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Theme: Harvesting

Task No: F20010
Milestone Number: 2.10.01

Report No. FFR - H006

Advanced Hauler Vision System: A Feasibility Study

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Date: 30 June 2011

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EXECUTIVE SUMMARY

The primary goal of the FFR Harvesting Theme is to reduce the cost of harvesting on steep country by introducing new technology that is more productive and cost effective than existing equipment. The secondary goal is to remove workers from the hazardous tasks of manual tree felling, breaking out and unhooking. The specific aim of this project (Task 2.1) is to provide better vision for the hauler operator in order to improve the grapple/carriage positioning and loading element times of the hauling cycle. These aims will be achieved by developing a video camera, communication and display system for use in a swing yarder operation.

Video information is used in a variety of other industries, including security and surveillance, mining and precision agriculture. Forest harvesting is not so different from mining in terms of the harshness of the environment, and computer technology is in common use in mechanised processing, so there is a precedent for the field use of sophisticated equipment. Video equipment is routinely mounted on machinery to aid the driver or a remote operator, but remote-display, battery-operated video camera systems with zoom capability are less common outside military applications.

This report describes a feasibility study which addresses the development of a camera system for grapple extraction by swing yarder. The proposed forest harvesting video system includes a remote zoom-capable camera that will supplement one or two machine-mounted cameras.

The economic analysis of a swing yarder application showed (on the basis of some reasonable assumptions, including a relatively small reduction in average grapple time of 14%) a substantial increase of almost 4% in overall hauler productivity could be expected as a result of using a camera system. With estimated maximum capital expenditure of $25,000 over an expected 12-month life (with no resale value), the annual costs of the proposed camera system amounted to less than 1.5% of the annual total logging system cost. A cost benefit analysis showed this productivity improvement would translate to a decrease in the effective logging rate of about one dollar per tonne of wood produced. Given these costs and benefits the break even usage rate for the camera system would be 35% of total productive time.

INTRODUCTION

Reducing the cost and improving the safety of steep country harvesting has been identified as a priority by the New Zealand forest industry. The primary purpose of the FFR Primary Growth Partnership (PGP) programme, “Innovative Harvesting Solutions” is to reduce the cost of harvesting on steep country by introducing new technology that is more productive and cost effective than existing equipment. The secondary goal is to remove workers from the hazardous tasks of manual tree felling, breaking out and unhooking.

The Programme has been divided into three interrelated Objectives:

1. Mechanisation on steep terrain.
2. Increased productivity of cable extraction.
3. Development of operational efficiencies.

The purpose of Objective Two of the programme is to increase productivity of cable extraction to reduce the cost of cable harvesting in three ways: better vision for hauler operators (Task 2.1); improving grapple control (Task 2.2); and developing an innovative yarding system (Task 2.3). The specific aim of this project (Task 2.2) is to improve the visibility to the hauler operator of the grapple/carriage and breaking out operation in order to improve grapple/carriage positioning and grapple loading time. These aims will be achieved by developing a video camera, communication and display system for use with a swing yarder.

This report describes a feasibility study carried out to investigate the economic and technical feasibility of the technological solution, namely an advanced hauler vision system for grapple swing yarder operations.

METHODS

Engineering developments often follow five distinct stages:

1. **Feasibility** – brainstorming what's out there that we can adapt and development of concepts.

2. **Simulation –** computer modelling to test if it can deliver the expected benefits, identify the flaws, and develop some very early stage prototype.

3. **Alpha prototype –** development of a lab prototype to test the concept and develop the specifications for a working model.

4. **Beta prototype** – development of a working prototype that can be field tested under carefully monitored conditions and used as the basis for a commercial design.

5. **Commercialisation –** going from the Beta prototype to production of the commercial unit, and securing uptake of the unit by industry through technology transfer.

A feasibility study is an investigation into whether or not a proposed development is possible, and how successful it is likely to be[1]. Commonly there are four main feasibility criteria, typically covering technical, social, economic and operational aspects, but there may be other considerations depending on the nature of the project. In this feasibility study, titles and approach are based on comprehensive feasibility study guidelines issued by the US Department of Energy[2].

This report covers the feasibility and simulation stages (one and two) of the development process outlined above.

The feasibility study methodology used in this report is described by the following headings:

- Current systems and processes
- Description of an improved system
- Comparison of some alternative systems
- Assumptions and constraints
- Analysis of benefits and costs
- Potential markets and scale-up issues.

CURRENT SYSTEMS AND PROCESSES

Factors Influencing the Visual System

An investigation into the use of cameras to assist in grapple use needs to consider the effect of human physiological as well as operational aspects. These factors illustrate the need for aids such as cameras where there is strong reliance on effective eyesight. Human visual perception is influenced by many factors which can degrade (or enhance) performance. The main factors are: colour, glare, illumination, defective vision, fatigue and ageing. It is important to be aware of these factors when designing a vision intensive system such as grapple control which relies almost entirely on visual information input.

Light Source Properties

The efficiency of the human eye is greatest under normal sunlight (a mixture of wavelengths). However if the surface is coloured 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. Similarly, brown stems with intact bark may be difficult to see against the soil on the cutover.

Glare

Glare overloads the light adaptation mechanism of the eye and can be affected by age and nutritional factors[3]. 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. Patches of sunlit and shady areas on the cutover can make it difficult to see stems and grapple them.

Illumination

The eye is more sensitive to change at high illumination levels, so visual performance is improved by increasing illumination[4]. However, too much illumination overloads the visual system, causing glare. For example, grappling is made difficult if the operator must look into the sun to see stems on the cutover.

Defective Vision and Fatigue

Accuracy (performance) of the human visual system is reduced due to short and long sightedness, colour deficiencies, photophobia, night blindness, field defects and double vision [3] [4] [5]. The 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. Trying to focus on the grapple at long range can tire the eyes.

Ageing

Grapple yarder operators may be older members of the crew because of the logging experience required and lower physical demands of machine operating than other logging tasks.

There are a number of effects of ageing which degrade the accurate operation of the human visual system: the lens hardens; muscles controlling the diameter of the pupil weaken reducing both the speed and range of accommodation to changing illumination levels; 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, producing a "veiling luminance" [3, 5].

Camera and Display Technology

Camera systems are available off the shelf and many are designed for outside operation. Digital IP (Internet Protocol) video or CCTV cameras are becoming more common than the older analogue signal cameras.

Cameras can be fixed focus, vari-focal (manual zoom) or Pan Tilt Zoom (PTZ) type.

Fixed Focus Cameras

Dakota Micro (DM) manufactures the Agcam [6] line of robust video cameras for agricultural use. They can also be used with remote operation using their Ranch Hand 1.4 GHz wireless RT system. This camera system is used by Eagle carriages[7] in their Mega claw/Yoder claw grapples. These cameras are often mounted on vehicles.

Agcam prices – e.g., US$1,196 for a one-camera system with 9 inch screen (excluding Ranch Hand RT US$322 and antenna US$163).

Vari-Focal Lens Cameras

Figure 1: An Axis 5 MP P1347E Network camera (with a vari-focal lens)[8].

Vari-focal (manual zoom) cameras such as shown in Figure 1 are digital video cameras which often have limited optical zoom capability but also use digital zoom techniques. They are often used in conjunction with digital pan and tilt software (Pan-tilt-zoom, or PTZ) where the operator can select a portion of the image and enlarge it, viewing that segment as a separate window. Wireless IP PTZ systems in an outdoor environment might comprise:

- Digital cameras, including Dome cameras which incorporate PTZ functions[8] or PTZ mountings which require a separate camera and have their PTZ functions built in. [9]
- PTZ controller, a joystick and pad.
- WLAN hardware – including Access points, amplifier and antennas (2.4 or 5GHz).
- A monitor or display.

Pan-Tilt-Zoom (PTZ) Cameras

These digital cameras are more complex and are typically used in the security industry. They are often designed for exterior use and mounted on buildings. PTZ cameras can be either IP (Internet Protocol) or Analogue (Closed Circuit TV or CCTV) based. There seems to be a trend to the use of IP cameras. A wide range of zoom capabilities is available (up to 35x) and many are HDTV compatible. A recent feature is auto tracking which enables the camera to automatically follow movement within the camera's field of view. Many cameras are capable of providing vision under low light conditions. PTZ cameras used in the security industry are relatively inexpensive compared to military grade cameras such as those made by FLIR Systems Inc. [10].

IP cameras are also called webcams, but are mostly used for surveillance. IP cameras can be either centralised or decentralised. Centralised cameras use a central Network Video Recorder to handle recording and video management. Decentralised cameras can record directly to digital storage media such as flash drives. PTZ video cameras (Figure 2) have an established position in home and business security applications. Systems often work on wireless systems of 2.4 and 5.8 GHz.

Figure 2: A PTZ camera used in surveillance applications [8]

Night Vision Cameras (Thermal cameras, infra red cameras)

The use of thermal cameras might enable limited night operations where grapples are used. Thermal cameras are expensive, but are used extensively in some sections of the mining industry. Figure 3 shows an example of a combination Thermal/daylight camera unit. This model manufactured by FLIR Systems Inc.[10] features a Pan/Tilt/Zoom function (Price US$18,950).

Figure 3: A combination Thermal/daylight camera unit (Security HD Patrol Pro Thermal Vision - FLIR) [10]

Figure 4 illustrates the kind of display expected from a thermal camera.

Figure 4: FLIR Systems hand-held camera image (source: article.wn.com-FLIR)[10].

Displays

Displays can vary from the use of a small laptop or notebook computer to touch screen (such as the Apple i-Pad tablet or even Apple i-Phone). Any device using internet protocols could display video signals. The most commonly used displays are of the LCD (Liquid Crystal Display) type.

Communications Systems

Wireless communication systems for video signals and other data are generally known as WLAN systems (Wireless Local Area Network) and tend to fall into two bands that have been designated under IEEE standard 802.11, the latest version being 802.11n. [11] The 802.11b standard is also known as Wi-Fi (Wireless Fidelity), and the latest version, 802.11n has the advantages of wider bandwidth and faster data transmission rates than the earlier versions of 802.11a, b and g. Both 2.4 and 5.0 GHz bands are used for WLAN and fit well with digital IP cameras. Communication is dependent on line of sight between transmitter and receiver. Approximate transmission range quoted is 250m [11], but field studies have been carried out over distances of several kilometres [12]. Maximum ranges in the order of 50 km with directional antennas and specific transceivers are quoted in some manufacturers' literature[13].

Some Camera Systems and Applications

Video information via camera systems is now used to aid the positioning of machinery and attachments in many industries outside forestry, including mining, construction, aviation, security and surveillance, and precision agriculture. Video equipment is routinely mounted on machinery to aid the driver or a remote operator, but remote-display, battery-operated video camera systems with zoom capability are less common outside military applications.

Vehicles and Cranes

The Orlaco website[14] claimed that a study showed a 22% increase in tower crane operating speed with a qualified camera load view solution vs. a "blind" operation (Figure 5).

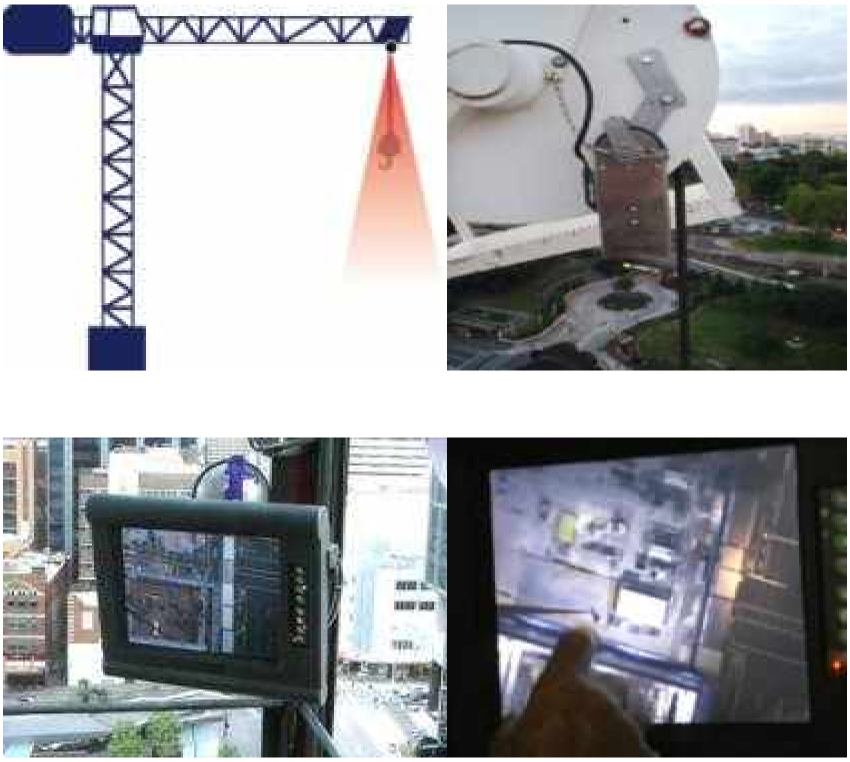

Figure 5: Orlaco Load view system on a Tower Crane [14]

Figure 6 shows some other vehicle applications for a camera system suggested by the Orlaco Company.

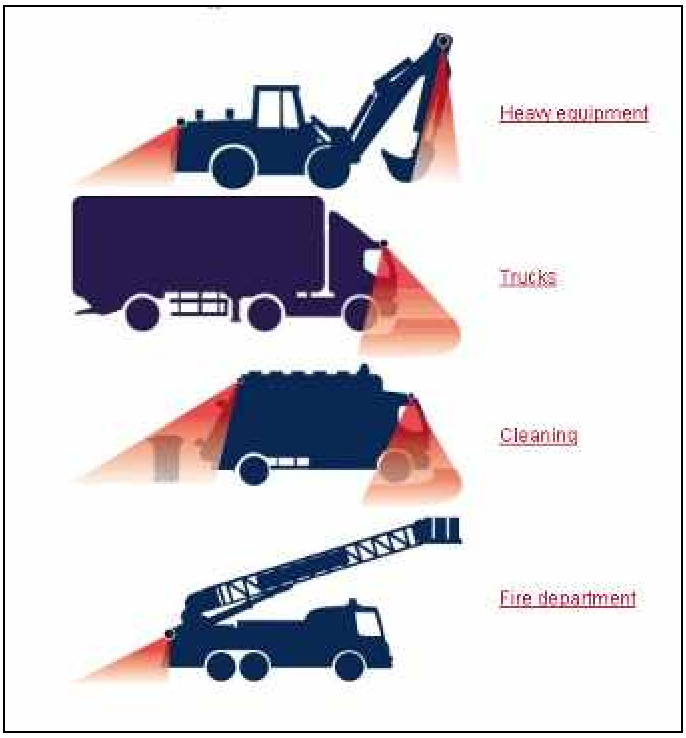

Figure 6: Other vehicle camera applications [14]

Closed circuit television (CCTV) systems are commonly used on heavy vehicles. The Exploration and Mining Group of the CSIRO have developed ‘Monster vision’ which is a CCTV camera mounted above the rear axle of dump trucks (Figure 7) proving a colour image to a television monitor in the truck cab.

Figure 7: Dump truck fitted with CSIRO “Eye in the Backside” rear-vision video camera system (N.B. operator is cleaning camera lens).

In an assessment of visibility aids for workplace vehicles, researchers from the Health and Safety Laboratory in Buxton, Derbyshire concluded that “CCTV appears set to become the norm as a vehicle visibility aid”. [15] 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 this earlier study 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[16].

Figure 8: Boeing 777 cockpit with ground manoeuvre camera system.

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 forward 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”[17]. The split-screen image shows the view from three cameras, one located beneath the forward fuselage to display the nose wheel, while two display the main landing gear wheels from mountings in the leading edge of the horizontal stabiliser at the rear of the aircraft (Figure 8).

Mining

There is established use of CCTV cameras, both white light and thermal imaging types, in open cast and underground mining operations.

In New Zealand, Solid Energy’s Stockton Alliance open cast coal mining operation has an application where a camera mounted by a conveyor provides an image to be seen by a haul truck operator on a display as the truck reverses up to the conveyor to be loaded. The image is only seen when the truck is in the vicinity of the camera. Transmission is by wireless network on 2.4GHz.

Precision Agriculture

Sensors and radio communications systems such as GPS have long been considered for use in agriculture. Wireless communication systems have been proposed[18, 19] and tested [12] in crop monitoring field studies. It has been proposed that Wireless Sensor Networks (WSN) could enable:

- Remote monitoring (e.g., of gauges and sensors)
- Remote control (e.g., of gates, valves and pumps)
- Information transfer (e.g., maps, weather vehicle locations)
- Communication (e.g., text, voice and video)

- Asset tracking
- Remote diagnosis.

In the future, systems that make use of a range of sensors will be known as WSN systems (Wireless Sensor Networks)[20]. These systems can also integrate video information. An example of a farm system is shown below in Figure 9.

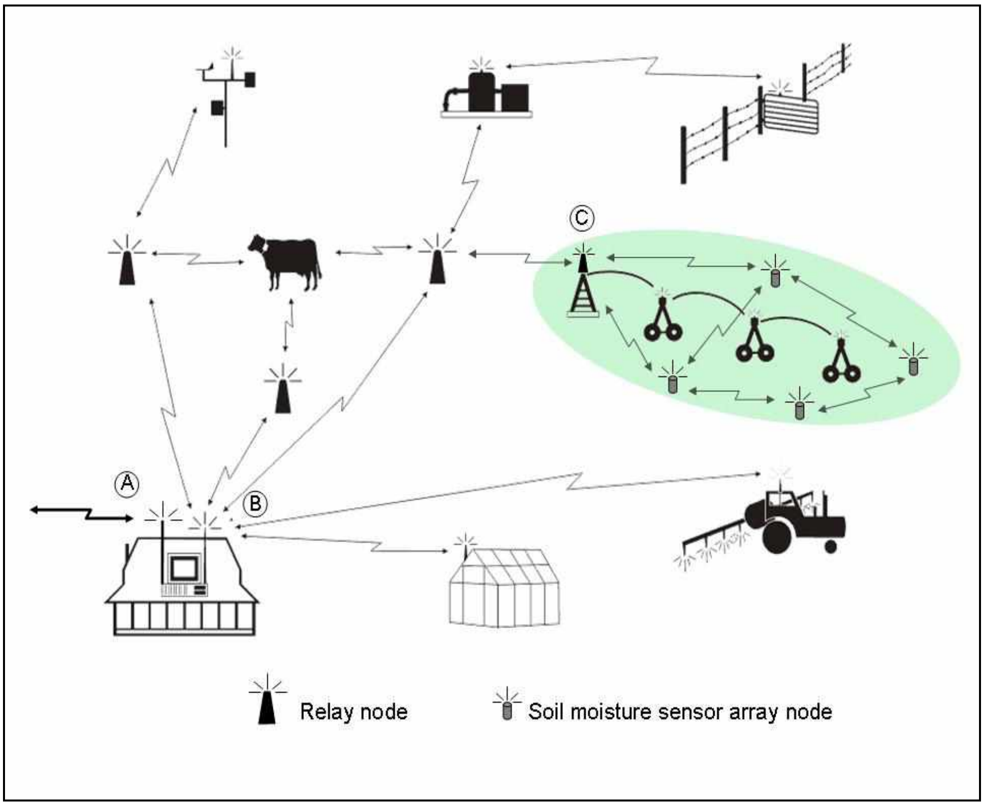

Figure 9: Schematic of a farm showing three nested levels of wireless networks [20].

Applications in the Logging Industry

Cameras have been tried in the past in logging operations with only partial success. With improvements in technology, camera systems have the potential to improve grapple yarding productivity.

Early Experiments with Vision Systems on a Grapple Swing Yarder

MacMillan Bloedel [21], a Canadian forestry company active in research and development, tested a trial camera system in the 1980s. A video camera (with display in the cab) was located in the cutover to enable the grapple yarding of a gully not visible to the operator (Figure 10). The hourly production rate for the test was nearly double that normally expected (58 logs vs. 30-35 logs per hour). Recent enquiries have suggested the system was not extensively used as no further records have been found.

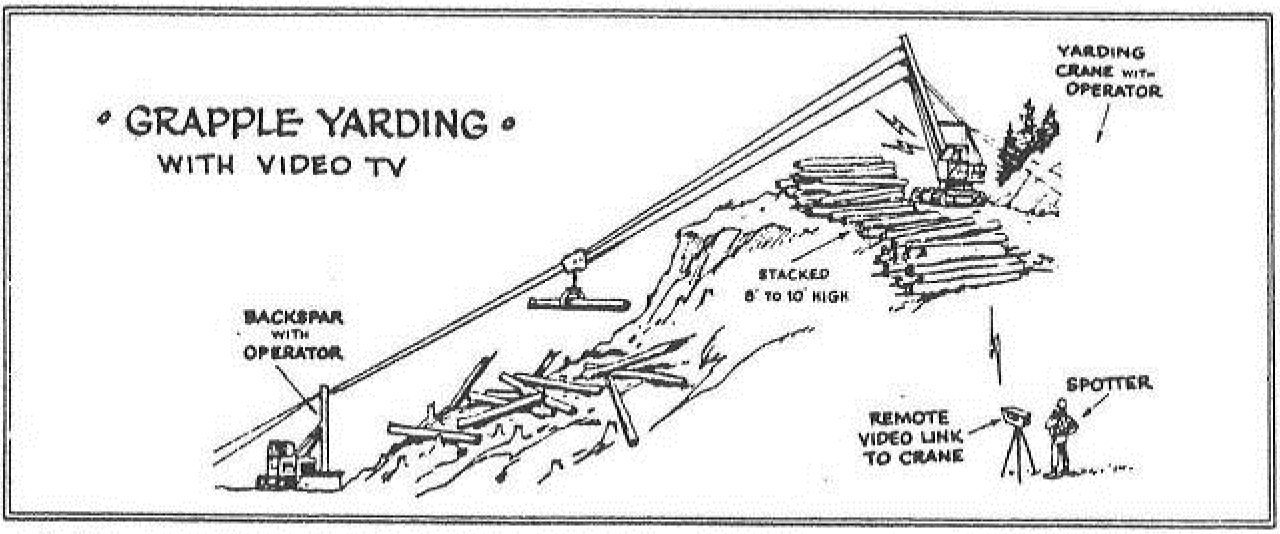

Figure 10: Illustration of early video system [21]

More Recent Developments: The Eagle Carriage

Figure 11: Mega Claw line grapple carriage (camera location shown) [7]

A recent development is a grapple carriage designed to operate on a live skyline (raised and lowered to grapple the drag), in a shotgun rigging configuration [7]. Eagle Carriage and Machine Inc. of La Grande, Oregon manufactures two hydraulically operated grapple carriages: the Yoder claw (817 kg) for light excavator yarders and Mega Claw Line Grapple (1270 kg) for swing yarders (Figure 11). These grapples have 360° rotation and the opening and closing functions are radio controlled. The hydraulic power is supplied by an accumulator which is charged during outhaul on the skyline. These grapple carriages open to 213 cm (84 inches) and can also function with chokers but are non-slackpulling. Because these grapples are on a live skyline they operate clear of the ground and do not have to be as ruggedly constructed as other non-slackpulling grapple carriages. Also these carriages are fitted with an AgCam camera[6] so that the yarder operator can view the trees being grappled. Yarder operators using these grapples have experienced some difficulty using the cameras to locate a tree while the carriage is in motion, due to camera shake or vibration. No studies or evaluations of these grapples could be found to indicate the success or otherwise of these grapples in operation.

Use of Cameras in Other Harvesting Machines

Video reversing cameras (non-wireless type) have been tested on a processor head with a view to helping a processor operator identify log sweep defects[22]. The trial showed that when the camera system was used (Figure 12), fewer reject logs (sweep–related) were produced, but a significant period of training was required to enable the operator to make full use of the video system.

Figure 12: Example of use of reversing cameras to give operator a view of stem shape.

A remotely guided felling machine, the Triton Sawfish[23], has been developed to fell trees underwater where they have been submerged in a lake as a result of dam construction. This device is guided by video camera in addition to GPS and sonar (Figure 13).

Figure 13: Graphic of Triton Sawfish underwater felling machine [23]

In Europe, Herzog-Forsttechnik [24] have used cameras on the Forcar forwarder to monitor the linefeed on the winch drum used to assist the mobility of the forwarder on steep slopes (Figure 14). A camera also monitors the line wrap on the winch drum (Figure 15).

Figure 14: Camera position (see arrow) on Forcar forwarder with Herzog winch.

Figure 15: Display of cable wrap on winch drum[24] .

DESCRIPTION OF AN IMPROVED SYSTEM

Forest harvesting is not so different from mining in terms of the harshness of the environment, and computer technology is in common use in mechanised processing, so there is a precedent for the field use of sophisticated equipment.

Good visibility of the breakout site for a hauler operator is important or advantageous for hauler operations (using either grapple or chokers) for a number of reasons:

1. For choker operations, visibility provides an additional factor of safety for the breaker out(s)
2. For grapple operations, visibility provides the means for an operator to help interpret a spotter's instructions. If a spotter is not used, visibility enables sufficient grapple control to enable a tree to be grappled successfully and extracted.

Without binocular aids, most human depth-of-field perception is limited to about 6 m; at greater distances, the brain compensates through estimating relative sizes of known objects.

In general, most tower operations do not use grapples. Grapples are more often used with swing yarders. In grapple yarding operations, visibility of the tree is critical to the productivity of the logging system. De Souza[25] identified a number of visibility problems in grapple yarding operations and grouped these into categories:

- cab design (cab location, window size and protection);
- environmental (ground, stand and climatic conditions); and
- operating (yarding distance and log size)

For these reasons, grapple swing yarders typically operate with the use of a spotter who calls instructions to the operator to guide the swing yarder operator (via VHF radio or "Talkie Tooter" signal) in controlling the grapple because of the reduced visibility of the target tree owing to:

- distance;
- lay of the land (intervening spurs or gullies);
- vegetation and/or slash; and
- other felled trees and branches.

Use of a spotter to grapple unseen (by the operator) or poorly visible trees (spotting) is a slower process than if the operator is able to see the grapple and the tree.[26]. Evidence suggests that this is largely because of a time delay between instructions and the effect of the operator's actions, as well as difficulties with communication of instructions.

In an extensive study of grapple yarding in British Columbia, Howard [27] determined that grapple time was positively, and significantly ($p>0.05$) correlated with distance. Using regression equations developed from the data, there was on average a 30% increase in grapple time when haul distance was increased from 150 metres to 200 m. This may have been a result of either communication issues with the use of spotters or a reflection of the operators' ability to discern target trees at longer distances. However, over distances shorter than 150 m there may be little measurable effect[7].

Discussions were held with several grapple yarder contractors/operators in New Zealand (contractors Kinney, Harvey, Hancox, Whyte, McCormack and Barnes). When asked to identify their biggest concerns, three of the six contractors noted the following issues relating to grapple yarding:

- Planning – unsuitable setting selection and landing location by company planners.
- Operational system – Grapple yarders work best in an unconstrained environment, e.g. piling trees in the chute or at roadside.
- Operator training – operator ability is seen as a key factor for yarder productivity. Operators learn "on the job".

- "Spotter" safety – this was identified as an issue when they are close to the grappling area.

Because of the above higher priority concerns, these contractors stated that the concept of video technology for reducing grapple loading time had not been seen as necessary or important. Three of the contractors (one Harvestline contractor and two of the swing yarder contractors) were more positive about the use of cameras. Although one contractor did not see an advantage for either a yarder or tail hold mounted camera (claiming that if the operator could see the tree, he could grapple it effectively, often without a spotter), all three were in favour of development of a cutover-based camera to provide vision when the operator could not see the trees to be grappled.

On the basis of this limited survey (6 contractors) there appears to be sufficient evidence of difficulties with current grapple yarding operations to justify improvements in grapple yarder vision systems:

- poor visibility of stems due to gullies, standing scrub and vegetation;
- availability of trained/experienced grapple operators, especially where visibility is poor;
- grappling small piece size unbunched wood;
- availability of trained "spotters"; and
- inadequate, delayed or poor spotter/operator communication

Grapple Camera - Trinder Engineering, Nelson

A grapple-mounted camera system is being developed by Trinder Engineering Ltd in Nelson. Trinder Ltd are developing a grapple carriage-based camera system using an Agcam camera system[6] as used in the Eagle carriages. Trinder purchased an Agcam camera system and successfully tested it in a forest environment in New Zealand. Currently, efforts focus on mounting the camera and transmitter on a modified rider block. Initial concerns include the shaky, rapidly moving view on outhaul which can disorientate the operator. Figure 16 shows the camera view from an early version of an Eagle grapple carriage.

Figure 16: AGCAM camera view on an Eagle Logging Claw grapple[28]

The hardware is an analog camera/communications system (Figure 17). However, Agcam four-channel wireless systems are available only in the US and Canada. This means that Agcam wireless systems developed in New Zealand will have to be single camera applications. The

Agcam system is not IP-based but may be compatible with monitors used with IP PTZ cameras, with the use of a video encoder.

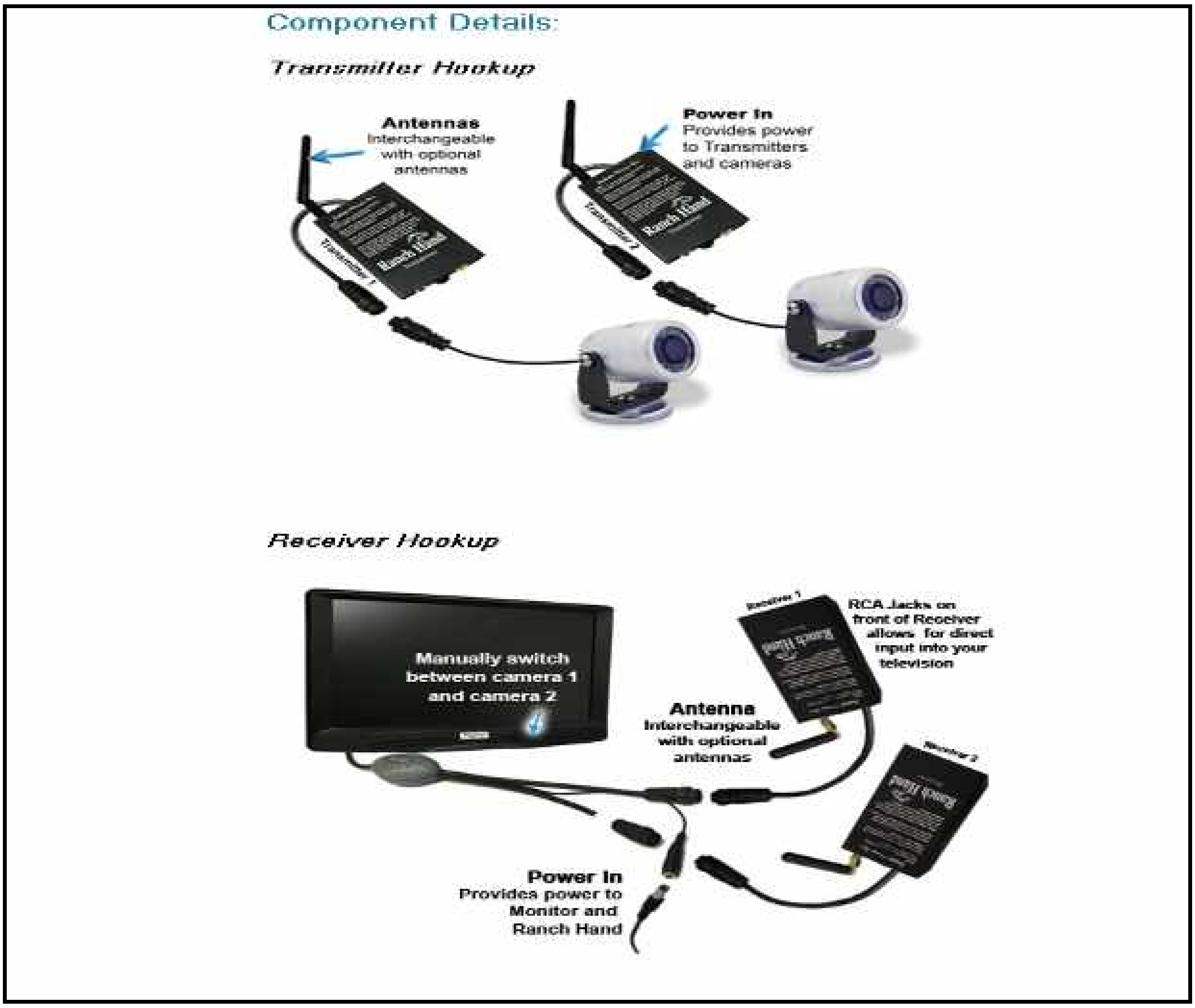

Figure 17: Agcam system from Dakota Micro [6]

Camera System for Other Locations – Scion, Rotorua

There are two communication systems considered for this option:

- Wireless Local Area Network (WLAN) as used with IP cameras. PTZ cameras can be used with this system. Frequencies used may be 2.4 or 5 GHz.
- UHF Radio, 2.4 GHz (AGCAM system) as used with CCTV cameras (analogue). This system mainly caters for fixed focus or zoom cameras.

Note: Both these systems are 100% line-of-sight, and directional antennas will provide the best quality signal.

A camera/communication system is proposed, comprising up to three WLAN-linked (Wireless Local Area Network or Wi-Fi) digital video cameras located:

- on the yarder,
- on the tail hold, and
- on the cutover.

The cutover-based camera may comprise the following:

- An Axis [8] P1347E IP camera (Figure 17) with a 3.5-10 mm Vari-Focal lens
- A Tripod or monopod mount
- A Lithium-ion battery pack
- 5.7 GHz Wireless Ethernet hardware (transmitter, receiver and antennas)
- An I-pad type tablet touchscreen display
- The construction of an alternative protective hood to accommodate a larger Vari-Focal lens (enabling a total of 8X zoom for the system)

The yarder and tail hold-mounted cameras would require only wireless Ethernet hardware.

Table 1 shows a number of possible camera combinations if a carriage-mounted camera is included in the mix.

Table 1: Some combinations of various camera locations

Location/combination	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Carriage	x	x	x	x		x	x	x							x
Tail hold	x	x	x		x	x			x	x				x	
Yarder	x	x		x	x		x		x		x		x		
Cutover (Tripod)	x		x	x	x			x		x	x	x			

COMPARISON OF SOME ALTERNATIVE SYSTEMS

A comparison of some camera combinations is shown in Table 2. This lists advantages and disadvantages, including spotter remote control as an option.

Table 2: A comparison of some alternatives (estimated costs) Note – Camera systems can work with any hauler, spotter remote control works only with computerised haulers.

	Location	Advantages	Disadvantages	Hard-ware Cost	Relative development cost	Relative risk of not meeting objective
System						
3 Camera	Yarder Tail hold Cutover	• Complete coverage • Robust	More expensive	$25,000	Low	Medium
2 Camera	Yarder Tail hold	• Partial coverage • Robust	No coverage of gullies	$20,000	Low	Medium
1 Camera	Cutover	• Partial coverage • Robust	Needs to be moved periodically	$10,000	Low	Medium
Carriage camera	Grapple carriage	• Partial coverage • Single camera system	• Risk of damage • Vibration • Movement • No guide to grapple zone	$10,000	High	High
Helmet camera or monopod	Helmet cutover	• Partial coverage	• Spotter limited • Vibration, movement • Single camera system	$5,000	Low	High
Remote control	Spotter cutover	• Complete coverage of grapple zone	Spotter needs to be close to the grapple site	$20,000	High	Medium

ASSUMPTIONS AND CONSTRAINTS

Formulated Assumptions

Data from an earlier study of grapple yarding in coastal British Columbia by Howard in 1991[27], and from a previous FFR study of a steep slope excavator feller buncher by Evanson and Amishev in 2010 [38] were used to derive reduced grapple time values assuming improved hauler vision at a haul distance of 200 metres. A summary of the values used in the economic analysis is given in Table 3 below.

Table 3: A summary of values used

Description	Unimproved system	Improved system
Grapple time (min) Kelly study 143 m AHD, unbunched trees.	0.630 min	
Increase in grapple time from 150m to 200 m, Haul distance. Derived from the Howard dataset.	30%	
Extrapolated grapple time (min) Kelly study, at 200 m AHD	0.819 min	
Estimated average reduction in Grapple time due to technical innovation (vision system)	0%	14%
Estimated grapple time (min) at 200 m, reduced by 14% for Improved system.	0.819 min	0.704 min
Outhaul (standardised to 200 m AHD)	0.514 min	0.514 min
Inhaul (standardised to 200 m AHD)	0.995 min	0.995 min
Other fixed elements	0.720 min	0.720 min
Total cycle time	3.048 min	2.933 min
Trees per haul (unbunched)	1.06	1.06
Average piece size (m^3)	1.92 m^3	1.92 m^3
Average haul size (m^3)	2.035 m^3	2.035 m^3
Hourly productivity (m^3/PMH)	40.06 m^3	41.63 m3
Productive hours/day	6.0 PMH	6.0 PMH
Daily productivity	240.36 m^3	249.78 m3
Days per year	235	235
Base harvesting system cost per year	$1,864,525	$1,864,525 plus camera system
Base harvesting system rate/m^3	$33.00	
Camera system costs/year. Three different options.		$25,000 $15,000 $10,000

Assumptions made in calculating cycle and production values for the purpose of analysing possible improvement:

1. Average grapple element times for use in the analysis were derived from the earlier FFR study of the grapple yarder operation at Kelly Logging Ltd.
2. The Howard dataset of multiple grapple yarding regressions enabled quantification of the effect of haul distance on grapple time, hence an estimate of additional 30% grapple time at 200 m haul distance was applied. The increase in grapple time at distances greater than 150 m may be attributed to communication and co-ordination problems with spotting.
3. Grapple element time at up to 150 m haul distance where there is a clear view is assumed to be independent of the efforts of a “spotter”. That is, 150 metres is the limit of operator-only grappling. Recent communications with grapple operators support this assumption.

4. An estimated 14% improvement in average grapple element times in using a hauler vision system. This estimate is derived from an assumed reduction in mean element time of 0.25 of one standard deviation of the mean grapple time from the Kelly data. For unbunched data, mean grapple time = 0.576 min and SD = 0.305 min. Improvement in grapple time is therefore 0.25 x 0.305 = 0.076 min. Improved grapple time = 0.576 – 0.076 = 0.50 min. (or an improvement of 13.2%). For bunched wood, mean grapple time = 0.640 min, SD = 0.42. Improvement in grapple time is estimated to be 0.25 x 0.42 = 0.105 min, and improved grapple time = 0.640 – 0.105 = 0.535 min (an improvement of 16.4%). Averaging these two results gives an average improvement factor for bunched and unbunched wood of 14%.
5. Inhaul and Outhaul element times were standardised at 200m haul distance. An average haul distance of 200 m was assumed to be the distance at which the improved system would make a significant difference. This is because the point where the advantage given by the vision system starts to apply was assumed to be 150 m, and for distances beyond 200 m inhaul/outhaul times made up a greater proportion of the total cycle time.
6. That haul size of the improved system stays the same as the base case (2.035 m^3). That is, improvement due to the system applies to the hauler cycle time only.

Other Assumptions

- A camera system is assumed to be operating in a grapple yarding operations. There may be work safety and other benefits if camera systems are used with tower yarding systems, using chokers and manual breaker outs, but these benefits have been ignored in this analysis.
- It is assumed that the reduction in grapple time is the same for any alternative as for a 3-camera system (Yarder, Tail hold, Cutover).
- The system is expected to have an economic life of 12 months, with replacement of all equipment after one year.
- Camera system costs are estimated at a fixed cost per year. It is assumed that maintenance costs are negligible over the life of the camera system.
- As new technology is developed it is expected that the camera system would be upgraded, although some hardware may be retained through subsequent years.
- No change in costs were assumed for other components of the harvesting system.
- Camera use may be limited operationally, depending on the degree of grappling difficulty experienced by the operator. This will affect the economic viability of the systems proposed; therefore a range of usage will be evaluated.
- The advantages of camera use are unproven. Single camera systems will be tested to quantify any benefits and identify any issues with multi-camera systems. It is assumed that similar results are obtained by one, two or three-camera systems.
- Testing of a prototype camera system will determine under what conditions improvement can be expected (e.g. reduced grapple time element for both uphill and downhill yarding).

RESULTS

Analysis of Benefits and Costs of the New System

Costs

The estimated costs of development of the prototype system are given in Table 4. In the economic analysis a range of camera system costs from $10,000 to $25,000 is used to represent a low cost (assuming economies in parts purchase) up to a high cost (in case of price rises or the estimates have overlooked some increased costs).

Table 4: System costs ($NZ) [8] [13] [30] [31] (N.B. Items marked * are estimates only).

Item	Number	Price for	Total
P1347E Camera with 3.5 -10 mm Varifocal lens and protective housing	3	$2,114	$6,342
Transceivers (Wifi) and antennas	3	$203	$609
Touchscreen tablet display	1	$2,412	$2,412
Battery pack*	2	$1,000	$2,000
Tripod/Monopod*	1	$500	$500
Brackets/Hood*	3	$500	$1,500
Software	1	$1,250	$1,250
Construction/testing*	1	$3,000	$3,000
Total			$17,613

Benefits

The average reduction in mean grapple time of 14% resulted in reduction in cycle time from 3.048 minutes to 2.933 minutes. At an average payload of 2.035 m^3 per cycle, this equated to an increase in productivity from 40.06 m^3/PMH to 41.63 m^3/PMH (+3.9%) through use of the camera system.

The base cable logging rate for the "no camera" system was $33.00/$m^3$. At the highest estimated annual cost of $25,000 and a usage rate of 100% the productivity advantage of the camera system resulted in a logging rate of $32.19/$m^3$. This equated to a minimum saving of $0.81/$m^3$.

Sensitivity Analysis

Effective logging rate (based on improved production rate) was calculated for different usage rates and annual costs (Figure 18). Varying usage rate reflects occasions when the operator can grapple trees unaided, or it is not possible to use a camera system.

Results showed that the model was relatively insensitive to annual cost because camera system costs ranged from 0.5 - 1.3% of annual logging system costs. The productivity gain of around 4% reflects the scale of overall improvement possible if even relatively small time gains (6-7 seconds per cycle) are made to multiple recurring cycles (over 125 extraction cycles per day for a swing yarder operation).

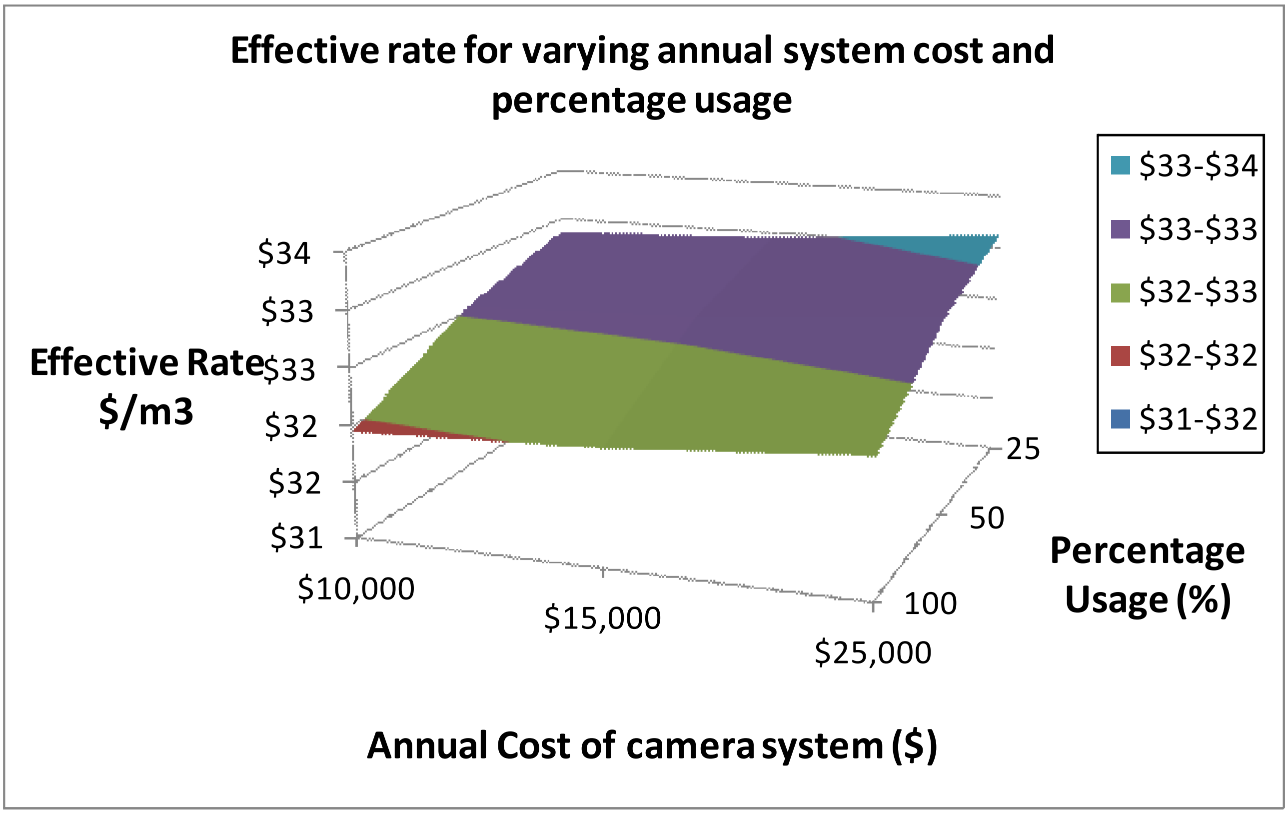

Figure 18: Effective rate for a range of annual costs and varying use of a hauler vision system

The cost benefit analysis showed that over the range of conditions of cost and usage the productivity improvement of the camera system would translate to a decrease in the effective logging rate of at least one dollar per tonne of wood produced (light green shaded area of Figure 18).

Breakeven Usage

A breakeven analysis (Table 5) showed that at an estimated cost of the system ($25,000) the camera system would have to be used for more than 35% of productive time to justify its installation.

Table 5: Breakeven analysis

Total Cost	% Use for break even
$10,000	15%
$15,000	21%
$25,000	35%

Benefit/Cost Ratio Matrix

The return on investment may be characterised by a Benefit/Cost ratio (Table 6). For example, 100% use results in an additional 2193 m^3/yr generated at $32.19/$m^3$ = $70,000 extra revenue per year. At a cost of $25,000 this is a Benefit/Cost ratio of 2.8.

Table 6: Benefit Cost ratios for different systems and usage percentages

System Cost $/year	25% use	50% use	100% use
10,000	1.7	3.5	7.0
15,000	1.2	2.4	4.7
25,000	0.7	1.4	2.8

Potential Markets and Scale-up Issues

An informal survey by Finnegan and Faircloth[32] in 2002 suggested that 75% of the current cable haulers working in New Zealand were of the tower or pole design. Of the remainder, 23% (49) were of the swing yarder type, and five excavator haulers were recorded.

A current estimate for the number of swing yarders in use is 45 to 50 machines, with 10-12 excavator conversions (Harvestline yarders)[33] to give a total of 55-62 machines. An FFR benchmarking study[34] in 2010 found that average logging production (all operations) was about 250 m^3 per day (57,500 m^3 p.a.) and the proportion of haulers was 53%, consistent over the two years of data collection. Given that annual logging production for the year ended on June 30, 2011 was about 25.7 million cubic metres, the number of logging operations in New Zealand is estimated to be around 450 and the number of hauler operations is estimated to be 240 (53% x 450). Only a small proportion of hauler operations use grapples however. A survey by Harrill and Visser[35] of crew owners, yarder operators, foremen and planners in 2011 showed that only 10% of those surveyed had used a grapple in their operations recently (within the last 5 years). This indicated that there is a big opportunity to increase the use of swing yarders, and more specifically grapple yarders in New Zealand.

Hauler vision systems are compatible with all swing grapple yarders. Given the estimate of 240 hauler operations in New Zealand, the estimated market potential for the hauler vision system for grapple yarding is 24 systems if current users of grapples are considered the primary market. If a hauler vision system reduces some of the difficulties less skilled operators face, then all swing yarder operations (an estimated minimum of 55 machines) constitute a potential market.

While not fully analysed in this study the scale-up issues identified included:

- identifying a manufacturer/assembler to source components on a cost-effective basis; and
- sourcing skilled technicians to install the systems

CONCLUSION

This project addressed the development of a camera system for grapple extraction by swing yarder. The aim of the swing yarder camera system is to reduce the time losses occurring from the use of a spotter namely, poor communication, and inevitable time delays in carrying out instructions. Effectively, there would be more productive cycles per day (i.e. outhaul, grapple, inhaul).

The feasibility study of the swing yarder camera system application showed that on the basis of some reasonable assumptions, including a relatively small reduction in average grapple time of 14%, a substantial increase of 4% in overall hauler productivity could be expected as a result of using the camera system. This productivity improvement would translate to a decrease in the effective logging rate of at least one dollar per tonne.

A cost benefit analysis showed that with an estimated 12-month life and $25,000 annual cost, a camera system would require a usage rate of 35% to break even. The annual costs of the proposed remote control system amounted to less than 1.5% of the annual total logging system cost.

On the basis of the results of this feasibility study, the development of a camera system has the potential to help achieve the primary goal of reducing the cost of steep country logging. The next steps in this research will focus on completing the beta prototype system, incorporating user feedback, and recommending a design for the commercial model.

ACKNOWLEDGEMENTS

The assistance of James Overington, Kajavala Forestry Ltd, in developing this project task is acknowledged.

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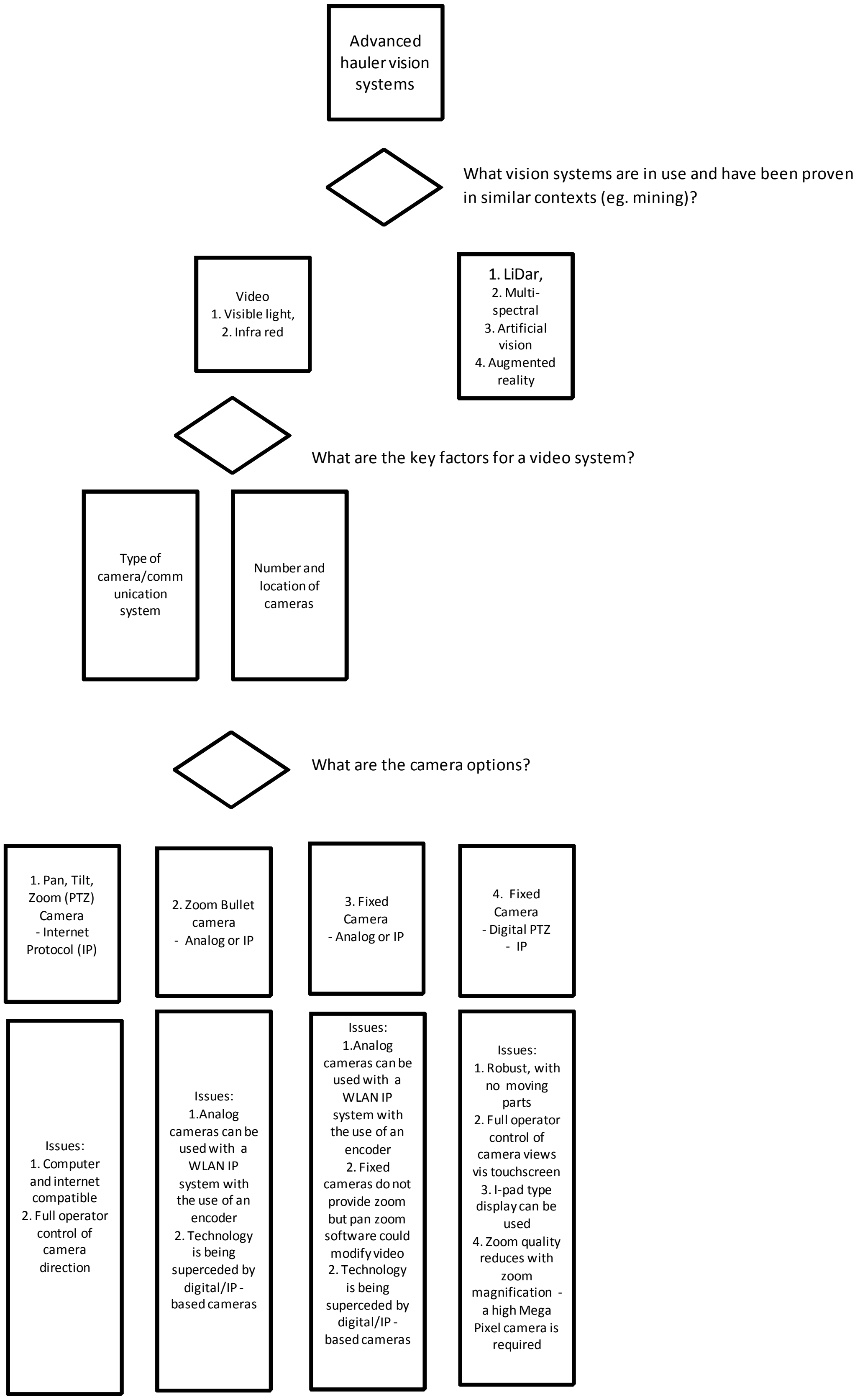
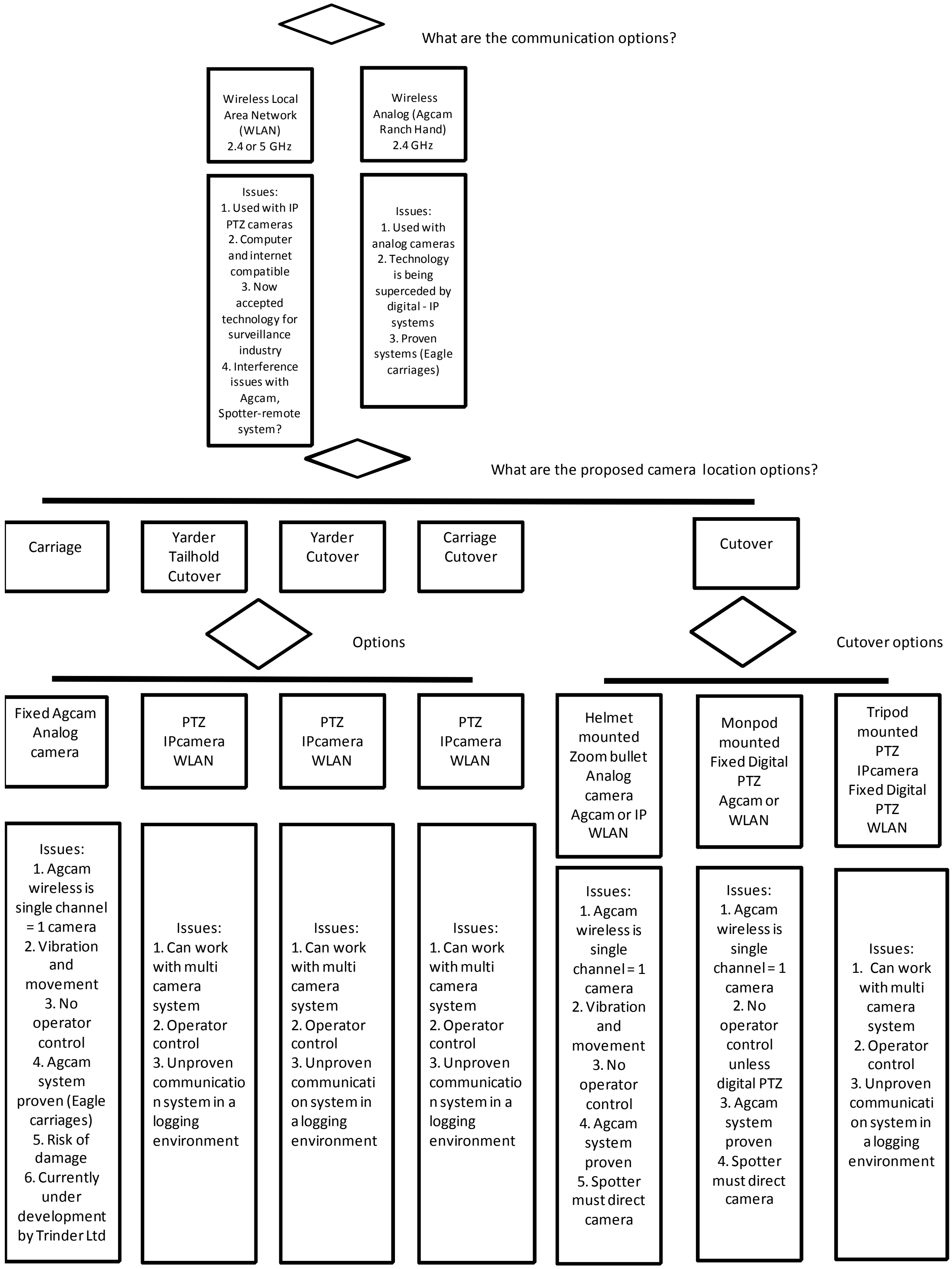
APPENDIX 1

An indicative guide to camera system options




What are the communication options?
Wireless Local Area Network (WLAN) 2.4 or 5 GHz
Wireless Analog (Agcam Ranch Hand) 2.4 GHz
Issues: 1. Used with IP PTZ cameras 2. Computer and internet compatible 3. Now accepted technology for surveillance industry 4. Interference issues with Agcam, Spotter-remote system?
Issues: 1. Used with analog cameras 2. Technology is being superceded by digital - IP systems 3. Proven systems (Eagle carriages)
What are the proposed camera location options?
Carriage
Yarder Tailhold Cutover
Yarder Cutover
Carriage Cutover
Cutover
Options
Cutover options
Fixed Agcam Analog camera
PTZ IPcamera WLAN
PTZ IPcamera WLAN
PTZ IPcamera WLAN
Helmet mounted Zoom bullet Analog camera Agcam or IP WLAN
Monpod mounted Fixed Digital PTZ Agcam or WLAN
Tripod mounted PTZ IPcamera Fixed Digital PTZ WLAN
Issues: 1. Agcam wireless is single channel = 1 camera 2. Vibration and movement 3. No operator control 4. Agcam system proven (Eagle carriages) 5. Risk of damage 6. Currently under development by Trinder Ltd
Issues: 1. Can work with multi camera system 2. Operator control 3. Unproven communication system in a logging environment
Issues: 1. Can work with multi camera system 2. Operator control 3. Unproven communication system in a logging environment
Issues: 1. Can work with multi camera system 2. Operator control 3. Unproven communication system in a logging environment
Issues: 1. Agcam wireless is single channel = 1 camera 2. Vibration and movement 3. No operator control 4. Agcam system proven 5. Spotter must direct camera
Issues: 1. Agcam wireless is single channel = 1 camera 2. No operator control unless digital PTZ 3. Agcam system proven 4. Spotter must direct camera
Issues: 1. Can work with multi camera system 2. Operator control 3. Unproven communication system in a logging environment