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BEST MANAGEMENT PRACTICES FOR WINCH-ASSIST EQUIPMENT

VERSION 2.0

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ABTRACT:

Learnings for Best Management Practices were compiled from research projects, on-site discussions with operators and contractors, safety alerts, published reports and discussions with a range of people. These learnings provide guidance for operating winch-assist technology safely and effectively on steep slopes.

30102887: STEEP SLOPE HARVESTING

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The information contained in this manual is offered for your reference only. It was developed using multiple local and international relevant resources to support the introduction of winch-assist equipment in Canada. The information represents current research results and technical information made available to FPInnovations from many sources, including researchers, winch-assist manufacturers, harvest planners, contractors, and operators, and is subject to constant review in light of new research, experiences, and changing government regulations. While every reasonable effort has been made to insure the accuracy of the information presented, and special effort has been made to assure that the information reflects the state-of-the-art, it is not intended to represent the only approach to any particular practice and neither FPInnovations, nor any of its employees, officers, contractors, agents or other persons acting on its behalf or under its control makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the use, application of, and/or reference to opinions, findings, conclusions, or recommendations included in this published manual, nor assumes any responsibility for the accuracy or completeness of the information or its fitness for any particular purpose.

This manual is not intended to provide professional advice and is not intended to replace or supersede occupational health and safety regulation provisions or specific instructions from the supplier of the equipment you are using. It is the responsibility of users to exercise professional knowledge and judgment in the use of the information.

TABLES OF CONTENTS

LIST OF FIGURES

1 INTRODUCTION

Cable-assist, winch-assist, traction-assist, and tethering are all terms that have been used to describe the practice of attaching a cable or cables to a forest machine to increase its operability on slopes. The cable's tension increases the machine's traction to prevent slippage and to increase the machine's stability on slopes. The increase in traction allows the machine to work on steeper slopes while reducing its ground disturbance. These systems are being used to increase the operating range of ground-based equipment and reduce the need for workers on the ground such as hand fallers or choker setters. Benefits include: reduced incident risk associated with manual workers; improvements in harvesting productivity and costs; reduced site disturbance and potentially increasing the economically available timber supply.

This is the second version of best management practices (BMP) document for operating this new technology safely and effectively. It draws on available documentation from manufacturers and landowners, safety alerts, field discussions with operators, owners, and equipment manufacturers, observations of working machines, and related research reports. Best practices are continuing to evolve as more system hours are logged and techniques are developed. It is anticipated that the document will be updated on an ongoing basis as feedback is received.

1.1 History of winch-assist development

The US Forest Service studied the concept as early as 1973 (McKenzie et al). Kassbohrer introduced their first winch-assisted Piston Bulley winch-cat snow groomer in 1983 (Fatzer). Klaus Herzog of Switzerland developed the idea for forest harvesting in the 1990s and launched the first forestry traction winch in 2004 (Wald und Holz). The first forestry systems were used in Europe on forwarders to enable them to retrieve logs from steep terrain worked by untethered wheeled harvesters. Winches were then added to the wheeled harvesters to prevent wheel slippage and reduce the environmental impacts of ground-based harvesting on steep ground. Ross Wood developed the first New Zealand system in 2006 which was followed by the first Climbmax prototype that was built in 2009. Winch-assisting harvesting started in North America with the delivery of the third commercial Climbmax unit to Tolko Industries' BC operations in July of 2013.

Currently, there are about 20 manufacturers of forestry winch-assist systems, found in Austria, Canada, Germany, New Zealand, Sweden, Switzerland, and the USA.

1.2 Current status

Winch-assist systems are operating worldwide with the largest concentrations in Europe, New Zealand, and South America. Ponsse, for example, have about 200 units working worldwide. FPI estimates that there are about 50 winch-assist harvesting systems working in BC. Although the systems have been only recently introduced to North America, there is strong industry support here.

Although manufacturers and forest companies have developed some specific safe working procedures, there are no comprehensive national or international standards around this technology. Rien Visser of the University of Canterbury notes that "no European country has yet implemented specific cable-assist rules, although machine manufacturers have started to develop their own guidelines. Common to nearly all is the fundamental principle that the machine must remain stable and have traction without the cable—the cable is only a traction assist and no additional rules need be incorporated. Only a few manufacturers are providing slope limits, such as Komatsu noting a limit of 55%." (Visser and Stampfer, 2015)

WorkSafe New Zealand has six points in their Approved Code of Practice for winch-assist systems (MBIE, 2012).

1. All mobile plant using the assistance of a wire rope and/or winch shall be specifically designed, tested, demonstrated to be safe, and certified by a Chartered Professional Engineer to be safe when operated on steep slopes.
2. The tension on the wire rope shall be restricted to 33 percent of its breaking load at all times.
3. The maximum operating weight of the mobile plant shall not exceed the rated breaking load of the wire rope.
4. An emergency back-up system shall be incorporated into the operation to ensure the stability of the mobile plant should the winch, wire rope or anchor fail.
5. All winch-assisted mobile plant operations shall have a documented safe working best practice, including as a minimum:
    i. hazard management
    ii. machine and wire rope inspection and maintenance routines
    iii. operator fatigue plans
    iv. work alone procedures
    v. an emergency plan.
6. All winch-assisted mobile plant shall be constructed to provide adequate emergency access and egress points that can be activated internally and externally.

A sample of specific manufacturers and landowners' best practises guides and manuals are listed in Appendix 11.1.

2 CRITICAL ELEMENTS TO INCLUDE IN BEST MANAGEMENT PRACTICES (BMPs)

There are critical elements or categories of topics that should be included in a comprehensive compilation of BMPs for traction-assist systems. They include (1) general elements which are applicable to all systems, and (2) machine-specific elements which should be described by the manufacturer.

In cases where no manufacturer specification is available, general elements will apply.

1. General elements, applicable for all systems to be considered in establishing BMPs:

- Pre-work requirements: ground inspection, hazard assessment, operator training and competence, machine inspection, identification of no go areas
- Previsions for other workers' safety including – emergency response plan, fatigue managment plan, safe working distances, location, remote control machine considerations, road closures and signage

- Practical considerations and planning- cutting pattern, trail access, selection of the best suited base machine and head for conditions
- Engineering, block design and planning
- Rigging practices – set up, line changes, anchors, guying
- Winch inspection criteria and schedule
- Wire rope care and maintenance, inspection criteria and inspection schedule
- Wire rope replacement criteria – wear and tear, broken wires, shock loading
- Hardware integrity – shackles, connectors, etc. – inspection and replacement criteria
- Machine stability considerations – best machine and boom positions
- Shutdown / no go criteria – workers' ability to refuse unsafe work, rainfall/ weather shutdowns, upset conditions
- Environmental considerations

2. Machine-specific elements that should be described by the manufacturer:
   - Machine design considerations – system and component factors of safety, redundancy requirements, emergency stop procedures/ devices, attachment point location and design, connecting hardware requirements, operator restraints
   - Wire rope specifications
   - Safe working load and maximum loading for wire rope and system components
   - Maximum allowable winch tension
   - Inspection and replacement requirements
   - Safety check procedures

3 WorkSafeBC REQUIREMENTS

There are also several WorkSafeBC regulations that are applicable to winch-assist systems. These include:

1. Traction-assist logging equipment inspection checklist[1]
2. Planning and documentation: OHSR 26.2(1), 26.2(3)(a), 26.2(3)(b)(c), WCAct 119(b)
3. Prime contractor responsibilities: OHSR- 26.2(2), 26.2(3)(a), 26.2(3)(b)(c), WCAct- 118(2)(a)(b)
4. Employer responsibilities: OHSR 26.16(4)(a)(b), WCAct 115.1(a), 115.2(a)-(f), OHSR 26.16(2-4)
5. ERP (Emergency response plan) – OHSR 4.13(1-3), 4.14(1-4)
6. Supervisor responsibilities – OHSR 26.3(1), 16.4, 16.6, WCAct 115(2)(e), 117(1)(2)
7. Operator/Worker Responsibilities – OHSR 3.12(1), 16.5, WCAct 116(2)(a)(e)
8. Supplier responsibilities – OHSR 4.4, WCAct 120
9. FOPS –OHSR 16.21
10. ROPS – OHSR 16.22
11. Cab guarding (Figure 1)

[1] www.worksafebc.com/en/resources/health-safety/checklist/traction-assist-logging-equipment-inspection-checklist?lang=en

- Cab G602
- Roof G608 or SAE231
- Boom Side G604 or SAE J1084
- Front G603 and G604
- Door and Door Side Windows G603 and G604
- Back Window G603 and G604

Figure 1. Cab guarding on John Deere (left), and HSM (right) harvester.

12. Emergency escape – OHSR 16.17
13. Slope limitations – OHSR 26.12.1, 26.16. Exceeding slope limitations requires:
    - Risk assessment
    - Written safe work practices
    - Must not be operated in a particular location or manner if its stability cannot be assured
14. Worker training – WCAct- 115, 26.3, 3.23, 16.4
15. Cranes and hoists – OHSR 14 with 14.9 (14.5 to 14.8) exception for logging
16. Rigging – OHSR 15, including section 3.5 on cable inspection
17. Planning – OHSR 26.2
18. Radio controlled equipment –OHSR 26.12.2 must be equipped with a "fail safe" or "stop" mechanism that becomes operational if the remote control device fails.
19. In addition WorkSafeBC's document "*Understanding the Requirements for Mobile Logging Equipment in British Columbia*" [2] identifies the following areas of concern that may be dealt with by manufacturer's instructions or written safe work procedures under "Safe work procedures and manufacturer instructions specific to winch-assist equipment":
    - Stump selection, method of securement, and frequency of inspection (Figure 2)
    - Winch and cable inspection – frequency and standard
    - Potential to damage or sever cable with head, boom or logs

[2] https://www.worksafebc.com/en/resources/health-safety/information-sheets/requirements-for-mobile-logging-equipment-in-bc?lang=en

- Abrasion of cable on rock outcrops or other obstacles
- Safe working area around the machine and cable. Area of no entry
- Rescue procedure for breakdown or misadventure
- Worker training
- Lockout and de-energization procedures
- Winch capacity/load rating, safety systems, and failsafes.
- Cable size and strength

20. Snubbing loads on steep grades – OHSR 16.38

Figure 2. Stump anchors.

In the absence of regulations or guidelines, WorkSafeBC may check that operations are compliant with recommendations in manufacturers' manuals.

4 ITEMS THAT MAY AFFECT BEST PRACTICES

Not all systems operate the same way. Different or additional best operating practices may be required for various systems or applications.

4.1 Application

4.1.1 Above the road vs below the road operations

Planning should allow for an exit route for cutting below the road where there is no road access below. Careful planning is needed where there is no road or built trail above the block. A route for cutting up to the top of the block, or a means of dragging the cable up the hill is required. Due diligence for selecting and using anchors is required (see sec 5.12).

4.1.2 Cutting-head type

The four types of felling heads, continuous rotation disc (hot saw), intermittent disc, feller-director, and harvester all have potential for severing the wire rope cable. A continuous rotation disc saw (Figure 3) poses the greatest risk because of its high disc rotation speed, heavy duty disc and saw teeth and instant damage potential from even minor contacts. An incident of a hotsaw cutting the chain was reported in a Washington safety alert[3] (SHARP 2017).

Figure 3. Continuous rotation disc saw (hot saw) (left), feller director (middle) and harvester head (right).

- It may be that the saw type makes little or no difference to the risk because a line under tension is already at a greater risk of breaking if it comes into contact with a sharp edge.
- Testing or engineering analysis may be required to rank the relative risk of various head types. As an interim measure it is recommended that the lowest necessary line tension be used when cutting near to the cable regardless of the cutting attachment.
- The amount of time that the cutting head is in close proximity to the cable should be minimized.

4.2 Back-up systems

The New Zealand ACOP indicates that winch-assist systems are required to have a back-up system in the event of failure (sec 1.2). Different back-up systems have advantages and disadvantages and none can be guaranteed to work in all circumstances.

4.2.1 Blade

The ClimbMax system uses a blade that can be rapidly deployed to brake the machine if traction is lost **(**Figure 4).

[3] http://www.lni.wa.gov/Safety/Research/Files/97_03_2017_Logging_NearMissAlert_TetherLineCut.pdf

- Advantages – designed to stop the machine if the cable, attachment point, or anchor fails
- Disadvantages – sliding machine momentum may lead to a “tripped upset” where the downed blade actually serves as a pivot point; also, the blade may not be applied in time to stop the machine
- BMPs:
    - Do not use with a non-constant tension system
    - Never allow slack to develop in the line
    - Tethered machine should have a low center of gravity (CG)
- Experiences so far – anecdotal reports of successfully stopping the machine in cases where the cable has failed

Figure 4. Fast-actuating blade mounted on a ClimbMAX winch-assist machine.

4.2.2 Double lines

Some New Zealand systems have double winches and lines as a backup system in case a rope fails (Figure 5).

- Advantages
    - If one cable fails, the second cable is designed to hold the assisted machine in place. See Washingon safety alerts[4],[5] (SHARP 2017, 2018). However, there are concerns that failure of one cable may shock load the second cable
    - If one cable is accidently cut by the felling head, the operator may be able to correct the situation before the second cable fails
    - Some operators are less stressed while working with a second cable
- Disadvantages
    - More complex mechanisms for control and maintenance
    - More difficult to manipulate two cables around obstacles

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[4] https://www.lni.wa.gov/safety/research/files/97_03_2017_logging_nearmissalert_tetherlinecut.pdf
[5]https://www.lni.wa.gov/safety/research/files/97_06_2018_logging_nearmissalert_tethercablebreaksattermina tionpoint.pdf

Figure 5. Two line systems – Electrical & Machinery Services (EMS) Tractionline (left), Remote Operated Bulldozer (right).

- BMPs:
    - Do not exceed the anchoring capacity of the machine anchor's site specific condition
    - Monitor the weather, soil moisture and frozen conditions which may affect the traction and load capacity of the machine anchor (this applies to stump anchor systems as well) and adjust operations (e.g. max allowable slope) as necessary or cease operations until conditions improve
- Experiences so far – at least two anecdotal reports of both cables failing at the same time.

4.2.3 Warning system

Warning systems may include anchor movement detectors (Figure 6).

- Advantages – operator is aware that only their skill and speed of implementing the emergency operating procedures can prevent an incident. This may prevent them from taking unsafe risks
- Disadvantages – relies on the operator receiving the warning and following the operating procedures in time to prevent an incident
    - There may be a delay in the signal from the anchor machine, and reaction time for the operator to remove feet from the pedals and stop the anchor machine from moving further
- BMPs :
    - Maintain and test warning system daily and after any suspect event
    - Operators should practice the emergency operating procedures monthly in a low risk environment
- Experiences so far – no known failures reported

Figure 6. Movement monitoring device.

4.2.4 Working method

European winch-assist practices have developed using integrated winches (Figure 7) and requirements to test machine stability by slacking the cable to test that the working machines remain on the slope without slipping.

- Advantages – when used as designed, a component failure will not result in uncontrolled movement of the machine or risk to the operator
- Disadvantages – Reduces maximum operating grade; operator may unknowingly or accidently or intentionally exceed the safe working slope limit and work without a back-up system
- BMPs
    - Test the machine’s traction and stability without cable tension regularly, including before and after any machine movements, and during machine movements if the terrain or conditions change
    - Use only with limited (low) traction assist line tension systems
    - Design the tension system so the operator cannot increase the line tension above the manufacturer’s specifications
- Experiences so far – Approach used in Europe and internationally since 2004 with no known serious incidents reported

Figure 7. European style Ponsse (left) and Haas (right) winch-assist system.

Other working methods as a backup include resting the tracks against a stump or obstacle.

5 RECOMMENDED BEST PRACTICES

The basic mechanical elements of a winch-assist system are the base machine, the anchor, (i.e., a machine anchor or natural anchor, i.e. stumps or trees, or artificial anchor, i.e. rock bolts or deadmen), the winch, the wire rope, and the associated rigging components. Other non-mechanical system elements which greatly affect the system's safety include the machine operator, environmental conditions, operating procedures, and any applicable regulations.

Winch-assist is now applied to falling, hoe-chucking, forwarding, skidding and rehab, which will each require adapted best practices. Recommended best practices would would not be universally applicable for all machine designs and harvesting operation phase.

5.1 Machine design and features

5.1.1 There are several types of base machines

For felling and processing :

- Levelling or non-leveling wheeled harvester (Figure 8)
- Levelling or non-leveling tracked harvester/feller-director/feller-buncher (Figure 9)

Figure 8. Levelling (left) and non-levelling (right) winch-assist wheeled harvester.

Figure 9. Levelling (left) and non-levelling (right) winch-assist tracked feller-director.

For log or tree extraction :

- Levelling or non-leveling tracked excavator forwarder (Figure 10)
- Wheeled forwarder or clambunk skidder (Figure 11)
- 4- or 6-wheeled rubber-tired skidder (Figure 12)
- Levelling machines are more comfortable for operators especially when slewing during fellling or hoe-chucking
- When moving, operators may not level the machine so they can feel the ground better and dig in the boom faster if traction is lost

Figure 10. Flat-bottom excavator-loader downhill (left) and tilting feller-director uphill (right) stem forwarding.

Figure 11. Winch-assisted wheeled clambunk skidder (left) and forwarder (right) downhill log forwarding.

Figure 12. Winch-assisted wheeled skidder uphill stem forwarding.

5.1.2 Braking mechanisms

An EMS anchor machine was pulled off the hill when one drum was releasing cable faster than the other and the over-speed alarm activated. This engaged the parking brake, locking the drums. Once the alarm was reset, the operator stopped to cut a tree, then began travelling downslope but the parking brake was still engaged. The anchor machine, located on the crown of the road, pivoted and fell over[6,7]. Learnings in the form of BMPs involved :

- Winch systems should have an auto-stop mechanism where tension is gradually applied in the event of catastrophic loss of tension or energy
- Working machines should have an emergency stop button that immediately brakes the winch or machine[8]
- Before operating, make sure all safety systems are operating
- Ensure the anchor machine is level
- Use a mechanism or system to prevent accidental operation of the assisted machine when the winch is in manual mode
- Even experienced operators can be caught off guard by some of the new aspects of tethered systems. Extra attention should be paid to becoming familiar with safety features
- Don't override safety controls

5.1.3 Safety features

It is recommended that the following features be included in the base machine (and/or winch machine, if applicable) by the original equipment manufacturer or as an after-market addition for these steep slope applications:

- Inclinometer that measures and displays machine frame angle with the horizontal (Figure 13)

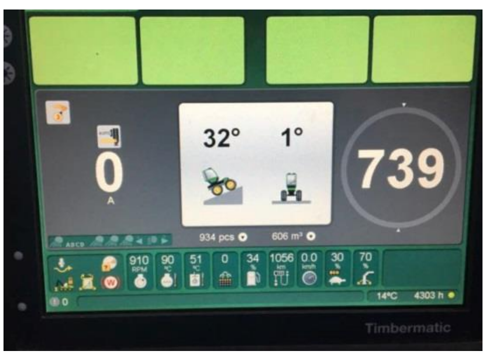

Figure 13. Example of an in-cab longitudinal and lateral machine slope display

- Fluid systems (hydraulics, engine oil, coolant, fuel) that are designed to operate on steep slopes
- Adequate tractive and swing power for steep slopes
- Traction devices suitable for the conditions, e.g. tire chains or tracks for wheels, ice lugs or double grousers for tracks (Figure 14)

6 http://www.lni.wa.gov/safety/research/files/97_05_2018_logging_nearmissalert_basemachinepulledover.pdf
7 https://www.timberlinemag.com/2018/01/safety-alert-2/
8 https://worksafe.govt.nz/topic-and-industry/tree-work/safety-during-tree-felling/

Figure 14. Welded ice lugs on every other track plate (left) and welded double grousers on every track plate (right).

- Cable attachment points engineered for the expected loads
- Live display of cable tension (Figure 15)
- Digital display of the remaining available rope length and rope length in use (Figure 15)

Figure 15. Live display of cable tension on a Tractionline (left) and ROB (right) winch-assist system.

- Audible and visual warning for cable overloads, winch failure, spooling errors, cable damage, anchor movement, and when the minimum number of cable wraps is reached
- GPS navigation system with potential hazards identified on a map display
- Camera display of winch drum(s) if not visible from the operators cab (Figure 16)

Figure 16. Display of winch drum (left) and winch drum and obstructed view area (right).

- Camera display of obstructed view areas (Figure 16)
- Secure operator restraints, i.e., minimum 4- or 5-point harness system, ideally with an adjustable locking mechanism
- Hour meter that tallies the number of hours the winch and cable has operated, to monitor cable use and life
- Display of winch hydraulic temperature with indication of operating limits, visible to the operator of the assisted machine
- Mechanism or system or prevent accidental operation of the assisted machine when the winch is in manual mode

5.1.4 Anchor machine safety machine features

- Tiebacks or guyline drum(s) to secure the anchor machine (Figure 17)

Figure 17. Tied back anchor machine (photo credit Ecoforst).

- Anti-lock style braking system that applies winch brake gradually in an emergency or power failure to prevent shock loading to the wire rope and other system components

- Hour meter that tallies the number of hours the winch and cable has operated, to monitor cable use and life
- Data-logger of the cable tensions
- Alarm when anchor machine cab door opens

5.2 General best practices

5.2.1 Traction assistance vs tethering and machine support

Most European winch-assist system manufacturers recommend, as a general rule to maximize safe operations, that the winch system should only be used for tractive assistance and should not be used to support any weight of the assisted machine. In these cases :

- Machine stability must be tested by releasing the cable tension regularly when working including whenever the machine is repositioned
- Test to ensure the machine is stable without assistance. If it is not stable during the test, work must not start or continue in this position until conditions improve

In many cases, with various winch-assist systems and under certain terrain and weather conditions, the winch can safely provide more support than just tractive assistance. In such cases:

- Minimum pulling and braking force of the winch and cable must be suitably rated for this application and is a function of the weight of the supported machine including the load, the traction coefficient of the surface (soil, debris, ice, snow, etc.), and the maximum gradient the supported machine is expected to work on
- Properly functioning fail-safe mechanisms, warning systems and sensors must be ensured and regularly inspected and monitored
- Working procedures should minimize the risks for loss of traction, and provide the operator with steps to rapidly mitigate any loss of traction

5.2.2 Operational general best practices

- The traction winch cable should only be used for traction assist and never for other purposes such as pulling logs or winching the machine into place
- Operate the machine only in places where the operator feels comfortable. The operator cannot be compelled to work in areas or conditions where he/she feels there is a safety risk (right to refuse unsafe work)
- A steep slope assessment should be completed as per OHS OHS Regulation 26.16 and incorporated into the work plan, and revised as conditions change
- An alternative plan must be established if conditions change, i.e. unsuitable weather or soil (heavy precipitation, freeze up)
- The winch on a winch-assist system should be used whenever working on slopes over 40% unless the steep slope assessment has determined that winch-assist is unnecessary
- Always assume a wire rope could break at any time and operate as if untethered

- Where possible the operator should dial down the tension to protect the life of the gears within the winch system. See New Zealand '*Maximizing incident learning opportunities*'[9] (Scion 2017)
- Do not work near or pass under or over the cable while the machine is in operation, maintain safe distances
- Do not work near or below a machine that is in operation
- Stay clear of the wire rope during operation
- Do not ride on or in remote controlled machines when they are moving or operating
- Inspect and maintain all mechanical components as per the manufacturer's specifications. i.e. winch, gearbox, slewing ring, pumps, control systems
- Always wear a secured 4-point or greater seat belt during operation
- Remove or secure all loose objects in the cab before operation
- Cab entry and exit
    - Position the machine on flat or less steep ground if possible
    - Ensure the machine is secure before attempting to enter or exit the cab
    - Position the machine to utilize the tracks, stumps, or logs to reduce the distance to ground on steep slopes
    - Level the cab if possible to reduce the effect of gravity on the opening and closing of the cab's door
    - Use a three point stance at all times and use any provided hand or foot holds
    - Use caution if the cab is not level as gravity will cause the door to swing if not controlled

5.3 Wire rope best practices

The section references some key points from Boswell and Field (2016), *Wire Rope Integrity for Winch-Assist Forestry Equipment*. Illustrative material can also be found in Naillon and Rappen (2019).

- Rated safe working load (SWL) rope strength should be known and the system should be operated so that the SWL is not intentionally exceeded. In BC cable yarding, SWL is calculated by appling a 3:1 safety factor to the breaking load of the wire rope. Safety factors of 3:1 and 5:1 are used by winch-assist manufacturers
- Wire rope's SWL should be reduced according to the efficiency rating of the weakest component in the system - wire rope, connectors, chains, shackles, pins and drum components
- A practical allowance should be used for deterioration and wear as well as fatigue from shieves and bends
- Wire rope attachment points should be visually checked daily (Figure 18)
- Damaged wire ropes sections should be cut off (FPInnovations Wire Rope Guide, 2017)
- The entire wire rope should be inspected following the manufacturer's or regulator's recommended procedures every 2 weeks or every 100 hours of operation
- Keep a log noting dates and details of: cable use hours, cable inspections, any cable damage, any shock loading incidents, any cable sections cut out, splices, and end connectors
- Knots should not be tied in wire ropes

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[9] https://safetree.nz/wp-content/uploads/2018/09/Machine-Rollover-2017-Full-report.pdf

Figure 18. Attachment points need daily inspection.

- Only replace with new wire rope to manufacturer's specification
- Avoid running the cable over sharp bends of rock and other material that may sever the cable. Utilize suitably-sized redirecting stumps/trees (Figure 19)
- Avoid cable contact with abrasive surfaces
- Avoid dragging the cable through the soil or on the ground. Place stems/logs on rough surface or ground for wire ropes to run over and protect from damage (Figure 20). Reposition the anchor machine, assisted machine, or rigging, or use catching stumps/trees as necessary to avoid dragging the cable deep through soil or on rough ground
- Ensure that cable connections (e.g. poured knobs) do not contact shieves. See Washington safety alert[10] (SHARP 2018)

[10] https://www.lni.wa.gov/safety/research/files/97_04_2017_logging_nearmissalert_basemachinemovebreakstether.pdf

Figure 19. High-stumps left on both sides of a sharp rock outcrop used for redirecting.

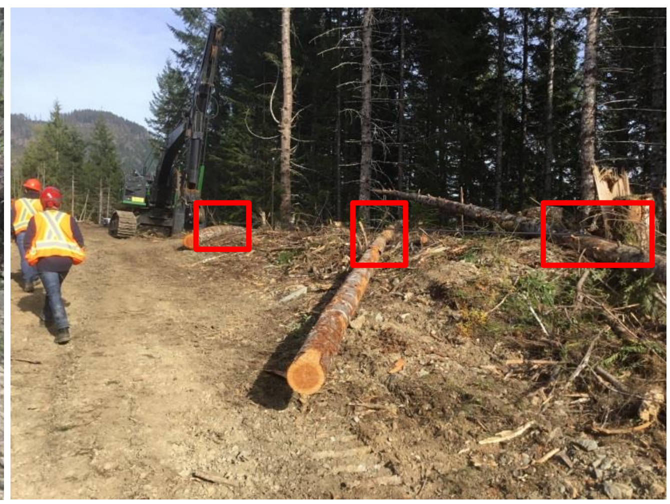

Figure 20. Use of a sill log placed on the road (left) or several whole stems (right) to protect the moving wire rope.

Some conditions that can lead to wire rope failure include shock loading, abrasion, and fatigue. Best practices for mitigating these conditions include:

- Sharp spikes in cable tensions (Shock loading)
    - Install and use tension monitoring and a tension recording system
    - Review tension log data daily and whenever shock loading is known or suspected to have occurred
    - If shock loading has occurred or is suspected, inspect the wire rope for damage. Cease operations and replace the rope if tension ever exceeds the elastic limit (usually 2/3 of the cable breaking strength)

    - If the rope's tension exceeds its endurance limit (usually 50% of breaking strength), the rope's lifespan is also reduced and more frequent inspections are required
- Fatigue
    - Monitor and record the operating hours on the cable and replace as per the manufacturer's requirements
- Abrasion
    - Inspect the wire rope for surface wear, nicks, cuts, broken wires. Note some types of cable (e.g. swaged) appear fine when they are actually worn out so know the characteristics of the cable type. Replace the cable as per the manufacturer's requirements for wear
    - Avoid running the cable over rock or on the ground (Figure 20)
    - Use a heavy duty chain segment to prevent or reduce wire rope wear close to the machine and in other high wear areas (Figure 21)
    - Position the anchor machine to prevent bends in the line at ground breaks, especially over rock. Move the anchor or anchor machine as needed to prevent cable contact at ground breaks (Figure 22)

Figure 21. Heavy duty chains are used in areas of high wear.

Figure 22. Cables with ground clearance.

- Bending fatigue
    - When a rope passes around a shieve or an obstacle, there is uneven stretching of the rope due to the difference in diameters of the inside and outside of a rope. As the ratio of the shieve diameter (D) to rope diameter (d) decreases, wear caused by the bending increases exponentially (Figure 23). Manufacturers' directions should be followed, or if unavailable, a minimum D/d ratio of 16 :1 is recommended (FPInnovations 2017)

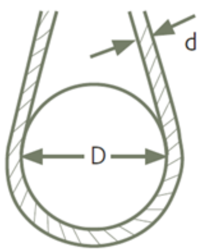

Figure 23. The D/d ratio affects bending fatigue.

5.4 Record keeping

- Maintain a schedule and document inspections, maintenance, replacements and incidents
- Document the number of hours the machine is in use
- Document all incidents of exceeding the SWL of the line. If the machine does not have a system that automatically records the line loading, the operator must record these events manually from the load cell read out
- A qualified person with wire rope expertise should review the line loading records regularly to ensure that the wire rope is replaced in a timely manner. Reviews must be done immediately after any overload conditions
- The operator's manual defining safe operating and maintenance requirements should be available

5.5 Connecting hardware best practices

Connecting hardware includes shackles, D’s, chains and wire rope terminations – for detailed information and illustrations refer to FPInnovations’ (2017) Wire Rope Guide

- Every connector’s rating must match or exceed the wire rope safe working load (unless it has been designed to be a “fuse” in the system that will fail in an emergency at a predetermined tension)
- Visually inspect every connector daily for wear or damage (Figure 24)
- Replace hardware as per the manufacturer’s recommendations
- Inspect the chain regularly for wear or damage. Measure the chain’s length and the links hole diameters (a simple gauge can be fabricated) to check for stretch. Replace the chain if it appears worn, damaged, or stretched beyond the manufacturer’s recommended limits

Figure 24. Daily inspection of connectors is required.

5.6 Machine attachment points best practices

- Use only engineered attachment point(s) designed to support at least the weight of the machine
- Use only attachment points that have been inspected and certified by a professional engineer
- Inspect the attachment points regularly for wear or damage, repair or replace as necessary. Points must be recertified after any major repairs or as per scheduled maintainence with record keeping
- A low frame-mounted attachment point is usually best
- Do not sling around the lower structure. Sharp edges can damage the rope or chain. Also the machine structure could also be damaged

5.7 Traction and Stability

Unless otherwise determined safe during the steep slope operation planning phase (see section 5.2.1, Traction assistance vs tethering and machine support), then operate only on terrain where you can maintain traction/stability to move up and down the slope.

5.7.1 Maintaining stability: all machines

- Conduct work straight up or down the slope, never travel across the slope. Minimize the angle 'out of lead'. Use a circle route to access timber if necessary
- Do not attempt to turn around on a steep slope; use a bench that is adequately flat and wide
- Cut narrower falling swaths to stay in lead as slope increases
- Avoid travel over obstacles; cut and move aside woody debris, minimize slash creation, shave stumps. Remove dense understory and ground cover that obscures operator visibility of the ground before moving machine
- Use booms and extendable grapples to reach trees and avoid travel across hazardous areas
- Understand and work within the machine's cutting diameter and lifting limits, considering boom reach and position relative to the ground slope; avoid "collecting" trees in the head and packing multiple stems
- Avoid small rock outcrops, or ensure stability when working on outcrops[11]
- Avoid double cutting
- Keep the saw head or grapple close to the ground for stability and to provide quick support if required
- Extend the boom uphill for travel when facing uphill. Do not travel uphill with the boom folded in or the attachment held high
- Keep boom close to the machine for travel when facing downhill
- Do not attempt to fell or lift trees that are greater than the machines safe lifting capacity
- Do not attempt to fell or lift trees that are beyond the machines safe reach
- Avoid swinging trees to the downhill side of the machine
- Avoid lifting the boom straight up and tilting trees back over the machine (to the downhill side).
- Position cut timber at 10 o'clock to 2 o'clock when working uphill
- Use a felling head that rotates at the wrist for better grappling of the tree
- Reduce bunch size taken in one swath if necessary
- Ensure the machine is in a stable position before swinging wood

5.7.2 Maintaining stability: wheeled machines

- Cut while facing downhill with a wheeled harvester. Keeping the weight of the engine uphill will increase stability
- Ensure proper tire inflation
- For line skidders, avoid winching a turn of logs at an angle to the machine
- For forwarders, ensure loads are close to the machine before initiating lift; avoid long reaches
- Use wheel spacers or wide flotation tires if conditions warrant
- Make smaller turns to avoid over-loading or over-balancing the machine
- Skidders: Carry turns as low to the ground as possible without hanging up on stumps and rocks

[11] http://www.bcforestsafe.org/files/Safety_Alert-New_Zealand_Rollover-June%2015-2016.pdf

5.7.3 Maintaining stability: tracked machines

- Work only from the bottom where slopes exceed 50%
- When working facing uphill, keep the idlers forward (upslope). Tracked machines are designed to have the load over the idlers when working
- When working facing downhill, keep the idlers downslope and the drive motors upslope. The drive motors are heavier and having more weight upslope will increase stability
- If it is necessary to swing downhill, swing gently and slowly and keep the boom and attachment close to the machine to avoid overwhelming the swing brake
- Extend the track frame to help increase machine stability

5.7.4 Maintaining traction: all machines

- Beware and exercise extra caution of higher risks when approaching or operating on :
  - Exposed rock and thin soils over rock
  - Wet, clay, and high organic content soils
  - Subsurface flows, springs, and poorly drained soils
  - Thick and solid bare ice surfaces
- Never back down a slope if you may need the attachment in front to stop a slide
- When negotiating a drop off, for example if the slope begins with a sharp edge, lower the boom and attachment ahead of the machine and use them to control the machine and prevent a slide
- For uphill travel use the attachment to stop the machine from sliding. It can be used to pull the machine uphill if necessary
- Do not swing the machine or boom when traveling on a slope as the machine may lose traction on one side

5.7.5 Maintaining traction: wheeled machines

- Use wheel tracks to increase traction
- Use chains with lugs on front wheels, or all wheels. Frequently inspect chains for integrity, condition and tightness
- Engage differential lock (if equipped) for added traction travelling uphill but disengage when descending or turning as steering will not respond properly when differential is locked

5.7.6 Maintaining traction: tracked machines

- Keep tracks and lugs in good condition
- Use narrow track configurations to increase ground pressure on very firm soils or rocky sites
- Use wide tracks to decrease ground pressure on soft surfaces. However wider track shoes may reduce undercarriage life more due to flexing when the machine travels over obstacles
- Use single bar grouser track shoes for the best traction on a slope. Single bar grousers allow deeper penetration and better traction and help prevent machine sliding
- Triple bar grousers are for flat ground and should not be used for harvesting on slopes

- Double grouser track shoes are a compromise between single and triple grouser shoes for both soft and hard ground, offering traction and flotation. Suitable for medium to firm ground
- Add ice lugs (tips or picks) to grousers to increase traction
- Keep the tracks parallel to the slope so the grousers provide resistance to sliding
- If a machine is equipped with a dozer type blade use it pointed downhill and pushed into the ground for grip against sliding. Do not raise and operate the machine up on the dozer blade structure. This reduces the traction of the track shoes and is hard on the dozer linkage.

5.7.7 Assessing risk of loss of traction

There are anecdotal reports both domestically and internationally of incidents where winch-assist cables have broken, usually from loss of traction. Traction loss leading to a rollover happens with an initial slip of the tracks/wheels leading to a slide and then a tip when an immoveable object is contacted. Initial slip of tracks/wheels can compact the soil and provide greater traction. At high soil water content with few air spaces, compaction of soil is limited because it can quickly become saturated, and saturated soil has a low tractive soil strength. These dynamic changes in the machine-soil interface during machine trafficking affects the coefficient of traction and impacts when or where a machine is likely to slide (McNabb et al, 2018). High slip is often a precursor to a track-soil failure resulting in a machine sliding downslope. High slip reduces soil strength by displacing slash and roots which help support the machine. During high slip the spaces between grousers can become packed with soil and a shear plane will develop at the bottom of the grousers. Machines can slide on moderate slopes 35-50%, with the risk of a tipover increasing on slopes >50%.

Precipitation and soil wetness are important factors affecting the dynamics of the slip-slide-tip process. The proximity of the capillary fringe of wet to saturated soil near the surface, and how water permeates into the subsoil layers or moves downslope is affected by geologic material, soil depth, restrictive layers and topography (Figure 25).

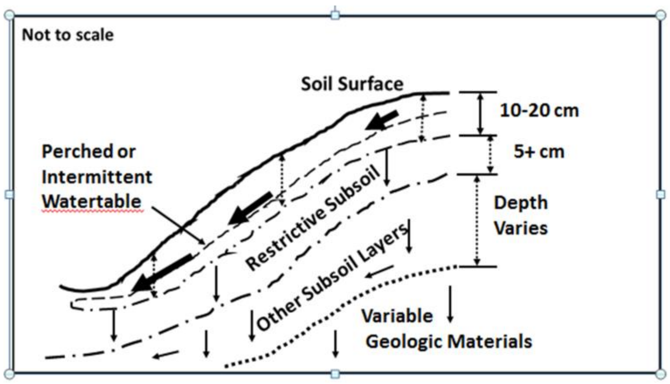

Figure 25. Factors affecting soil moisture and capillary fringe.

A preliminary risk rating for assessing loss of traction shown in Appendix 11.2 includes the following factors :

- Slope class
- Soil depth, restrictive layers
- Topography

- Soil texture
- Soil water content
- Precipitation

- Assess if soils are frozen since they usually have a low coefficeint of friction, which increases the risk of traction loss. Likewise compacted snow from multiple passes can create icy conditions.
- Soil profiles and soil moisture should be observed at road cuts close to operations.
- The potential for loss of traction should be considered during the steep slope assessment, prior to harvest, and revisited at start-up. Planning should aim to log wet areas when they are dry and have a plan to move to a lower risk site if it rains.

5.8 Engine slope limits

Most engines used in the construction industry are limited to 30 degrees or 70% for lubrication of the engine. A forestry machine with a leveling cab and engine compartment or with an engine with special provisions for working on slopes may allow a higher slope limit. Continual operation on slopes greater than the engine's design can reduce engine life. Inadequate lubrication could cause engine failure during operation and place the operator at risk.

- Ensure the machine's engine limit is known and not exceeded for extended periods of time.

5.9 Felling best practices

For general information on mechanized felling best practices on steep terrain, refer to the relevant materials from the BC Forest Safety Council (2011, 2015) available online[12].
To reduce the risk of severing the cable when cutting trees:

- Keep line tension to the minimum necessary
- Minimize swinging the energized felling head more than 90 degrees uphill when relying on the cable for support when facing in the downhill direction. This will prevent the cutting head from contacting and accidentally severing the cable or chain. Minimize the time that a hotsaw passes over the chain or cable

If trees are felled when the machine is facing uphill:

- Add a segment of heavy duty chain (~10 m long) between the assisting cable and the assisted machine (Figure 26). This will reduce cable wear from manoeuvers with the cutting head or grapple and will reduce the chances of severing the assisting cable with the saw head. (Not feasible for cutting machines with internal winch)
- De-energize a hot saw whenever the head is used to lift/reposition/move the cable/chain
- De-energize when climbing if not cutting

12 http://www.bcforestsafe.org/files/files/safety_info/steep_slope/BCFSC%20Steep%20Slope%20Assessment%20Form%20-%20Jul%2026%2011.pdf
http://www.bcforestsafe.org/files/res_xSteepSlopeLogging.pdf

- Activate grapple, feller director and intermittent disc type saws only when cutting a tree. Deactivate when performing other functions such as moving the head to/from tree, travelling with machine, manoeuvring or positioning the machine or head (i.e. for a multi-cut operation)

Figure 26. Heavy duty chain.

- Try to plan and layout felling four trees in advance
- If fallers are working after a buncher, do not fall trees into standing timber or brush timber, possibly creating overhead hazards. Create escape routes. See Washington safety alert[13] (SHARP 2017)
- Keep slash, logs and debris away from the front of machine, avoid traction loss
- Do not operate equipment below active felling
- The felling phase can create hazards if high stumps are cut lower, producing chunks that could roll down on workers later during extraction (Naillon and Rappin 2019)
- Multiple cuts should only be used to directionally fall a tree. The equipment must have sufficient pushing power to direct the tree against its lean. Sufficient holding wood should be maintained until the machine is positioned to make the final cut (see OHS 26.2-3 guideline)

5.10 Redirects

Redirects are commonly used to maintain the cutting machine straight up and down the hill, or as an alternative when there are challenges positioning the anchor machine. Terms such rub trees, siwashing or catching are also used. Wire rope may be accidentally or intentionally partially wrapped around an obstacle such as a stump, tree or rock. A redirected object may move or give way causing uncontrolled movement of the machine, shock loading of the cable, machine upset, operator movement relative to the cab, or line abrasion. Additionally, hazards may be created by the redirect object moving or as an overhead hazard from falling or leaning redirect trees.

A study by Hunt and Jokai (2019) with limited data found that wire rope tensions with redirects were high but comparable to tensions observed during operational logging without redirects. Spikes in tension occur with change in direction, starting uphill, climbing over obtacles and other operational activities. The study indicated that safe tension limits can be maintained if the manufacturers' directions are followed. A comparison of

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[13] http://www.lni.wa.gov/safety/research/files/94_07_2017_logging_tetherhazardsforfallers.pdf

redirects with a stump and block showed that tension at the feller buncher was 30% less than the tension at the anchor machine with a stump redirect of 35°, compared with 25% less tension at the buncher using a block. The friction of a stump redirect transmitted less tension to the feller-buncher (Figure 27).

Figure 27. Redirects with a stump (left) and block (right) at approximately 35°.

- The load on a stump/stem increases with an increasing angle of redirect. Wire rope can saw through a stump/stem, especialy a single-line (Figure 28). If a sharp redirect angle is used on an individual stump, the time and distance traveled using the redirect should be limited to reduce the chance of failure

Figure 28. Redirect stump that has been sawed through by a single wire rope.

- Multiple stumps or stems should be used to redirect wire rope for winch-assist operations (Figure 29). Reliance on a single stump could result in shock-loading if the stump fails (Figure 30)

Figure 29. Redirect with three rub trees.

Figure 30. Redirect stump about to fail (left arrow). Stump failed and rope caught on adjacent stumps (right arrow).

- The use of multiple redirects will cause wear to the wire rope but is deemed a safer alternative than relying on a single stump.
- Blocks should be used to reduce cable wear.
- Minimize sharp angles when redirecting.
- Position the rope low on the redirect object.
- Only stable redirect objects that will not move should be used.
- Frequently check redirect objects to confirm stability. Check a redirect object after any change that may reduce its stability, e.g. saturated soils after heavy rain.
- The diameter of the wire rope in relation to the diameter of the redirect object (D/d ratio) should be considered so bending fatigue doesn’t compromise the wire rope integrity (see sec 5.3).
- Standing trees used as a redirect must be felled promptly before workers can access the area.
- Keep two tree lengths away from any standing tree redirects when the rope is under tension.
- Position the rope to avoid unintentional redirects. Inspect the rope’s route regularly for unintentional redirects and remove them.
- Operators should be trained on the primary factors that influence tension spikes. Maximum tension spikes occur most often when the machine stops and starts while moving in the downhill direction. This is primarily due to imperfect synchronization and non-constant tension between the winch and the machine.
- Regular inspection and maintenance of wire rope and system components is required

- The Safe Working Loads of all the components of the system (e.g. wire rope, connectors, chains, shackles, pins and drum components) must accommodate the maximum anticipated loads.
- Data loggers should be used to collect tension data from the anchor machine. This will facilitate continuous improvement to identify high tension events and modify practices to reduce tension spikes. Data would also provide due diligence in the event of an incident. Monitoring tension at the working machine connection would provide even better data.
- Anchor machines are commonly set up parallel to the road where road width is limiting. A series of redirects are sometimes used so fewer anchor machine moves are required, improving productivity (Figure 31). This provides an element of protection in case the anchor machine should be pulled off the hill. Holes must be properly filled in if the anchor machine is dug in on the road.

Figure 31. Anchor machine aligned at 90° with redirects.

5.11 Lead angle

The lead angle is the angle from the anchor, winch, fairlead, or catch to the supporting machine.

- Keep the cable straight and directly up and down the hill for a direct uphill pull on the assisted machine. Minimize side pull on the assisted machine.
- Follow any manufacturer's specifications about the lead angle of the cable exiting the fairlead. Reposition the anchor machine or use catching as necessary to maintain a suitable lead angle that is within any manufacturer's specifications for horizontal and vertical angles, e.g. horizontal angle maximum: 30 degrees from winch machine centerline in either direction; vertical angle maximum: 45 degrees from the horizontal plane.
- Operate straight up and down the slope, avoid cross-slope operation.
- Align the cutting machine with the direction of pull when winching.

5.12 Anchoring

Typically an excavator or bulldozer is modified to act as an anchor for the base machine. Other anchors include stumps, standing trees, deadmen and rock anchors. Extensive illustrative material and specifications for anchors suitable to winch-assist application can be found in WorkSafeBC's Cable Yarding Systems Handbook (WorkSafeBC, 1993)

5.12.1 Machine anchors

- Anchor machines should be "dug in". Use the anchor machine's blade or bucket to secure the machine by placing the blade or bucket against a stump or dig it into the ground, as necessary. For bulldozer style blades, force the anchor machine's blade at least half-way into the soil (Figure 32). Reversing the excavator bucket improves its purchase in the soil
- Fill in dug in holes in roads so hazards to traffic aren't created[14]
- Avoid soft road shoulders
- Guy the anchor machine to one or more stumps, trees or other suitable anchors on the machine's uphill side with one or more guylines as necessary to prevent anchor movement (Figure 17). Ensure guyline(s) are tight and the forces are equal (if using more than one guyline) before operating the system
- Ensure the anchor machine is level, or slightly elevated in front. Road crowns can act as a pivot. See Washinton safety alert[15] (Sharp 2018)
- For down sloping ground, place the anchor machine in the least down sloping position and secure it using one of the methods above
- Extend excavator booms past 90 degrees
- Align the anchor machine so the pull is as straight as possible
- Position the anchor machine far back from the edge of the road to provide better angles when the working machine is close to the anchor machine
- Apply the anchor machine's track brakes during winching operations
- Use an anchor machine with a low center of gravity and low cable exit point(s) to prevent overturning
- A longer rope deployment may add extra ground friction resistance to the anchor system and help to improve the anchor's resistance to movement
- Install and use a tension monitor that relays information to the base machine operator (Figure 33)
- Install and use video camera(s) to provide a live feed of cable spooling on winch drum to base machine operator
- Operators should do a straight pull test after each set up to ensure the anchor is holding.
- If the communication signal is weak between the anchor and working machine, suspend opertions until the signal can be improved
- Install and use anchor movement alarm (break away switch) that signals the operator and applies the winch brake should the anchor machine move
- Take extra care to secure the anchor machine adequately on frozen ground as the coefficient of friction will be very low

[14] http://www.lni.wa.gov/Safety/Research/Files/94_10_2018_Logging_BaseMachineRoadHoles.pdf
[15] https://lni.wa.gov/safety/research/files/97_05_2018_logging_nearmissalert_basemachinepulledover.pdf

Figure 32. Machine anchor.

Figure 33. Cable tension display from data logger.

5.12.2 Stump and tree anchors

- Use appropriately sized stumps and trees. See cable yarding literature (WorkSafeBC, 1993) for recommendations on how to select a good anchor stump or tree (Figure 34)
- Use accepted tie back procedures if using multiple stumps or trees. Refer to the Cable Yarding Systems Handbook (WorkSafeBC 1993)
- Where necessary, notch stumps as per standard cable logging methods
- Anchor straps must match or exceed the safe working load of the wire rope in use
- Use caution if rigging a block purchase to redirect the rope's force as forces on the anchor can become large, depending on the angles involved, i.e. the force on the anchor can be double the pull on the rope

Figure 34. Use of appropriate species and sized stump.

5.12.3 Deadmen and rock anchors

- Review and follow Instructions for selecting and installing deadmen and rock anchors described in the Cable Yarding Systems Handbook (WorkSafeBC 1993)

5.13 Emergency procedures

Follow any emergency procedures provided by the manufacturers in the event of an incident. In addition to regular safety inspections and maintenance, the following procedures are recommended.

Emergency planning

- Check-in procedures should be implemented and tested
- Inspect and test escape hatches. Schedule drills to ensure that the operator can fit through the hatch[16]
- Have a plan for evacuating an operator off the hillside
- Have a plan for repairs and delivering heavy parts to a downslope machine
- Always move machines to safe areas to perform maintenance[17]
- Clean and inspect build up of flammable materials or leaks within the engine compartment (e.g. Tigercat procedures[18])
- Fire suppression systems should work in any orientation
- Have procedures for using and maintaining a handheld tool for operator to cut their way out in the event of a rollover, or rescue procedures for crews to cut operators out (Figure 35)

Cable system failure (may include machine attachment point, connectors, chains, wire rope, and anchors):

- Activate the blade braking device on the assisted machine if available
- Activate the track or wheel brakes on the assisted machine

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[16] http://www.bcforestsafe.org/files/August%202010%20Escape%20Hatch%20Alert%20of%20Month.pdf
[17] https://www.bcforestsafe.org/files/Alert-New_Zealand-Stem_Enters_Processor_Cab-May_30-2019.pdf
[18] https://www.tigercat.com/wp-content/uploads/2014/08/safety_fire_prevention.pdf

- Use the head's grapple to hold on a tree or stump or set the head or heel rack (if available) into the ground to provide further braking resistance
- Exit the cab only if safe to do so once the assisted machine is fully immobilized

Communication failure between operator and winch assist machine:

- Follow the manufacturer's operating procedures. With a constant tension system, the winch will continue to maintain the tension that was pre-set before the communication failure.

Figure 35. Handheld tool for emergency egress.

6 ENVIRONMENTAL CONSIDERATIONS

Ground-based equipment can potentially damage soils through excessive disturbance, primarily by causing rutting or compaction which can reduce future tree growth. Rutting on steep slopes may also cause water redirection or concentration and result in erosion and mass wasting. Best practices to limit environmental impacts include:

- Use tire tracks on wheeled machines to help prevent wheel spin
- Use wider track pads to reduce ground pressure on tracked machines
- Distribute slash and drive equipment over it in soft ground conditions
- Align logs and slash so water flow is not concentrated
- Minimize the turning of wheels and especially tracks
- Closely monitor operations where track/wheel spin is damaging soils and cease or relocate if necessary
- Minimize repeated machine passes over the same trail
- Avoid turning the tracks when working on sensitive soil types as this may create ruts which could direct and concentrate water flow onto slopes
- Use the winch system wherever an un-tethered operation would cause soil damage
- Maintain a constant tension so the machine does not slip or slide
- Be aware of any track or tire spin due to malfunction, unsuitable conditions, or exceeding the limits of the system and stop before damage is done to the soils
- Follow wet weather shutdown guides or any specific prescriptions by a qualified professional
- Recognize that winch-assist operation may not be suitable everywhere and an alternative harvest system such as hand falling, or cable yarding may still be necessary in some areas under certain environmental constraints.

7 OPERATOR CONSIDERATIONS

- The operator must be trained, skilled and competent at working on steep slopes
- Newly hired operators should have a training schedule with competency evaluations by qualified staff and gradual exposure to steeper slopes.
- Complacency is a risk. Complacent operators could skip steps such as inspections or engaging the anchor movement indicator. Operators are trained and skilled yet may not apply all the procedures due to human factors. Just because he says he completed the checklist, did they? Regular safety observations are recommended (Figure 36). Inspect to ensure that safety features are not bypassed[19] (Figure 37)
- Ensure equipment inspection is completed for loose connections after moves[20]

Figure 36. Conduct monthly safety observations on operators.

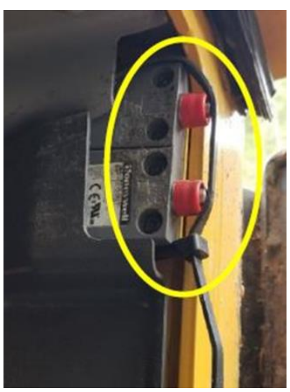

Figure 37. Safety override. Interlock buttons held downby zap strap. (Photo Washington Labour and Industry).

- Do not allow untrained employees to operate equipment (e.g. move anchor machines) unless under direct supervision of a trained operator[21]
- Operators should understand the risk mitigation systems in use for each upset condition (Worksafe New Zealand 2018).

[19] https://www.lni.wa.gov/Safety/Research/Files/94_16_2019_Logging_SafetyInterlockBypass.pdf
[20] http://www.lni.wa.gov/Safety/Research/Files/97_01_2017_Logging_NearMissAlert_SplicedEyeBreak.pdf
[21] http://www.lni.wa.gov/Safety/Research/Files/97_04_2017_Logging_NearMissAlert_BaseMachineMoveBreaksTether.pdf

- Operating tethered equipment on steep slopes is both physcially and mentally exhausting. Operator fatigue plans should be developed and followed.
- Operators should be physically fit and able to climb up road cuts to move a machine
- See the BC Forest Safety Council's (BCFSC) Steep Slope Logging Resource Package[22] for more information on operator considerations.

8 PLANNING AND LAYOUT

There are many anecdotal reports of problems with winch-assist operations that stem from poor planning and layout. This is an area of potential improvement in safety and efficiency.

- Planners should understand the contractors' suite of equipment and understand the equipment capabilities, limitations and contractor preferences when designing blocks. The type of equipment available, method of extraction and winch line length strongly affects layout design and extraction distances.
- All phases – falling, extraction, processing, loading should be considered during layout.
- It is helpful for contractors to have input in road development early on (e.g. 2 years) when harvest areas are being developed.
- Recommed that company planners and contractors revisit harvested winch-assist blocks on site to discuss what worked and didn't, and how planning and layout can be improved going forward.

8.1 Steep slope assessment

- Blocks should be walked to identify hazards
- A steep slope assessment must be done by a qualified person for operations with tracked equipment on slopes >40%, or with equipment specifically designed of use on slopes >50%, as per OHS Regulation 26.16. Required elements of the assessment are indicated in the OHS Regulation Guideline Part 26, Equipment Operation[23]
- Recommend following the Steep Slope Hazard Assessment Tool portion of the BC Forest Safety Council's Steep Slope Resource Package[24]
- Update the steep slope assessment or work plan as conditions change[25]
- Site specific procedures should be developed for each type of equipment operating on a steep slope
- Anything over 40% is potential winch ground - describe soil types and rock types as part of the assessment

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22 http://www.bcforestsafe.org/files/res_xSteepSlopeLogging.pdf
23 https://www.worksafebc.com/en/law-policy/occupational-health-safety/searchable-ohs-regulation/ohs-guidelines/guidelines-part-26
24 http://www.bcforestsafe.org/files/res_xSteepSlopeLogging.pdf
25 http://www.bcforestsafe.org/files/Safety_Alert_Canfor-Buncher_Rollover_02-1-2019.pdf

- Clearly identify rock bluffs with some detail on height and ground features. Steep terrain combined with soft ground on top of bedrock; heavy duff, moss on top of an edge or rock or sheet rock (e.g. flat granite or shale with minimal traction) is a no go situation for tracked machines.
- Dense understory kills machine productivity – include stand description for contractor's consideration of felling head attachment options

8.2 Maps

- Layout crews should use the best available map tools, preferably LiDar and geo-referneced PDFs. A combination of electronic and printed LiDAR maps should be provided to the contractor (Figure 38):
    - Provides better accuracy and granularity of info
    - Assists operators with their approach to gullies
    - Hill shades might be better to identify terrain features on slopes less than 40%
    - Colour coding of slopes works best if more detailed in the 50 to 70% range of slopes (separate colour for each 5% change) and less detailed for the rest (one colour for 15 to 20% change)

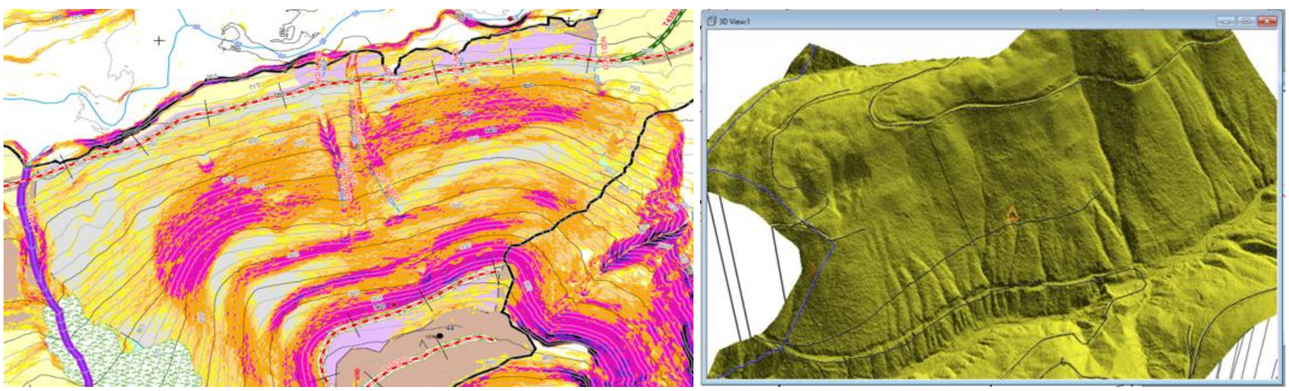

Figure 38. Colour-coded slope contour maps (left) and hillshading (right) for harvest block planning.

- Identify bench locations that are important for access, anchors and design consderations
- Indicate proposed cutting patterns and corridor locations, which provide a starting point for contractors
- Show some ground distance measures to operators perspective relative to amount of available winch cable
- Clearly identify pertinent information such as deflection lines (Figure 39) and slope directions to improve contractor and operator efficiency:
    - Hazards and control measures (location of unstable ground, rocks, bluffs, danger trees)
    - Environmental and heritage resources (bear dens, eagle nests, CMT locations)
- Identify any block adjacency issues (e.g. powerlines)
- Provide information on all known hazards to contractors and workers

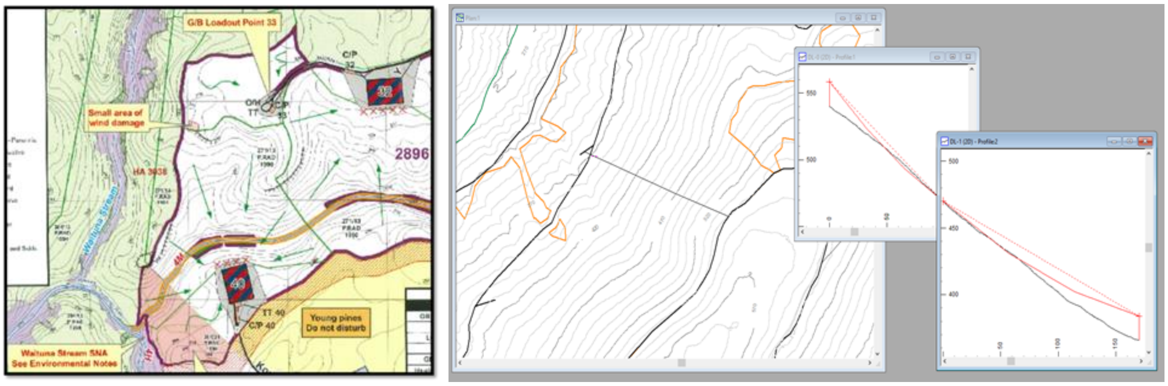

Figure 39. Contour map with pertinent site information (left) deflection lines if cable extraction (right).

8.3 Winch-assist general layout principles

- Identify anchor points, landings, trails
- Block boundaries should, wherever feasible, follow the contours of the terrain and have straight lines up and down the slope with minimal side-sloping
- For optimal winch-assist operations, leave patches within harvesting blocks should ideally have square-shaped, straight lines and located the farthest possible from access points (Figure 40). Locating them near access points at the top of the harvest block and having them irregularly shaped negatively affects productivity and could pose some safety challenges trying to harvest around them
- Locate upper and lower boundaries at flatter slope breaks to allow for trail construction and equipment access

Figure 40. Optimal shape and location

- Avoid rock and undulating ground, excessive amount of obstacles (large rocks or old-growth stumps) especially with track-based systems
- For extraction, decking, processing and loading, field planners should clearly communicate to right-of-way crew the need to leave suitable-sized strong high stumps on both sides of road – used for winch-assist anchors, redirecting, decking space (Figure 41), and guyline anchors

Figure 41. High stumps used for decking.

8.4 Planning of harvesting phases

- Each harvesting phase should be considered during planning - felling phase should make extraction phase easier and then processing and sorting and loading
- Winch-assist systems can result in higher productivity in the downstream phases than traditional methods. Plan operations to avoid phase congestion which is having phases too close together which creates a high risk for injuries or incidents

8.4.1 Felling

- Establish the order of operations
- Manual fall first to avoid creating overhead hazards[26]. Involve fallers in the planning process[27]. See Naillon (2017)
- If leaving a hand falling "island", keep those clear of overhanging hazards, leave access and emergency retrieval routes. No hand falling should commence until a risk assessment has been undertaken by the hand faller and his supervisor
- A BC Forest Safety Infoflip is available to help plan the integration of mechanical and hand falling operations
- Provide the falling machine operators with pre-established yarding direction and decking locations on maps so they can orient the wood for yarding

8.4.2 Cable yarding

- Decking space is critical when grapple yarding bunched wood from winch-assist systems. Change the road location if necessary to ensure adequate decking space for high-productivity grapple yarding
- Ensure adequate guyline clearance above the road
- Felling direction for yarding should be determined beforehand

[26] http://www.lni.wa.gov/safety/research/files/94_07_2017_logging_tetherhazardsforfallers.pdf
[27] http://www.bcforestsafe.org/files/aom_2019_09.pdf

- Identify areas where trees out of deflection should be forwarded into lead with good deflection through the use winch-assist equipment to faciliate yarding
- Provide a thorough deflection line analysis of the block
- Identify volume of wood coming to each “landing” on the road and keep them 20-30 meters away from the “draws” and the gullies

8.4.3 Hoe chucking

- Less stump-rigging for grapple yarding is possible by using a hoe-chucker to consolidate wood for cable yarding
- Then spur roads may not be needed to get volume that is out of deflection for cable yarding
- Road to road harvesting is optimal (i.e. a road location along the top boundary and along the bottom boundary of block)
- Plan for straight lines of block boundaries - corners, leave tree pockets and holes make winch-assist operations more difficult
- Clearly identified old trails and benches are very beneficial
- Road construction crew should identify and design wider spots or ramps for getting on and off the road.
- Hoe-chucking more than about a tree length uphill is very challenging

8.4.4 Skidding

- Clearly identified old trails and benches are very beneficial
- Identify skid trails for extraction and rehabbing afterwards
- Road construction crew should identify and design wider spots or ramps for getting on and off the road.

8.4.5 Forwarding

- Clearly identified old trails and benches are very beneficial
- Sideslope movement is to be avoided for forwarders – up and down the slope preferred
- Road construction crew should identify and design wider spots or ramps for getting on and off the road

8.5 Roads and trails

In comparison to cable yarding blocks, winch-assist harvesting is usually associated with higher production volumes potentially leading to bottlenecks at the extraction and processing phase.

- Ensure sufficient decking space locations could avoid such bottlenecks.
- Consider second-stage forwarding of some of the extracted volumes to a nearby spacious processing area identified by layout engineers where road width could be limiting for operational requirements
- Road locations can sometimes be moved to cheaper locations or roads eliminated compared to normal grapple yarding because the wood can be moved into areas with adequate deflection by the winch-assist machine
- Roads should go to the end of blocks - go-ahead roads help for anchoring, decking and processing space and reduce bottlenecks

- Provide adequate pull-outs for pickups and equipment
- Provide an access ramp through steep road cuts and fills so the working machine can safely access the block (Figure 42)

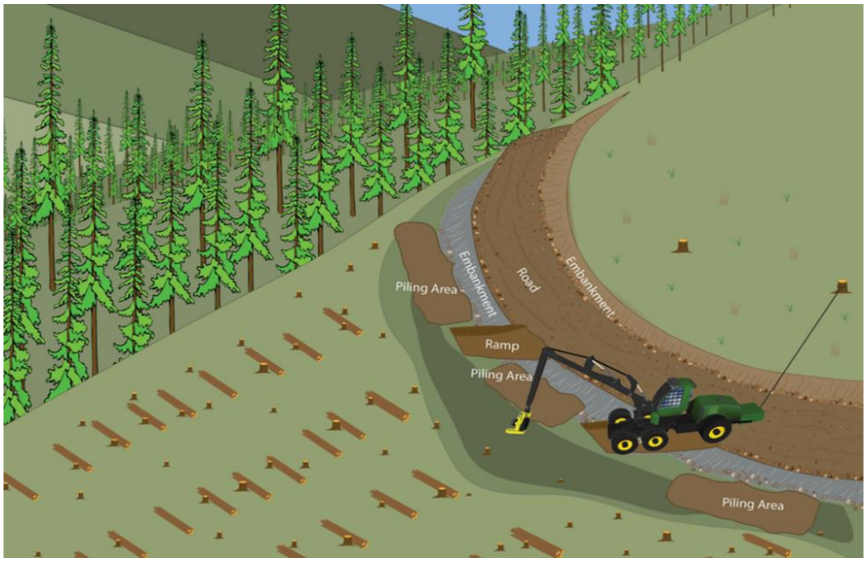

Figure 42. Ramps providing access off the road.

8.6 Anchor points

- Anchor locations may limit what can be reached with winch-assist systems, especially if redirecting is limited
- With winched anchor systems, there are generally two contractor preferences:
    - Use a dedicated operator in the anchor machine to monitor operations as well as reposition the anchor winch machine as required to always stay in lead with assisted machine without the use of cable redirects. This is common where small tree size limits redirect options
    - Some contractors try to position anchor winch machine only once a day (or less) and fell multiple corridors using redirecting techniques (Figure 43). When this technique is possible, it can help minimize machine moves, keep the anchor machine further away from falling operations, and can help when space on road locations prove challenging to face the anchor downhill. To take advantage of large high stumps on road right of ways, field planners and road construction crews should identify the need for high stumps and leave them to provide options for the winch/falling phase. Reducing anchor moves can increase productivity and improve overall utilization

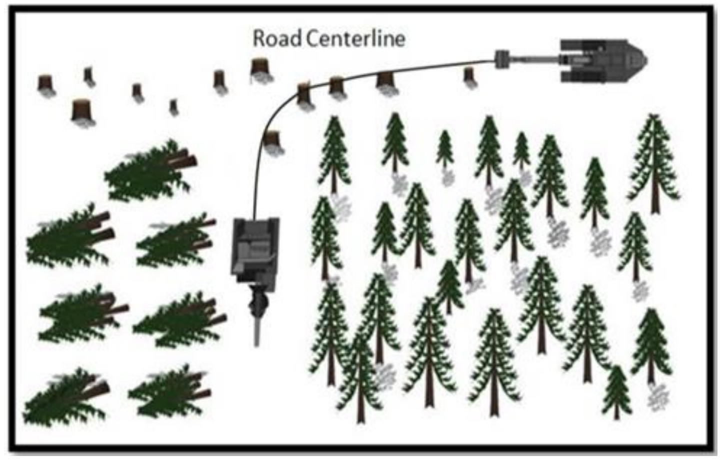

Figure 43. A photo (left) and a schematic example of anchor positioning at distance using redirects (right).

9 CONCLUSIONS

Winch-assist harvesting has progressed considerably since Demo 2016 when it was first showcased in BC. This report describes best practices for winch-assisted forestry operations but is not exhaustive as new practices continue to evolve. Further collaboration with contractors, operators, regulators, researchers, planners and manufacturers will continue to provide learnings that will make steep slope harvesting operations safer and more efficient. It is also expected that feedback on this draft document will be received from a wide range of groups which will be incorporated to improve future versions.

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11 APPENDICES

11.1 List of manufacturers' and landowners' best practices guides and manuals

Haas Machinenbau GmbH & Co. KG, 2015, Haas engineering foundation engineering part processing hydraulics operating manual for the JD harvester with a traction aid cable winch (tacw), 38 pp.

Haas Machinenbau GmbH & Co. KG, n.d., Haas engineering special bodywork part processing hydraulics operating manual for the JD forwarder with a traction aid cable winch 25 pp.

Hancock Forest Management, 2016, Interim best practice guideline cable assisted steep slope harvesting, 37 pp.

Herzog alpine synchrowinch forwarder, 2013 Manual del usuario forwarder número pieza de repuesto pd1000, 91.pp. with appendices 207 pp.

Herzog alpine synchrowinch universal, 2013, operator's manual, 88.pp. with appendices 151 pp.

ROB Remote operated bulldozer, n.d., specification booklet, 19 pp. plus example forms

Tmar Industries, 2015, Log Champ LC150 steep slope traction assist machine, operation and maintenance manual, 83 pp.

Tractionline, n.d., Induction/operator training, 5 pp.

Tractionline, n.d., Operators manual & safe working practices, 38 pp.

Weyerhaeuser, 2016, Weyerhaeuser best management practice guideline cable assisted steep slope harvesting, 12 pp.

11.2 Preliminary risk rating for loss of traction

Criterion	Deep soils >1 m		Soil Depth <1 m		Restrictive <1 m		Perched Water Table	
	30-50%	50+%	30-50%	50+%	30-50%	50+%	30-50%	50+%
Topography (check all that apply)								
- Convex	0	0	0	0	0	0	0	0
- Concave/valleys	1	1	1	2	1	2	2	2
- Lower slope positions	1	1	1	2	1	2	1	2
- Downslope: uneven/obstacles	0	2	0	2	0	2	0	2
- Wet Site Plant indicators	2	3	2	3	2	3	2	3
Soil Texture (check one)								
- Sandy	0	0	0	0	0	1	0	1
- Silty	1	2	1	2	2	3	3	4
- Clayey	2	3	2	2	2	2	4	5
Soil Water Content (check one)								
- Dry	0	1	0	1	0	1	0	1
- Wet	2	4	2	4	3	5	3	5
Precipitation (check one)								
After Wet Weather Safety Shutdown (>5 cm precip)								
- Shutdown > 48 hours	0	2	1	2	1	2	2	2
- Shutdown < 48 hrs	2	3	2	4	3	5	1	5

Preliminary risk ranking system (McNabb et al, 2018)

For slopes <50%, the rating is for sliding only.

For slopes >50%, the rating is for sliding and tipover

For slopes >50%, the risk of sliding resulting in a tipover increases as the values increase above 12-19.

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