in Figure 5.6. Immediately before reversing, Operator 1 would most frequently not glance but simply shift from moving forward to moving in reverse (FBack – reverse then move forwards).

Operator 1 may have glanced to the left or right while moving forwards, determined the way to be clear and then reversed. This could only be determined by more detailed Markov analysis where sequences of events are analysed (Martin and Bateson, 1987). The most obvious effect was the much greater proportion of time Operators 2 and 3 stopped before reversing compared with Operator 1 (BStop – Stop then reverse). This may be due to poorer dexterity with the grapple picking up logs.

The operators tended to show differences in the elapsed time between glancing and reversing (Figure 5.7). For each operator the elapsed time between glancing left and reversing or glancing right and reversing was not significantly different. However, there was variation between operators. Operator 3 moved the Bell Logger into the reverse direction more quickly after glancing that Operator 2 ($p<0.05$). When glancing left before reversing Operator 1 was not significantly faster or slower than Operators 2 and 3. The mean elapsed time for glancing left and then reversing for Operators 1 and 2 had large variation. However glances to the right showed much smaller variation for all operators, perhaps because the rear-vision monitor was mounted left of centre in the cab and they could glance at it while glancing to the left. Operator 2 was slower at initiating reversing after glancing to the right ($p<0.05$) than Operators 1 and 3.

Operator 1 tended to move the Bell Logger forward more rapidly after glancing than before reversing. Operator 2 had a similar trend with significantly ($p<0.05$) shorter elapsed time between glancing left and moving forward than glancing left and reversing. Between glances the operator is looking forward and can see most hazards that will be encountered when the Bell Logger moves forward.

The author could find no published literature which reported the analysis of sequences of visual activity (behaviour) in conjunction with vehicle movement activity. There is, however, a large literature reporting sequence analysis in animal and human behaviour (eg. Brown, Bakeman, Snyder, Fredrickson, Morgan & Hepler, 1975) which should be a valuable source of methods for the ergonomist.

5.5 Future work

Video rear vision is a valuable tool but will take some time to be fully accepted as part of conventional vehicle design. History has shown that the acceptance of rear-view technology is not immediate and is influenced by culture. The first recorded practical rear-view device for a vehicle was in 1911 when an American racing car driver added a novel feature to his car – a mirror (Bockelmann, 1991). The mirror replaced a passenger who was required, in racing cars, as a 'lookout'. Mirrors were first offered as an optional extra in passenger cars in 1914. Countries differ in their acceptance of rear-view mirrors. In the United States convex mirrors on passengers cars were not used before 1990 and were still prohibited from the interior and driver's side door (NHTSA, 1991 cited by Flannagan and Sivak, 1993). In contrast convex mirrors were common in Japan, England and Europe. A New Zealand example is the imported second-hand Japanese car. Many arrive with the external mirrors mounted on the fender whereas New Zealanders prefer the mirrors mounted on the doors. In fact, the Japanese placement of mirrors would make it easier for older drivers with poor near accommodation to use convex mirrors on the fenders of cars (Seeser, 1974 cited by Flannagan and Sivak, 1993).

Other areas of vision research have not been addressed in this project but could offer valuable insights to the problem of rear vision from a mobile machine.

Perceptual style

Some people are 'field – independent' and can more easily distinguish a complex target shape from its background. Others are 'field – dependent' and have more difficulty (Witkin, 1950 cited by Langham, 1998). Perhaps successful Bell Logger operators are field - independent and can focus on fleeting and driving while moving through the busy skid site full of fast changing visual scenes.

Mental workload

With the addition of a rear-view camera system, the addition of more visual information for the operator to attend to, may increase mental workload. The NASA Task Loading Index (TLX), an established subjective measure of mental workload, was used Jordan and Johnson (1993) to assess the effect of operating a car radio while driving. They concluded the TLX was useful in discriminating the mental workload change due to operating a car radio while driving. It could be used with Bell Logger operators. However, the TLX requires the introduction of an artificial secondary task for the operator. The objective measures used in this thesis may be superior.

Wide angle lenses and magnification

Van Erp and Padmos (1998) investigated driving performance when the only forward view was through a camera-monitor system. They found best overall performance was with 100° horizontal field size (compared with 50°) and no magnification (magnification of 1) compared with magnification of 0.5. The lens used in the Bell Logger for rear view did not magnify and had a horizontal view of 30° and a vertical view of 36°. Other magnifications and fields of view may be more suitable for rear view.

Location of the camera

The study by van Erp and Padmos (1998) reported that subjects used portions of the vehicle in camera view as a reference when manoeuvring. "A standard rule for rear-view mirrors is to have part of the vehicle in view for self reference (the operator-vehicle unit is an expanded self)" (Owen, *pers. comm.*).The camera mounted on the Bell Logger did not have any part of the Bell Logger in view. Perhaps relocating the camera to include part of the structure of the machine in camera view would aid in manoeuvring.

5.6 Conclusions

The introduction of a video rear-view system resulted in changes in driving activity and glance behaviour of the three operators. The Bell Logger was driven 20 % faster (forwards and backwards movements) with the rear-view system. It appears that operators use the rear-view system to ensure the path behind is clear, then glance to the left or right and then reverse. This effect could be identified with further sequential analysis of the data.

Improvements to the design of the study which could be incorporated in future data collection include: a repeatable fleeting task, an automated method to record Bell Logger movement and head movements, an eye tracking device, a formal questionnaire of operators' attitudes to vision from the cab with and without a rear vision system and of course a larger sample size.

The obvious solution to reducing the risk of injury from reversing machines is to eliminate all workers on foot from the vicinity of the machine. However other machines and obstacles (logs, holes in the ground, banks of earth) still exist and can set the occasion for collisions. Rear vision is useful, even if there are no workers nearby.

This study has achieved the aims stated in Section 1.3.

1. Mobile machine related injuries on the skid site are a significant problem resulting in 1304 lost work days in the period 1995 to 2002.
2. The normal operational environment of the Bell logger operator is characterised by frequent machine changes in direction (eight to 10 per minute) and frequent head movements (four to five per minute) to see if the way is clear.
3. Results of this study indicate that the rear-vision camera system appears to have potential as a valuable addition to the Bell Logger operating under typical New Zealand forestry conditions and resulted in a 20% increase in Bell Logger activity.

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APPENDIX 1 - Logging terminology

(Based on Spiers, 1985)

Term	Definition
Bell Logger	A versatile 3 wheeled logging machine
Breaker out	Worker who connects stems or logs to a hauling rope
Breaking out	1. Initial movement of the stem from felled position when hauled.
	2. Operation of a breaker out
Bunch	Assemble stem or logs to form a load
Cable logging	Hauling system employing a stationary winch to pull stems to a skid site or landing
Clearfell	To cut down and extract an entire area of forest
Contractor	Independent business owner engaged to fell trees and extract stems
Delimb	Trim branches off a tree, stem or log
Drag	Stems or log bunched and hauled to a skid site
Faller	Person who cuts down trees
Fleeting	Positioning stems and logs by machine in preparation for a subsequent action
Ground based logging	Use of tractors or skidders to extract stems
Hauler	Machine equipped with winches and ropes to haul stems in steep terrain
Limb	Branch
Log making	Person who assesses stems for quality features and marks where logs should be cut
Logging	Harvesting timber from a forest

Operator	Person who operates or drives a machine. May drive the machine to a location then operate a tool fitted to the machine such as a log handling grapple
Skid site	A prepared area where logs are cut from stems and sorted and stacked. Also known as a landing.
Skid worker	Person who works on a skid site
Skidder	Four wheel drive tractor with a winch to haul stems to the skid site
Skiddy	Skid worker
Stem	Felled tree
Tractor	Caterpillar tracked "bulldozer"
Tree	Standing tree
Trimming	To cut limbs or branches from a tree, stem or log

APPENDIX 2 - Informed consent

INFORMATION SHEET

Researcher:
Richard Parker
Liz Ashby

Contact address
COHFE
Sala Street
Private Bag 3020
Rotorua

[redacted]

Study Objectives

There has been discussion about the need for rear vision for Bell Logger operators. The effect of introducing a rear vision video system to the Bell Logger has not been measured.

This study will be comparing Bell Logger operators, with and without the rear view video system. We will record the time taken to perform actions which are part of the Bell logger operation process and record the occurrence of Bell Logger movements and operator head movements. The study will last for two sessions of one hour each.

At the end of the study we will be able to make comparisons between the two methods.

If you agree to participate in the study we will ask you to

- Continue driving task following normal working rates and methods as far as possible
- Answer our questions about discomfort and fatigue and questions on your opinions on the camera system
- Allow researchers to video or photograph you as you work

PLEASE NOTE:

- Your are free to ask questions regarding the study, at any stage
- The information provided by you is confidential to the researchers
- All information will remain anonymous
- You may refuse to answer any questions or withdraw from the study at any stage, without having to give an explanation, and without any disadvantage to yourself

COHFE
Centre for Human Factors and Ergonomics

Field test of reversing video camera

The purpose of this field test is to investigate the practical design of a machine mounted video camera for operator rear vision.

The camera does not offer complete protection of the machine operator or people working around that machine.

The current design may increase the chance of the operator being distracted by display screen in the cab.

I understand that video system is experimental and I must use care and vigilance when using it.

____________________ ____________________

Bell Operator (signature & date)

____________________ ____________________

Researcher (signature & date)

APPENDIX 3 - Operator questionnaire

BELL OPERATOR QUESTIONNAIRE

1. How much did you like using the rear camera?

   (not at all) 1___2___3___4___5___6___7 (very much)

2. Overall, how useful was the rear camera for your driving?

   (not useful at all) 1___2___3___4___5___6___7 (very useful)

3. How much did the rear camera help you pay attention to your driving?

   (not at all) 1___2___3___4___5___6___7 (very much)

4. How much did the rear camera interfere with your driving?

   (not at all) 1___2___3___4___5___6___7 (very much)

5. Was it easy to get used to using the rear camera?

   (not easy at all) 1___2___3___4___5___6___7 (very easy)

6. How much did the rear camera distract you from your driving?

   (not at all) 1___2___3___4___5___6___7 (very much)

7. What situations did you use the rear camera?

   ____

   ____

   ____

   ____

8. Did you look at the TV when driving forwards?

   (not at all) 1___2___3___4___5___6___7 (very much)

9. Did you look at the TV when driving backwards?

(not at all) 1___2___3___4___5___6___7 (very much)

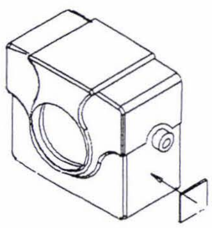
THANK YOU

APPENDIX 4 - Rear vision system used in study

USER PASSPORT

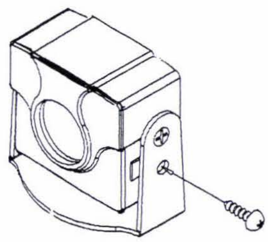
15-CG25M Ultra Mini Hardwire Mirror Type Color Camera

1. Overview:



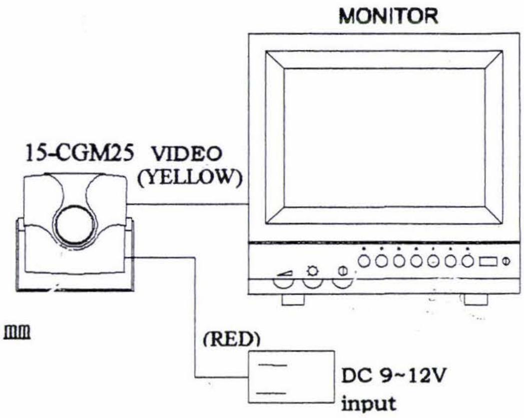
Gasket

(FIG 1)



Screw 2×5 ㎜

(FIG 2)



(FIG 3)

2. Caution for Installation

2.1 According fig1 and fig2, screw on the attached gasket & screw to avoid picture moving by vibration.
2.2 Avoid places where there is direct sunlight.
2.3 Be careful, never let any water in this equipment.
2.4 Do not directly touch the CCD element. If necessary, use a soft cloth moistened with alcohol to wipe off the dust.
2.5 Avoid places where temperatures exceed 50 °C or more.
2.6 Please input power DC 9~ 12V.
2.7 When any abnormalities occur, make sure to unplug the unit and contact your local dealer.

3. Packing

3.1	15-CG25M Camera	× 1
3.2	User Manual	× 1
3.3	Screw 3.0×20mm	× 2
3.4	Screw 2.0×5mm	× 2
3.5	Plastic-Conical-Anchor	× 2
3.6	Power + Video Signal Cable	× 1
3.7	6M Extended Video Cable	× 1
3.8	Gasket	× 2

4. Specification

ITEMS		15-CG25M
TYPE		COLOR
PICK UP DEVICE		1/4" CCD IMAGE SENSOR
PICTURE ELEMENTS		NTSC:512 H×492 V- PAL: 512 H×582 V
HORIZONTAL RESOLUTION		330 Lines
MINI ILLUMINATION		2 Lux
HORIZ. SYNC. FREQUENCY		NTSC: 15.734 kHz – PAL: 15.625 kHz
VERTICAL FREQUENCY		NTSC: 60 HZ – PAL: 50 HZ
CLOCK FREQUENCY		NTSC: 19.0699 MHz – PAL: 18.9375 MHz
SCANNING SYSTEM		2:1 INTER LACE
S/N RATIO		46 dB
ELECTRONIC SHUTTER		NTSC:1/60~1/96,000 sec – PAL: 1/50~1/96,000 sec
LENS		1.78 ㎜/ F:2.0
MIRROR		YES
GAMMA		0.45
DIMESIONS	L×W×H mm	27× 39× 36
WEIGHT	g.	62
VIDEO OUTPUT		1 V p-p, 75 Ohms
POWER SUPPLY		9~12VDC
POWERCONSUMPTION		160 mA
STORAGE TEMPERATURE		-30℃~60℃
OPERATION TEMPERATURE		-10℃~45℃

APPENDIX 5 Commercial video rear vision system

MITSUBISHI ELECTRIC

MITSUBISHI

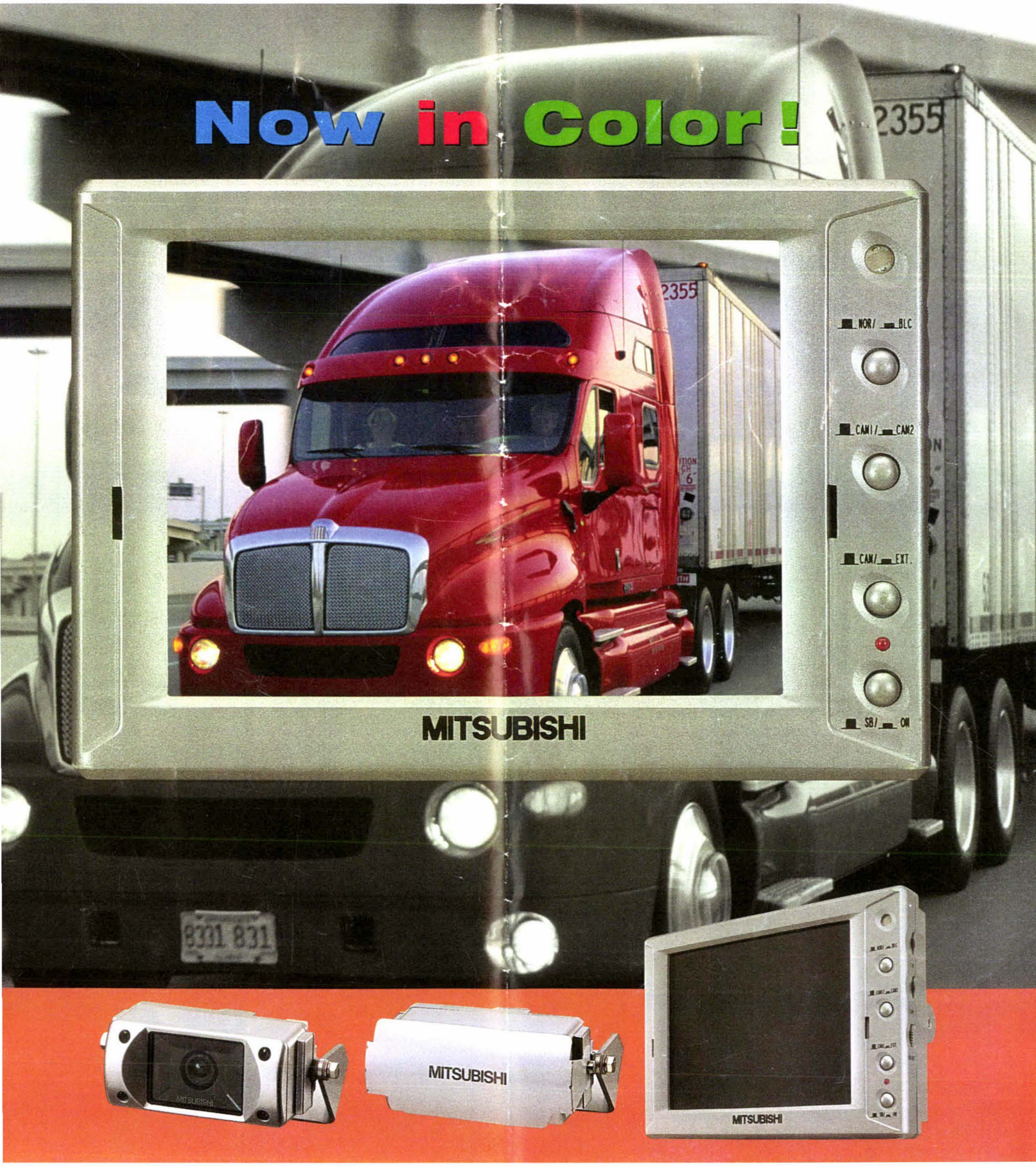
REAR-VIEW MONITOR & CAMERA SYSTEM

ISO 14001 EC 98J1014 1998.6.22

ISO 9001 JQA-1522 1996.12.27

CAR VISION

Clear color images and an extra-wide field of view make reversing safer than ever.
Car Vision packs great functionality in an easy-to-use body.



Superior color imaging over a wide area in a tough, compact body.

Easy-to-read TFT color image

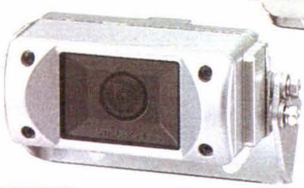
The large-screen, 6.8" color monitor is a liquid-crystal TFT with clear, high-resolution images. And while perspective was hard to judge on monochrome monitors, this color screen makes it easy to gauge distances. For even greater safety, dots on the on-screen display show the distance between people or objects and the rear of the vehicle.

Easy-to-install, purpose-built monitor

The simple camera and monitor system is easy to install. The camera body is encased in metal, making it tough and resilient to the elements.

PAL/NTSC dual-system monitor

The dual-system monitor accepts either PAL or NTSC camera signals.



C-4050
(with shutter)

COLOR TYPE

1/4-inch color CCD camera

C-4000/4100 *1 *1: C-4100 is PAL

C-0405
(with shutter)

MONOCROME TYPE

1/3-inch CCD camera

C-0400

MONOCROME TYPE

1/3-inch CCD camera

C-0300

COLOR TYPE

6.8-inch color monitor

CM-7000 *2 *2: PAL and NTSC dual-system

MONOCROME TYPE

4.5-inch monochrome monitor

M-0400

MONOCROME TYPE

6-inch monochrome monitor

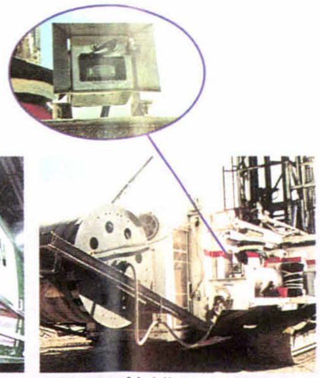
M-0600

Installation Examples

Camera installation examples

Garbage truck

Garbage truck



Mobile crane

Mobile home

Road sweeper

Bulldozer

Dump truck

Tough, waterproof body stands up to 100G

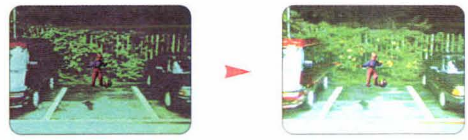
The camera is housed in a durable diecast aluminum body. It's unshakeable even on bad roads in the worst conditions, and withstands even high-pressure water jets.

Tough, shakeproof and waterproof body

The camera's diecast body is incredibly tough and durable. It withstands up to 100G of pressure and temperature ranges from -15°C to 50°C.

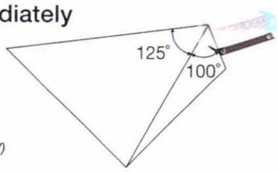
High-sensitivity color camera for clear images

The high-sensitivity color CCD-type camera ensures images stay clear even in dim light conditions. Night reversing is safer too.



Extra-wide field of view for greater safety

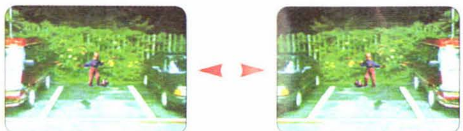
This ultra safe wide-angle camera *(125° horizontal and 100° vertical) covers the entire blind spot. It delivers a clear, wide view from immediately behind the rear bumper to the far distance.



**Monochrome camera only. (Color camera: 118°H & 85°V)*

Actual/mirror image switch

You can also switch between the actual image and the mirror image. This allows safety checks of the rear, the front, even the interior of the vehicle.



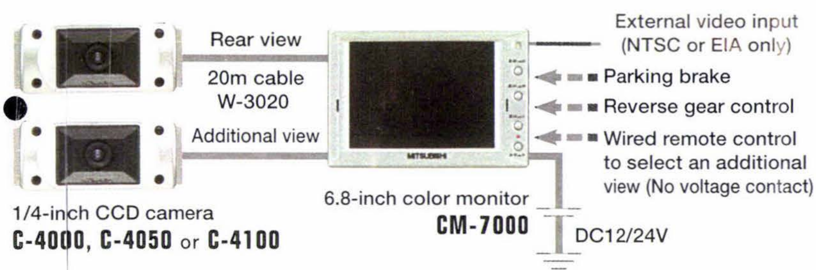
Actual Mirror

Super compact design fits even small vehicles

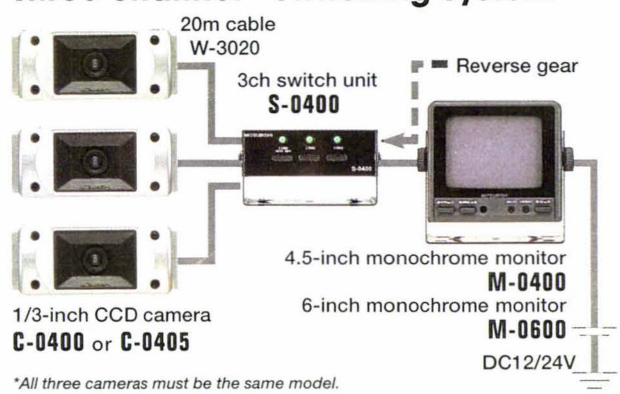
At just 85 x 40 x 50mm, the super compact camera body is ideal for vehicles large and small. It provides an eye on the blind spots behind any vehicle.

Car Vision Installation Examples

Two-channel color system with external video input

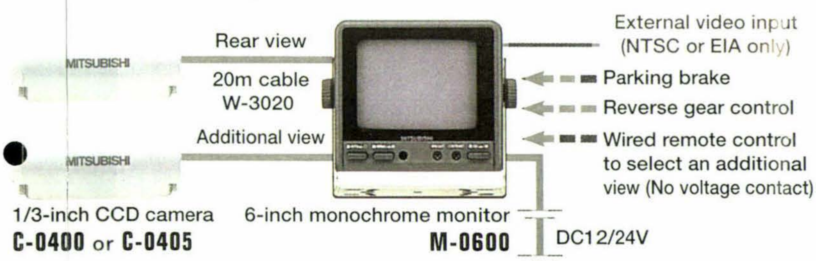


Three-channel* switching system

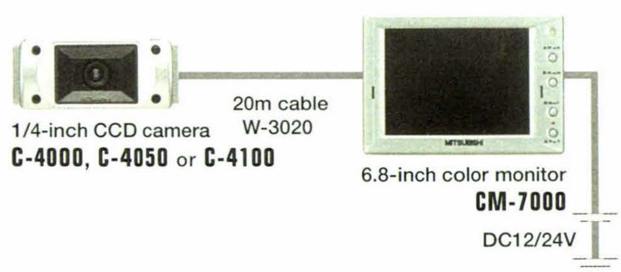


**All three cameras must be the same model.*

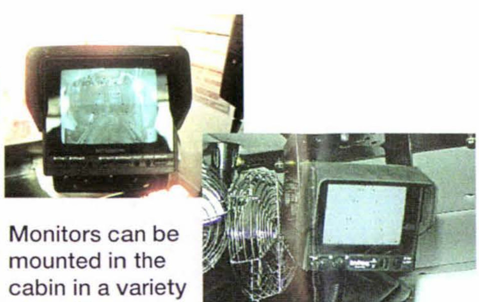
Two-channel system with external video input



Standard color camera system



Monitor installation examples



Monitors can be mounted in the cabin in a variety of positions.

Car Vision monitor and operation pad.

The monitor can also be custom installed into the dashboard as above.

Camera and Monitor Specifications

Color camera

	C-4100	C-4000	C-4050
Signal type	PAL	NTSC	
Imaging element	1/4-inch CCD (512H x 582V)	1/4-inch CCD (512H x492V)	
Lens	f=1.9mm, F=2.0 (horizontal approx. 118°, vertical approx. 85°)		
External dimensions (WxHxD)	85 x 40 x 55mm (main unit only)	85 x 40 x 55mm (main unit only)	85 x 40.6 x 57mm (main unit only)
Weight	Approx. 250g (main unit only)	Approx. 250g (main unit only)	Approx. 310g (main unit only)
Waterproofing standard	JIS D 0203 rank S2 (corresponds to 60kg/cm high-pressure wash jet)		
Color	Metallic silver		

Monochrome camera

	C-0400	C-0405	C-0300
Imaging element	1/3-inch CCD (512H x 492V)		
Lens	f=2.0mm, F=2.0 (horizontal approx. 125°, vertical approx. 100°)		f=2.5mm, F=2.6
External dimensions (WxHxD)	85 x 40 x 44mm (main unit only)	85 x 40.6 x 46mm (main unit only)	50 x 50 x 37.4mm (main unit only)
Weight	Approx. 160g (main unit only)	Approx. 220g (main unit only)	Approx. 140g (main unit only)
Waterproofing standard	JIS D 0203 rank S2 (corresponds to 60kg/cm high-pressure wash jet)		
Color	Metallic silver		

Color & Monochrome monitor

	CM-7000	M-0400	M-0600
CRT	6.8-inch color TFT	4.5-inch monochrome CRT	6-inch monochrome CRT
Functions	PAL and NTSC Dual system, 2-Camera switching, Distance indicator, External video input terminal/output, Auto brightness control	Brightness switch (Auto/Day), Power switch (Auto SB/Continuous ON), Exposure Supplement switch	Brightness switch (Auto/Day), Power switch (Auto SB/Continuous ON), Exposure supplement switch, 2-Camera switching, External video input terminal
Dimensions (WxHxD)	195 x 138 x 57.3mm (main unit only)	127 x 118 x 154mm (main unit only)	158 x 139 x 192mm (main unit only)
Weight	Approx. 1.0kg (exc. mounting bracket)	Approx. 1.0kg (inc. mounting bracket)	Approx. 2.0kg (inc. mounting bracket)
Color	Metallic silver	Dark grey	

Overall rating

Power supply	DC 12 / 24V
Operating luminance	Monochrome 0.3 ~ 100,000lux/Color 1.0 ~ 100,000lux
Usable temperature range	Monochrome -15 ~ +50°C/Color 0 ~ +50°C
Vibration and shock (Monitor & other equipment)	JIS D1601 step 4 (4.5G)
Vibration and shock (Camera)	JIS D1601 step 9 (9G)

Cable for Car Vision

W-3023	23m cable
W-3020	20m cable
W-3015	15m cable
W-3012	12m cable
W-3008	8m cable
W-3004R	Waterproof cable (4m)

Optional units

3-Camera switching unit / S-0400

Applicable camera	C-0400 / C-0405
Applicable monitor	M-0400 / M-0600
Camera input	Maximum 3 channel (Din connector)
Reverse gear detection	To select the REAR VIEW
LED indicator	Light up which camera is selected now.
External dimensions (WxHxD)	100 x 35 x 120mm (main unit only)
Weight	Approx. 200g

Power adapter / P-0400

Applicable camera	C-0300 / C-0400 / C-0405 / C-4000 / C-4050 / C-4100
Video output terminal	1.0Vp-p/75ohm (RCA PIN)
External dimensions (WxHxD)	52.4 x 32.2 x 88mm (main unit only)
Weight	Approx. 150g

Model for the EEC type-approval mark

Approval Number	Model Name
e11 020147	C-0400, C-0405, M-0400
e11 020183	M-0600
e11 020184	C-0300
e11 020329	C-4100, P-0400
e11 020184	S-0400
Pending	CM-7000

MITSUBISHI ELECTRIC CORPORATION
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Specifications subject to change without notice.

APPENDIX 6 - Bell Logger in motion

.AVI file of Bell Logger fleeting logs.

To view:

place disk in computer drive

locate disk in file directory

double click on Bell2b.avi file

APPENDIX 7 – Reports written from this work

1. Bentley, T.A. & Parker, R.J. 2001. Injuries to loggers during skid work: An exploratory analysis of New Zealand forest industry injury data. *Journal of Health and Safety, Australia and New Zealand* 17, 391-399.

2. Caughley, A.; Parker, R.J. & Ashby, L. 2001. *Intelligent rear vision video for forestry vehicles*. Proceedings of the 10th Conference of the New Zealand Ergonomics Society. 26th & 27th July, 2001. Rotorua. 91-94.

3. Parker R.J. & Bentley, T. 2000. Skid work injuries 1995 – 1999. *COHFE Report* Vol. 1, No. 4.

4. Parker, R.J.; Ashby, L.; Legg, S.L. & Bentley, T.A. 2002. *Video rear vision and driving behaviour of Bell Logger operators*. Proceedings of the 11th Conference of the New Zealand Ergonomics Society. 14th & 15th November, 2002. Wellington. 87-92.

5. Parker, R.J.; Ashby, L.; Legg, S.L. 2002. *Evaluation of video rear vision for forestry log handling machine operators*. Proceedings of the International Seminar on New Roles of Plantation Forestry Requiring Appropriate Tending and Harvesting Operations. 29th September to 5th October, 2002. Tokyo. 369-375.