Mechanized Harvesting, a Safer Alternative to Manual Tree Falling

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Under what conditions is mechanical harvesting going to be a safer alternative to manual tree falling in B.C.?
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SUMMARY

- Removing workers from exposure to overhead hazards and placing them in ROPS/FOPS-protected cabs will almost always improve worker safety.
- The transition toward safer harvesting should focus on increasing the safe operating range of mechanized harvesting equipment that protects workers in machine cabs.
- North America has ten new winch-assist systems operating, and 50 machines are expected to be operating in B.C. this year. The rate of adaptation and innovation in applying the new technology in B.C. is very fast. This is a very positive development, because it means manual falling is increasingly being replaced by mechanization.
- The biggest challenges of adopting the safest tree falling technology in B.C. are the lack of operator training and lack of adequate best management practices.
- In order to transition to safer tree falling, further expertise on planning and layout for new steep-slope harvesting is needed, and WorkSafeBC should emphasize the importance of planning for safe practices in the steep slope assessment and layout phase. Early adopters should be supported by licensees, regulators, and researchers to increase implementation of new technology. Further development of best management practices and operator competencies is needed. For areas that cannot be felled mechanically and hand-falling is still required, development of new technologies should be encouraged, such as remote control or robotics.
- Greater government support is needed for operator training. This should target training schools, in order to attract more recruits and to provide simulators for more cost-effective training. On-the-job training should also be supported because formal training will not produce enough operators quickly enough to meet short-term needs.
- The regulatory implications of this project involve standards for manufacturing and importing equipment into B.C., and safe operating practices. It is recommended that the development of B.C. winch-assist standards should be in alignment with the International Standards Organization (ISO) as much as possible.
- Safe operating practices for new winch-assist techniques will still need to be adapted to some of the unique regional conditions in B.C. Because the technology is new and evolving, it is recommended that WorkSafeBC carefully monitor work practices, keep field staff informed of developments, and work with industry to ensure that current due diligence is applied. WorkSafeBC should identify issues of concern and work with researchers, industry, and manufacturers to find solutions and develop guidelines.
EXECUTIVE SUMMARY

This study addresses the research question, *under what conditions is mechanical harvesting going to be a safer alternative to manual tree falling in B.C.?* Seven main topics addressed in the study are:

1. Challenges faced in B.C. with adopting the safest technology in tree falling
2. How the B.C. industry can best transition into safer tree harvesting
3. The type of training programs required to adopt mechanical harvesting
4. Review of available technologies available worldwide that have potential use in B.C., and how their injury rates and fatality rates compare
5. Review of existing science and research needs for developing international standards on safe operations for winch-assist systems
6. Development of best management practices (BMPs) for winch-assist systems
7. Physiographic conditions affecting the feasibility of adopting mechanical harvesting

The study methodology was to consult stakeholders in the forest industry, including the FPInnovations Steep Slope Steering Committee and Manufacturers Advisory Group, contractors, international research agencies, and the BC Forest Safety Council. Observations were also made from field trials. An on-line survey was conducted regarding operator training.

The biggest challenges of adopting the safest tree-falling technology in B.C. are the lack of operator training and lack of adequate BMPs.

Safer tree harvesting can be achieved by reducing hand-falling and worker exposure to hazards. The transition toward safer harvesting should focus on increasing the safe operating range of mechanized harvesting equipment that protects workers in machine cabs. In addition to operator training and BMPs, wide dissemination of information on technology options is needed. Competencies should be developed for operators. Further expertise on planning and layout for new steep-slope harvesting is needed, and WorkSafeBC should emphasize the importance of planning for safe practices in the steep-slope assessment and layout phase. New techniques need to be demonstrated and assessed for commercial, compliance, and technical suitability. Early adopters should be supported by licensees, regulators, and researchers to increase implementation of new technology. Development of B.C. standards should be consistent with international efforts, i.e., ISO. For areas that cannot be felled mechanically and hand-falling is still required, new technologies should be developed, such as remote control or robotics.
Training programs that facilitate the adoption of mechanical harvesting were reviewed in several jurisdictions. In most international cases where mechanical harvesting has been broadly adapted, formal training in institutions is the most common form of operator training. Greater government support is needed for operator training. This should target training schools in order to attract more recruits and to provide simulators for more cost-effective training. On-the-job training should also be supported because formal training will not produce enough operators quickly enough to meet short term needs.

Six tree-falling technologies were reviewed: 1) handfalling and felling machines that are 2) tracked, 3) wheeled, 4) wheeled winch-assist, 5) tracked winch-assist, and 6) remotely operated. Factors that limit mechanized tree falling in B.C. are terrain, slope, tree size, and very wet ground. The most important factors are terrain and slope, which are the focus of this report.

With a proper steep-slope assessment and diligent safe practices, both European and New Zealand winch-assist systems can be adapted to B.C. conditions. FPInnovations’ reports on winch-assist equipment evaluations and a comparison report that indicate the suitability of these system for B.C. conditions are included here, in Appendix 8.2. B.C.’s rugged terrain and natural forests provide challenges not found in other jurisdictions. Some special requirements for systems working in B.C. include the ability to work in the following conditions: above the road; in remote and rugged conditions, with rocky outcrops; in extreme cold and deep snow; and in natural forests with dense understories, snags, and large obstacles.

Nominal slope limits for the main falling methods were discussed. Actual slope limits vary considerably based on factors such as machine features, ground conditions, operator skill, and tree size.

Generally, tracks provide better traction than wheels because they have more surface area. FPInnovations’ research has shown that tilting undercarriages can improve the stability of tracked machines in most positions. Wheeled machines with articulated undercarriages can have better ground contact and stability on rough ground with obstacles compared to tracked machines. Manuals for European-style, winch-assisted, wheeled harvesters indicate that they are to be operated only on slopes where they would be stable without a winch.

Manual felling accident rates are clearly higher compared to mechanized logging rates. The highest accident rates with mechanization are in maintenance and repair activities, not actual tree felling. It is very challenging to differentiate injury rates for different types of systems. There has only been one serious injury with winch-assist operations.
Existing science on winch-assist operations is limited because the application is still very new. Further research is needed to understand the effects of operations on cable tension and how to prevent incidents from occurring. There is a need for greater understanding of the machine/soil interface. Stability and traction information is required to understand the safe working limits of forestry machines. For systems with winches integrated onto the cutting machine, tree or stump anchor strength is critical. Investigations are needed to ascertain how rub trees can be used safely or avoided.

Experience in New Zealand has been instructive, and it has shown that BMPs continue to evolve as experience is gained with the new winch-assist technology. BMPs have been developed by manufacturers, forest companies, and contractors independently. There is a need to compile BMPs for B.C., to share them, and to continuously improve them from learnings, research findings, and new developments. A preliminary draft BMP document is contained here, in Sec 8.1. A detailed section of the BMP, Wire Rope Integrity for Winch-Assisted Forestry Equipment – Draft Report, is included in Sec 8.2.

The physiographic conditions affecting the feasibility of adopting mechanical harvesting was discussed based on a GIS analysis conducted by MoFLNRO’s Inventory and Analysis Branch. The results indicated that 24% of the volume was on slopes greater than 35% for the province. Coastal and Interior proportions were 56% and 14%, respectively. Much of the steep ground is between 40 and 60%, and the proportion of ground greater than 80% is relatively small.

The regulatory implications of this project involve standards for manufacturing and importing equipment into B.C., and safe operating practices. It is recommended that the development of B.C. winch-assist standards should be in alignment with the International Standards Organization (ISO) as much as possible. Since the technology is new and evolving, it is recommended that WorkSafeBC carefully monitor work practices, keep field staff informed of developments, and work with industry to ensure that current due diligence is applied. WorkSafeBC should identify issues of concern and work with researchers, industry, and manufacturers to find solutions and develop guidelines.

Operator training is very important for ensuring that mechanical harvesting is a safer alternative to manual tree falling. Government funding and policies should be developed to support operator training, either through educational institutions or on-the-job training.

Keywords: steep slope; manual tree falling; winch-assist; tether; mechanized harvesting; safety.
REPORT

1 INTRODUCTION

In this report FPInnovations responds to the WorkSafeBC’s research question:

"Under what conditions is mechanical harvesting going to be a safer alternative to manual tree falling in B.C.?"

The approach taken to address this question presumes that mechanical harvesting is usually safer than manual falling. Removing workers from exposure to overhead hazards and placing them in ROPS/FOPS protected cabs will almost always improve worker safety. This study considered conditions when manual falling is required, when there are concerns with mechanization, and how mechanization can be more widely implemented safely.

2 METHODOLOGY

2.1 Terms and Definitions

- Winch-assist – also referred to as cable-assist, traction-assist, tethering, hang-forwarder or hang-harvester – the practice of attaching a cable or cables to a forest machine to increase its operability on slopes.
- Traction-assist vs machine support
  - “traction assist” only is an operational mode where the supported machine when stopped can remain stationary on the slope travelled upon without any further rope assistance;
  - “machine support” is an operational mode where, while being operated, the supported machine must be secured against sliding down the slope travelled upon or against overturning. In these cases, a back-up system is required.
- Back-up system – in the event of a component failure of the winch-assist system, currently accepted (in New Zealand) back up systems include a blade brake, a double-line system, a warning system, or a combination of any of those (see Appendix 8.1)
- Tethering/traction winch - a winch normally mounted on the self-propelled forest machine itself or placed separately providing additional traction for the forest machine on steep slopes or on soils with limited bearing capacity, which consists mainly of a rope, a power driven drum or a capstan power transmission and spooling devices, attached to the base machine’s frame or installed autonomously.
- Rope - steel wire rope according to EN12385-5 or synthetic rope, traction assistance winches normally work with.
- End connector - Device that enables connection of the rope to the load, the supported machine, an anchor point or transfer of the rope tensile force onto fastening gear.
• Attachment point - Connecting point at the supported machine which is designed for attaching the rope of an autonomous traction assistance winch.
• Anchors - Fixed point in the surrounding area of a traction assistance winch of sufficient bearing capacity (e.g. on a tree, on a heavy mobile machine or in the ground) used to attach the cable of an integrated winch or the body of an autonomous traction assistance winch to provide sufficient counter bearing for the arising forces of the rope of the traction assistance winch.

2.2 Methods used in the report sections

The methods used for addressing the seven sections of the contract are described below.

Sec 3.1 – Challenges faced in B.C. regarding the adoption of the safest technology for tree falling.

An analysis of challenges to adopting innovative tree falling technology was conducted by consulting stakeholders including forest industry members, manufacturers, contractors, BC Forest Safety Council and international researchers.

Sec 3.2 – How the B.C. industry can best transition into safer tree harvesting.

Generic steps to successfully introduce and implement safer alternatives were described following similar consultations as in Sec 3.1.

Sec 3.3 – The type of training programs required to encourage adoption of mechanical harvesting

Literature on forestry operator training was reviewed. Training agencies in B.C. were contacted and interviewed. FPInnovations conducted an on-line survey and contacted numerous international agencies to complete the survey.

Sec 3.4 – Review of technologies available worldwide that have potential use in B.C.

Based on FPInnovations expertise, a decision tree for mechanized alternatives to hand falling was developed. A matrix comparing alternative felling methods and technologies worldwide was compiled. Hazards, site and stand conditions, operating limits, and injury rates of fatality rates were discussed.

Sec 3.5 – Review of existing science and research needs for developing international standards for safe winch-assist operations.

Research needs were identified from ongoing activities within FPInnovations’ Steep Slope Initiative. International conference calls were conducted with the University of Canterbury (New Zealand), Future Forests Research (New Zealand), and Oregon State University to keep apprised of international research efforts. Additional contacts were made with BOKU (Austria). Research needs were discussed with industry and manufacturer steering committees.
Sec 3.6 – *The development of BMPs for winch-assisted, mechanized, steep-slope harvesting.*

Best practices documents and equipment manuals from forest companies and manufacturers around the world provided background for a draft BMP document. Other sources included contractors, field observations of working machines, discussions with operators, and related research reports. Any available information about equipment failures and incidents was also studied. The appended *Best Management Practices for Winch-Assist Equipment* (in Appendix 8.1) is preliminary because it was beyond the scope of this contract to complete a detailed, comprehensive document. The draft BMP document will be posted on FPInnovations’ Steep Slope Initiative website and it will be further developed through ongoing consultation with stakeholders. FPInnovations aims to facilitate continuous improvement of winch-assist BMPs and capture learnings in the BMP document. International and local harvesting communities will be consulted.

A separate section of the BMP focused on appropriate practices for wire rope and its hardware, maintenance, and replacement is included in Appendix 8.1.1.

Sec 3.7 – *The physiographic conditions affecting the feasibility of adopting mechanical harvesting.*

A GIS analysis of the Timber Harvest Land base by slope class was conducted by the Inventory and Analysis Branch of the B.C. Ministry of Forests, Lands and Natural Resource Operations. The GIS slope class information and insights gained from FPInnovations’ projects through the Steep Slope Initiative were used to describe the physiographic conditions that affect mechanical harvesting.

### 3 PROJECT FINDINGS/OUTCOMES

#### 3.1 Challenges faced in B.C. regarding the adoption of the safest technology for tree falling

Forest companies, harvesting contractors, equipment manufacturers, agencies, and universities all have different interests and challenges that need to be addressed in order to bring about the successful implementation of safer technologies. Some key challenges are discussed below.

- Challenges for contractors who invest in new equipment.
  - Lack of knowledge of new equipment, including:
    - Pros and cons of various winch-assist systems are poorly understood.
• Different operating procedures and technical factors are complex, e.g., single vs double cables, anchor machine vs integrated winch.
• Costs, productivity, and financial details are not known. Low utilization rates have been reported which complicates financial analysis.
• The learning curve to become productive and profitable is poorly understood.
• Concerns over harvesting rates, i.e., that gains in productivity would trigger rate reductions, which in turn is perceived as a disincentive to invest in new technology,
• Relationships between companies and contractors are often strained and lacking trust, which can make contractors feel they do not have secure work, so they resist pressure to invest in unproven equipment.
• Sharing of risk and benefits is difficult to negotiate.
• The industry is conservative and slow to adapt to change. Profit margins are low so contractors are risk averse.
• General concerns about whether a steady supply of suitable ground and timber is available to keep expensive new equipment operating.
• Poor harvest scheduling, engineering, and layout for new systems can impact contractor profitability. Shutdowns related to snow, break-up, and fire season can affect contractor revenue.
• General uncertainty in the industry, e.g., regarding the status of the Softwood Lumber Agreement, makes contractors reluctant to buy new forestry equipment which they may not be able to resell in an industry downturn.
• Availability of competent operators and training – concerns over the high costs of training, who pays for it, and who does it. Operator training and extension programs for operators are not well developed, with little or no availability of training specific to steep slopes.
• Regulatory requirements are not well understood and there are concerns regarding inconsistent interpretation and enforcement, and low confidence in regulator acceptance.
• The recently announced review of mobile equipment may provide solutions but it also creates uncertainty about what new requirements are coming, which can impact investment decisions. For example—what are the anticipated standards for safety or design factors, e.g., 3:1 or 5:1 standards.
• Cab guarding regulations have been a challenge for the introduction of cut-to-length harvesters.
• There is concern that new equipment will not comply with current regulations—e.g., *Ensure that the equipment is being operated in a manner that does not present undue hazard to the operator or any other person.*
• Availability of equipment – some manufacturers require several months to build or ship units.
• Availability of dealer support, availability of parts in remote locations—re ability to access and repair equipment on steep terrain.
• Safe practices, due diligence, and standards are rapidly evolving. Contractors are challenged to keep up to date and perform due diligence. Science and engineering are required to address some of the information gaps and ensure safe operations. Transferring new knowledge and capturing continuous improvement learnings for field application is challenging because there is limited local experience in this regard.
• Unquantified environmental impacts, social license.
• Challenges to equipment manufacturers in the development of new equipment:
  • Manufacturers have concerns about product liability.
  • The market is small, so capital for investment for development of specialized equipment is limited.
  • OEMs like clear, consistent standards so they do not have to produce machines to different standards for different regions with small markets.
  • Providing support and service to remote locations.

The biggest challenges observed by FPInnovations, and validated at Steering Committee meetings, presentations, and interactions with the industry, are:

• the lack of operator training
• the lack of adequate best practices

### 3.2 How the B.C. industry can best transition into safer tree harvesting

Safer tree harvesting can be achieved by reducing hand falling and the exposure of workers to hazards. The transition toward safer harvesting should focus on increasing the safe operating range of mechanized harvesting equipment that protects workers in machine cabs. Alternatives to hand falling—such as conventional mechanized falling with a feller-buncher or harvester, a tilting feller-buncher, winch-assisted felling, and remotely controlled felling—are described in Sec 3.4.
The proportion of steep ground in B.C.’s Timber Harvest Land Base with a slope >70% is relatively small, and it is possible to harvest much of this steep terrain with conventional ground-based equipment (see Sec 3.7). However, safe feller-buncher operations on steep terrain require a very skilled operator: the consequences for loss of traction and stability are high on steep ground. Wheeled European style harvesters have very good traction and stability and are an attractive option on moderate terrain. Winch-assist technology is probably the most attractive means to extend the operating limits of mechanized harvesting in the short term.

In the last 18 months, there have been rapid developments in the implementation of new winch-assist technology. It is anticipated that 50 machines will be operating by the summer of 2017. Many of the challenges indicated above in Sec 3.1 are being addressed. For example, several offshore manufacturers now have local distributors that are supporting implementation of new technology in B.C.

Suggested steps for transitioning toward greater use of winch-assist technology are:

1. Employ wider dissemination of information about possible technology options.
   Winch-assist options are now generally known, as shown at DEMO in Sept 2016. Equipment options are described in Amishev (2016) and Sec 3.4. But further transfer of knowledge about equipment options is needed, to facilitate wider implementation. FPInnovations can assist with knowledge transfer through the Steep Slope Initiative.

2. Develop operator training programs.
   Work is needed to improve training for steep slope operations and to increase the availability of training, as described in Sec 3.3.

3. Develop competencies for operators.
   Currently under development by the BC Forest Safety Council.

4. Support the forest companies’ planning and layout needs.
   This ongoing challenge is affecting the profitability and success of early adopters of winch-assist technology. The forest companies’ planners need to adapt quickly to new systems and must communicate effectively with contractors. Some initial considerations are addressed within FPInnovations’ BMP document. WorkSafeBC can message the importance of planning for safe practices in the steep slope assessment and layout phases.

5. Demonstrate and assess commercial, compliance, and technical suitability of new techniques.
   FPInnovations is facilitating studies of new techniques, and information exchange. Steep slopes are frequently discussed at conferences, and knowledge and understanding are increasing, but there is still a large need for more information and results.
6. Support early adopters, to encourage wider implementation.
   Licensees can support contractors with partnering contracts that share risk and benefits and provide steady, suitable wood, and Licensees can consider paying hourly rates for start-up and new endeavours. WorkSafeBC can work with early adopters, providing good communications on expectations, consistent guidance, and positive messaging on safety benefits of mechanization. Disseminate information about technical developments to WSBC field staff. Researchers can provide field practitioners with timely information about current BMPs, learning aides, and tools.

7. Develop standards and BMPs.
   Compile and synthesize relevant information from various existing sources. Funding and research is required to fill some of the information and knowledge gaps. Coordinate and share knowledge from international agencies and research organizations in a timely manner. Facilitate further development of BMPs and facilitate continuous improvement within the B.C. harvesting community. BMPs are discussed in detail in Sec 3.6.

8. Liaise with the International Standards Organization (ISO) and adapt regulations to address winch-assist operations
   Scientifically based standards development is a long process. Given the rapid development and implementation of this new technology, BMPs are a preferred alternative in lieu of standards in the short term. **Aligning WorkSafeBC efforts in standards development with ISO would be an efficient and cost-effective approach.** Otherwise, unique B.C. standards would deter equipment manufacturers from investing in innovation that is crucial for improving safety of B.C. workers.

While winch-assist provides a large gain toward reducing hand falling, there are still some conditions unsuitable for winch-assist operations and where hand falling would still occur, for example:

1. areas with large-diameter stems (old-growth)
2. areas with rocky outcrops, broken terrain, obstacles
3. areas with limited access
4. remote areas, or very small areas with poor logistics
5. areas with excessively steep terrain

New technology could be developed to harvest these challenging conditions. Robots or remotely controlled systems could eventually be applied. Remotely controlled tree felling capability currently exists at the pre-commercial stage; it has potential but has many challenges ahead. It is not expected
to be used operationally for a few more years. The market is small, development costs are high, technical solutions are still imperfect, and operating conditions are extremely challenging.

3.3 The type of training programs required to encourage adoption of mechanical harvesting

Operator training approaches vary around the world. European operators typically attend forestry technical schools for 2 to 3 years. Formal operator training at schools in B.C. is very limited. Some operators in western Canada are provided instructions by the manufacturer’s trainers when new machines are purchased. Otherwise, most training is done on the job. Currently contractors must absorb the cost of on-the-job training, but there is a lack of will to provide it because worker loyalty and security cannot be assured. Faced with the growing need for skilled operators, B.C. must develop further solutions.

FPInnovations conducted a survey to assess domestic and international equipment operator training programs. Survey questions and results are appended in Sec 8.3.

- There were 36 respondents from 17 different countries: 19 from Europe (Austria, Bulgaria, Finland, France, Germany, Italy, Norway, Poland, Sweden, and Turkey), 3 from Australia, 5 from New Zealand, 1 from Brazil, 1 from Chile, 1 from Japan, 1 from Newfoundland and Labrador, and 5 from USA (Alabama, Montana, Oregon, Washington).
- The composition of the respondents was: 12 researchers, 8 from academia, 5 from industry, 4 training organizations, 2 contractors associations, 2 manufacturers, 2 from government, and 1 consultant.

The results of the survey were:

- Operator training is provided by vocational training institutions in 20 jurisdictions, professional forestry schools in 15, machine manufacturers in 13, on-the-job by contractors in 8; there is no operator training available in 5 jurisdictions.
- Formal operator training is required for employment in only 8 jurisdictions and the length of that training ranges from 2 weeks to 36 months. In 36% of training programs basic literacy and numeracy is a prerequisite requirement.
- Machine operation is the largest component (22%) of the curriculum for all available training programs, followed by best operating practices (17%), safety (16%), and machine repair and
maintenance (13%). General forestry knowledge, environmental protection, product quality, and rules and regulations are also covered in such programs.

- Simulator training is provided in 71% of the training programs, with simulator hours averaging 25% of total training hours provided. Simulators are generally owned and provided by the training centers or equipment manufacturers, and in rare cases by government or even harvesting contractors. In 86% of the cases simulators are forestry specific, with single-grip harvesters and forwarders representing 80% of those available; excavator, skidder, and feller-buncher simulators are available in about 10% of the cases. According to respondents, when a trainee gets part of their training time in a simulator, the overall time required to produce a competent operator is 20% less than if the trainee gets all their training only on the machine.

- Nearly 50% of respondents stated that the cost to train a machine operator is less than €20,000 Euros; only 2 (6%) respondents selected “more than 75,000 Euros”. However, wages and benefits, loss of production, and increased maintenance and repairs were also stated as “hidden” costs for on-the-job training scenarios. According to respondents, the productivity of untrained operators averaged 39% of formally trained operators: at the start, informally trained operators reach 55% of the productivity of formally trained operators after 3 months of work, about 67% after 6 months, and 77% after 12 months.

- Operator training is partially or fully paid for by employers and contractors in 60% of the jurisdictions; government contributes in full or in part in 59%; and trainees self-fund in 29%, manufacturers in 11%, and forest owners in 7% of the jurisdictions. More than 90% of respondents stated that formal operator training is of high (cost:benefit 1:5) or good value (1:2).

- Recruitment in training programs is primarily done by advertising (75%), career days in schools (65%), family history (50%), or word of mouth (45%).

- An average of 8% of the total current operator workforce is trained annually; around 72% of those remain in the forest industry for at least 1 year and 53% are still in the industry after 5 years.

- Cable yarding is the only training available that is specific to steep terrain; there is no graduated system for ground-based equipment operators to progress from working on flat ground to steep ground. In regard to using winch-assist systems, respondents ranked on-the-job training as best (81%), followed by a formal training course (73%), manufacturer training (71%), or cable yarding experience (69%).

- Of the training methods ranked as the most successful, the one rated as providing the highest return on investment was a combination of simulator and actual machine operation (90%).
followed by on-the-job training (84%), vocational training (73%), actual machine operation only (69%), formal forestry school (63%), and workshops (56%).

Other studies also indicated stronger and well-established operator training programs with strong government support in European countries compared to Canadian provinces and most U.S. States (Vallières and Gingras, 2006; Forest Resources Association, 2015).

A comprehensive Canadian study (Vallières and Gingras, 2006) showed that international operator training programs were all government funded; municipal, regional, and federal governments all contributed. Most international programs for operator training involved participants that were already in the forest industry, or were recent high-school graduates. This contrasts with Canadian trainees, who were mostly unemployed when they entered a program. Program duration varied among countries, from 300 hours in Ontario to 5,000 hours in Finland.

A study by the Forest Resources Association (2015) examined logger training programs in 34 states and 6 Canadian provinces. In all Canadian provinces training was self-funded by participants, except in Quebec where internal program funding covered all costs. In the U.S., funding sources varied among states, with some funding support formulae worthy of consideration for B.C:

- Contributions of university extension services expertise
- Voluntary levy (per tonne of wood for companies and mills, or per hectare of forest for landowners)
- Contributions from contractor associations
- Grants from various government and non-government sources

FPInnovations contacted the educational organizations that conduct forestry operator training in B.C.: Thompson Rivers University in cooperation with the Interior Logging Association (Kamloops), Vancouver Island University (Nanaimo), O’Brien Training (Prince George), and the College of New Caledonia (Quesnel and Mackenzie). The only forestry-equipment-specific simulators used in B.C. are at Vancouver Island University and include excavators, feller-bunchers, dangle head processor, and dozers. However their training program for forestry equipment is still developing. Programs are 140 to 480 hours long with about one-third of the time spent in classroom training and the rest is technical and operational experience. The costs vary, depending on the program and equipment options, from $7,500 to almost $24,000 in tuition fees. In-kind industry contribution, through either contractor equipment or expertise and lost production time, was valued at an additional $20,000 to $40,000 per student. About 75% of the trainees are employed in the forestry industry within one year of completing the program.
The only continuously offered forestry equipment operator training program is at Thompson Rivers University in Kamloops with an output of 16 trained operators in 2016. The other forestry-specific programs have either been discontinued or are only offered once every few years, primarily due to funding shortfalls. This limited availability is extremely inadequate in helping to achieve increased mechanization of operations and improved safety for B.C.’s forest industry. There are cases in the province where winch-assist equipment is not being utilized due to the lack of qualified operators.

It is anticipated that contractors and operators will try to tackle steeper terrain with their conventional equipment. However, operators are not permitted on steep ground unless conditions and equipment are suitable and operators are competent. Most contractors have safe work procedures that specify operators have experience and competence with the equipment type on gentler slopes before advancing to steeper ground.

The lack of operator training has been discussed in B.C. for three years and there has not been much change from the status quo of contractors and manufacturers providing on-the-job training. There are some formal training schools but funding is limited and the number of graduates is low. This is not adequate for current and future needs. It is recommended that formal training opportunities be further developed and government funding should be increased. WorkSafeBC and the BC Forest Safety Council should encourage partnerships among government agencies, educational institutes, manufacturers, industry associations, forest companies, First Nations, research institutes, and unions, and target the goal of increasing the numbers of well-trained operators. There are opportunities to provide leveraged funding, in-kind contributions, apprentice positions, manufacturer-donated simulators, support/training materials, and expertise. Leadership and co-operation by WorkSafeBC and partners could stimulate the growth of operator training programs. This recommendation ties in well with one of WorkSafeBC’s mandates, i.e., to “partner with employers and workers in B.C. to . . . Promote the prevention of workplace injury . . . ”(https://www.worksafebc.com/en/about-us/who-we-are/mission-vision-values).

The proposed B.C. tax credit for which the Truck Loggers Association is advocating emphasizes on-the-job training. The rationale is that formal training will not produce enough operators quickly enough and the tax credit will provide an incentive to contractors that are faced with skilled labor shortages. Current rate models are production driven with tight margins and it is challenging for contractors to provide on-the-job training to new operators. A tax credit would provide some financial relief that would enable contractors to accept lower productivity during the training period.

The BC Forest Safety Council, with funding from the B.C. Ministry of Jobs, Skills and Training is developing competencies for forestry equipment operators. These competencies will be a valuable
complement to training initiatives. This development also tackles the very important issue of “training the trainer” – the individuals who will be conducting the planning of the mechanized harvesting of a cut block and supervising and training contractors and operators. These competency units will provide these individuals with the crucial practical tools to enable them to decide on the competency level of contractors and operators for a given steep slope cut block – are they qualified to accurately identify all hazards on the job and to recognize and implement the necessary means to control the hazards.

3.4 Review of technologies available worldwide that have potential use in B.C.

This section provides a review of steep-slope tree-falling technologies and offers some guidance for selecting the most appropriate one.

Factors that limit mechanized tree falling in B.C. are terrain, slope, tree size, and very wet ground. The most important factors are terrain and slope which is the focus of this report. Mechanization has already replaced hand falling in much of the B.C. interior where harvesting has been concentrated on gentle terrain. But across the province hand falling persists on steep terrain and on sites with large-sized stems or very rugged conditions.

Ground-based winch-assisted mechanized systems for harvesting trees on steep terrain have been used in Europe for over 10 years, primarily to facilitate operations on sensitive ground in order to reduce disturbance. In New Zealand mechanized ground-based systems for steep slopes were developed because of high fatalities in hand falling. Both systems are being applied in B.C. with advantages and disadvantages. With a proper steep slope assessment, and diligent safe practices, both European and New Zealand winch-assist systems can be adapted to B.C. conditions. However, B.C.’s rugged terrain and natural forests provide challenges not found in other jurisdictions.

Some special requirements for systems working in B.C. include:

- the ability to work “above the road” (without road access from above, cables have to be dragged up the hill, or the cutting machine must work up to an anchor point)
- the ability to work in remote and rugged conditions, with rocky outcrops
- the ability to work in extreme cold and deep snow
- the ability to work in natural forests with dense understoreys, snags, and large obstacles

The following section describes tree-falling options within a matrix of equipment factors that could be used for equipment selection or as part of an operational steep slope assessment. Table 1 shows nominal slope limits for the main falling methods. Actual slope limits can vary considerably based on
factors such as machine features, ground conditions, operator skill, and tree size. Below is a discussion of some of the factors that can increase or decrease a machine’s slope limits. This combined with the decision tree in Figure 1 will help in selecting the safest tree-falling technology for the conditions.

It is important to note that Figure 1 is only a starting point in a multi-layered, multi-objective decision process on selecting the best tree-felling option for the conditions in which safety is paramount. It provides decision-makers with a practical visual tool to consider and exhaust all available mechanized falling options before considering the far more hazardous but currently accepted hand falling option. In extremely hazardous situations leaving particular trees or stands unharvested should also be considered.

Table 1. Matrix of tree-falling technologies

<table>
<thead>
<tr>
<th>Falling method/machine</th>
<th>Nominal slope limits&lt;sup&gt;a&lt;/sup&gt;</th>
<th>WorkSafeBC slope limits&lt;sup&gt;b,c&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Downhill (%)</td>
<td>Uphill (%)</td>
</tr>
<tr>
<td>Swing to feller-buncher or feller-director or harvester on tracks with non-levelling or levelling undercarriage</td>
<td>5 to 10</td>
<td>40 to 60</td>
</tr>
<tr>
<td>4-, 6-, or 8-wheeled harvester on rubber tires</td>
<td>30 to 70+</td>
<td>45 to 65</td>
</tr>
<tr>
<td>Winch-assisted 6- or 8-wheeled harvester on rubber tires with on-board winch or anchor-machine winch</td>
<td>50 to 75&lt;sup&gt;e&lt;/sup&gt;</td>
<td>50 to 75&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>Winch-assisted swing to feller-buncher/feller-director/ harvester on tracks with non-tilting or tilting under-carriage and onboard winch or anchor-machine winch</td>
<td>85 to 100</td>
<td>85 to 100</td>
</tr>
<tr>
<td>Remotely controlled or teleoperated tracked feller-director or feller-buncher with non-levelling or levelling undercarriage, with or without winch on anchor machine</td>
<td>No limit</td>
<td></td>
</tr>
<tr>
<td>Hand falling</td>
<td>No limit</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>Observed or from literature; see text for features, conditions, and techniques that may increase/decrease these limits.

<sup>b</sup>If the manufacturer’s maximum slope-operating stability limit for harvesting equipment is not known.

<sup>c</sup>Exceeding these limits requires: a risk assessment, written safe work practices, and no operation in a location or manner where stability cannot be assured.

<sup>d</sup>Assumes the limit for rubber-tired skidders applies to all rubber-tired machines, because wheeled harvesters are not mentioned in the Regulation.

<sup>e</sup>Based on manufacturers’ literature, which requires equipment to be operated only on slopes where it will not slide if winch-assistance were not used.
Figure 1. Decision diagram for selecting which tree-falling method to use on steep slopes – see footnotes below.
“Manual Falling” should only be considered if there is no other option available. If manual falling is to be done then it should follow safe work practices and done by competent, qualified workers under close supervision. Also refer to section 3.4.1. “Handfalling” of this document for more considerations.

“MECHANIZED” falling should be the default method for most conditions on slopes under 40%. Although all mechanized tree felling attachments have an upper limit in regards to tree size they can handle, even with larger trees a mechanical assistance to manual tree felling should be considered to reduce the risks for the manual faller. On slopes under 70%, under certain conditions negatively impacting tractive capability and machine stability, winch-assist options have to be considered to ensure safety. Also refer to section 3.4.1. “Tracked machines” and “Wheeled harvesters” as well as section 3.4.2. “Extending and reducing the limits” of this document for more considerations.

“MECHANIZED Wheeled” falling should be the preferred option for mechanized falling where undulating slopes, rocky ground, partial harvesting, and downhill work play a significant role in a harvest block. On slopes under 70%, under certain conditions negatively impacting tractive capability and machine stability, winch-assist options have to be considered to ensure safety. Mechanized wheeled does not include drive to tree machines (not suitable for slopes). Also refer to section 3.4.1. “Wheeled harvesters” as well as section 3.4.2. “Extending and reducing the limits” of this document for more considerations.

“WINCH-ASSIST” mechanized falling should be the default method for any conditions on slopes over 70%. Certified and rated winch-assist systems from standard-compliant manufacturers should be implemented. Widely accepted best management practices for winch-assisted mechanized steep-slope harvesting should be followed. Also refer to section 3.4.1. “Winch-assisted tracked machines” and “Winch-assisted wheeled harvesters”, section 3.4.2. “Extending and reducing the limits”, as well as section 3.6 “The development of BMPs for winch-assisted, mechanized, steep-slope harvesting” of this document for more considerations.

“WINCH-ASSIST Wheeled” falling should be the preferred option for mechanized falling where undulating slopes, rocky ground, partial harvesting, and downhill work play a significant role in a harvest block. Mechanized wheeled does not include drive to tree machines (not suitable for slopes). Also refer to section 3.4.1. and “Winch-assisted wheeled harvesters”, section 3.4.2. “Extending and reducing the limits”, as well as section 3.6 “The development of BMPs for winch-assisted, mechanized, steep-slope harvesting” of this document for more considerations.

3.4.1 Factors that affect the selection of felling method

Tracked machines

Due to having rigid steel tracks, tracked excavator-base-style machines, such as feller-bunchers and feller-directors, have excellent traction for working on slopes. Tracks generally provide better traction than wheels because there is more surface area in contact with the ground, which is especially applicable on long smooth slopes. However, when the machine is working on undulating ground or around obstacles the surface area of the track that contacts the ground is less.

When cutting or travelling, a tracked machine is the most stable when it is facing uphill.

The equipment matrix (Table 1) does not differentiate between tilting and non-tilting undercarriages. However, research has shown that a tilting undercarriage can improve the stability of a tracked
machine in most positions (Boswell and Parker, 2015). The work showed that in static tests a feller-buncher with a tilting undercarriage could maintain marginal stability\(^1\) on slopes of 9% downhill and 67% uphill, compared to only 2% downhill and 40% uphill for a non-tilting machine.

The upper structure of some tracked machines shifts forward (uphill) when the undercarriage is tilted, which increases the machine’s stability when it is working uphill. A tilting undercarriage also improves operator ergonomics and reduces the power required to maintain control when slewing on a slope.

A zero-tail swing machine has no counterbalance on the rear of the machine; therefore, compared to a normal feller-buncher, it has less stability when lifting a heavy payload. A machine with a side-tilt mechanism has improved machine stability when working or traversing in a sidehill position. Operator comfort can also be improved with side tilt.

**Wheeled harvesters**

Harvesters are available in 4-, 6-, or 8-wheeled models from a variety of manufacturers. Some examples of wheeled harvesters are: the 4 wheeled Sampo Rosenlew HR46x, the 6 wheeled John Deere 1070E, and the 8 wheeled Ponsse Bear.

Generally, the longer the wheelbase and the more tires, the more stable these machines will be on slopes. Also, 8 wheels provide more contact with the ground than 4 or 6 wheels, thus providing better traction and climbing ability. However, sometimes the shorter turning radius and maneuverability of a smaller machine is preferred, for instance when thinning on a site where a tight final tree spacing is required. In ideal conditions 6-wheeled harvesters have been able to work on slopes equal to that of 8-wheeled machines. However, in less than ideal conditions they are more likely to spin their tires and dig into the ground. That can increase the effective slope of the machine and reduce its stability. The 8-wheeled machines also have better braking ability making them better suited to steeper slopes.

A wheeled harvester is more stable working downhill than working uphill because of the separated engine position. On rock, wheels with rubber tires provide better traction than steel tracks. A wheeled harvester does not have a tilting undercarriage, but it does have the advantage of articulation between its two or three undercarriage sections. This can improve stability because the machine can conform to the shape of the ground much better than a tracked machine. This is especially helpful on undulating slopes and rocky ground.

\(^1\) Defined as a load transfer ratio of 0.6.
A harvester may have a tilting cab or seat, which can improve operator comfort and reduce fatigue and musculoskeletal injuries on steep ground. A harvester with a tilting crane requires less power when slewing on slopes, which can increase tree control and machine stability.

**Winch-assisted wheeled harvesters**

European-style, winch-assisted wheeled harvesters are designed to be operated only on slopes where they can be stable without the use of a winch; their manuals specify that these types of harvesters are to be used only for traction assist. Therefore the maximum slopes quoted in Table 1 may appear to be conservative. In some cases, the maximum slope is less than the slope on which non-winch-assist machines are known to work in ideal conditions.

A harvester with a tilting winch allows the cable to align better with the slope on undulating slopes, which can reduce cable abrasion. A winch-assisted cutting machine with an integrated winch has a static cable for winching the machine up or down a slope. This helps minimize cable abrasion during siwashing and when the cable is in contact with the ground or an obstacle.

A harvester with an integrated winch may have its winch mounted at the rear or the front of the harvester. A rear-mounted winch facilitates working downhill, which is a more stable position for machines with a rear-mounted engine. Working downhill also eliminates the risk that the cable would be cut by the saw. A winch-assisted machine with a front-mounted winch (or cable connection) facilitates working uphill, which is the most stable working position for tracked feller-bunchers and feller-directors.²

Some machines (e.g., Haas/John Deer, Ecolog) allow a winch to be mounted on both ends of the machine, which allows effective cutting both downhill and uphill. The two winches can also be used together to increase support in sidehill positions.

**Winch-assisted tracked machines**

A winch-assisted tracked machine is usually one component in a system that includes a separate winch/anchor machine located uphill of the cutting machine.³ A section of heavy-duty chain can be installed between the cutting machine and the assisting cable, which provides protection from the possibility the cable could be severed when the cutting machine is working uphill.

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² Note that the Climbmax tracked harvester has been designed to work without a tilting undercarriage and in both downhill and uphill positions. This is possible because considerable weight is transferred from the upper structure to the undercarriage during the machine’s conversion from an excavator to a harvester.

³ However, the Climbmax machine is an example of a tracked machine with an on-board winch. See the advantages of an on-board winch discussed under tethered wheeled harvesters, above.
Tethered, tracked systems have been used on very steep slopes and some have been certified by their manufacturers for slopes up to 100% (Table 2). The Climbmax has been especially built for steep slopes and its manufacturer has indicated that it is designed to be stable on 45-degree slopes (100%) even without the winch cable (Paul Jensen pers comm). Some major manufacturers of cutting machines are developing “steep-slope-ready” machines that have adequate fluid circulation for the demand of working on steep slopes and engineered connecting points for tethering.

**Table 2. Specified slope limits for select tethered systems**

<table>
<thead>
<tr>
<th>Source, by machine type and manufacturer</th>
<th>Slope limit (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheeled</td>
<td></td>
</tr>
<tr>
<td>John Deere/Haas instruction manual</td>
<td>50 to 60</td>
</tr>
<tr>
<td>Komatsu instruction manual</td>
<td>55</td>
</tr>
<tr>
<td>Ponsee/Herzo instruction manual</td>
<td>75&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Tracked</td>
<td></td>
</tr>
<tr>
<td>ROB instruction manual</td>
<td>84 +</td>
</tr>
<tr>
<td>Climbmax</td>
<td>100</td>
</tr>
<tr>
<td>Tmar instruction manual</td>
<td>100&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>EMS instruction manual</td>
<td>100</td>
</tr>
<tr>
<td>Weyerhaueser instruction manual</td>
<td>100</td>
</tr>
<tr>
<td>Hancock instruction manual</td>
<td>119 +</td>
</tr>
<tr>
<td>Legged&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Spyder walking carrier</td>
<td>100</td>
</tr>
</tbody>
</table>

<sup>a</sup> “absolute safety limit, allowed only for transports and short distances on small slopes”

<sup>b</sup> Refers to slope of the support cable, not the slope of the assisted machine.

<sup>c</sup> Not tethered.

**Remote controlled<sup>d</sup> / tale-operated machines<sup>5</sup>**

Remotely controlled machine operation is probably the ultimate way to protect a worker from harm when falling trees in challenging conditions.

Several examples of experimental and commercial remotely controlled and tale-operated felling machines for forestry exist. Two, very small-scale, remotely controlled felling machines are

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<sup>d</sup> Line-of-sight operation.

<sup>5</sup> Beyond line-of-sight operation, by means of cameras.
manufactured in Europe: the eBeaver and the RCM Harveri. Recently a non-tilting, teleoperated feller-buncher has been used on flat ground to clear U.S. military land that had been used as a firing range. In New Zealand a tilting-cab John Deere 909 felling machine has been operated both by remote control and teleoperation. While it is not difficult or expensive to set up a radio-control system to operate a machine, it will take some time to develop a system of sensors that will provide an operator the information required to run it productively on difficult terrain (Boswell, 2012). Widespread commercial application of remotely controlled or teleoperated harvesting machinery is likely many years in the future.

**Handfalling**

While handfalling is generally considered feasible on all terrain, it is not the safest choice in most situations. It should be avoided wherever other methods are possible.

On the steepest slopes, even handfalling has limitations. Because the safety of the faller is paramount, sometimes bucking, delimbing, or directional falling may need to be reduced. In special circumstances jacking, winch-assisted handfalling, or the use of explosives may be required to overcome difficulties and maintain the faller’s safety.

The superior tree control and worker protection offered by mechanized falling are preferred in most situations today, as new technology and good planning extend the operational range of mechanical harvesting.

**3.4.2 Extending and reducing the limits**

The limits of ground-based mechanized felling equipment may be extended or reduced depending on equipment features, site conditions, and operating techniques.

**3.4.2.1 Special features that increase operability on steep terrain**

Table 1 does not distinguish between machines that have particular features or options which increase or decrease their suitability to work on slopes. Particular features that affect operability are discussed below.

**Balanced bogie axles for wheeled machines** – Balanced bogie axles are available on some harvesters, often only on the front. They improve the tractive effort that is transferred to the ground and can increase a machine’s operating range compared to normal bogies. They can also provide more ground clearance and smoother transition over obstacles compared to rigid axles.
Active stabilization – An active stabilization system detects a crane’s load, direction, and position and then presses the rear frame and wheels against the ground. It hydraulically transfers the lift resistance to the rear frame and engine mass. This improves the machine’s stability when working on rough terrain. e.g., Ponsse Scorpion.

Adjustable wheel heights, wheelbase, or track width – Adjustable wheel height can increase sideslope stability and helps to keep a machine stable on undulating terrain e.g., Rottné H11. An adjustable wheelbase can increase stability when working up and down the slope, e.g., Konrad highlander. Adjustable track width can increase sideslope stability on steep ground, e.g., T-bear harvester.

Boom/crane design – A longer reach allows access to trees that are further away from the machine. For example, this can be useful when machine is working near its slope limit and trees designated for cutting are on steeper ground but still within reach. However, a boom’s lifting limit is reduced at greater reaches, which may reduce tree control during falling. Machine stability can be more or less, depending on the machine’s position relative to the slope when the boom/crane is extended. Some wheeled harvesters are equipped with a tilting crane, which is more effective on slopes because it requires less power to slew and lift when the machine is on slope.

Head types and features – The type of cutting head can affect the safety of operations on slopes. Considerations include tree size, cutting capacity, and head mobility.

Generally, feller-directors have larger capacities than hot saw6 feller-bunchers and harvester heads. Feller-director limits for single cuts are 90 to 100 cm; large hot saw feller-bunchers have single-cut capacities of 60 to 70 cm; intermittent disc-saw feller-bunchers can single cut to 74 cm; and bar saw feller-bunchers can single cut to 80 cm. Most large harvester heads can single cut from 75 to 85 cm, although the Logmax 1200XT can cut to 102 cm.

To maintain stability on slopes it is important to select a cutting head that is well suited to the size of trees that will be cut. Multi-cutting7 can be used to extend the range of maximum tree size that a head can cut. This is safer than using a manual tree falling to cut oversized trees because machine stability can be assured which in turn provides and maintains adequate tree control during the falling process.

Feller-bunchers have accumulation capabilities that allow faster bunching of trees during the cutting phase compared to the other head types which require the trees to be felled first and then moved into position to create bunches. Feller-bunchers with hot saw heads perform better than other heads in

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6 Heads with continuous-rotation disc saws.
7 Multi-cutting refers to a method for cutting trees that are too large for the head to fall in a single cut. The head is repositioned part way through felling such that the tree is felled using two or more cuts.
small-diameter stands or in stands with a high proportion of non-merchantable stems. However, with large-diameter stems, feller-bunchers may have to cut only one tree at a time to maintain control or due to capacity.

Feller-director heads have hoe-chucking capabilities that can reduce or eliminate cable-yarding requirements. Hoe chucking with winch-assist systems can also improve the safety and productivity of downstream phases, as discussed in the planning and layout section of Appendix 8.1 Best Management Practices for Winch-Assist Equipment

The way that each type of falling head controls the tree during felling also varies. A feller-buncher lifts the tree after cutting and then uses the leverage of its tall frame to push the entire tree in the desired falling direction. A tree that is too heavy may be able to be cut but not lift, and tree control and machine stability may be compromised. Harvester heads and feller-director heads control the tree by pulling its butt away from the desired falling direction of its top. The tree is guided (directed) as it falls, but the full weight of the tree does not need to be supported. This can increase machine stability when cutting heavy trees.

High-rotation felling heads or linkages can also make it easier to reach a tree that is in an awkward position. This can prevent having to put a machine into a position where its stability could be compromised. These heads can also be helpful for cutting lower stumps on steep ground.

More considerations for selecting and operating different types of heads in terms of maximizing safety for winch-assist systems are also discussed in Appendix 8.1.

**Track and tire width** – Narrow tracks can increase traction on slopes, while wider tracks, wider tires, and dual tires will reduce ground pressures and may improve a machine’s slope capabilities on soft ground.

**Chains and band tracks** – can extend the operating range of wheeled machines in poor traction areas, however they should not be used on rock. Longer or additional grousers or ice lugs can do the same for tracked machines. Anti-skid spikes can also be added to band tracks to improve traction.

**Tire options** – Tire type and tread design can greatly affect machine traction and capability. Tire ballast, such as calcium chloride, can increase traction and reduce tire slip. The additional weight can also improve stability by lowering the centre of gravity. Reduced tire pressure can also increase traction. Check with the machine manufacturer and tire supplier for information on the best setup for the conditions.

**Winch-assist** – is currently the ultimate tool for extending the working range of a machine on slopes. An existing cutting machine can be paired with a separate winch and anchor machine provided the cutting machine has the necessary power and fluid transfer capability for the planned slope.
Alternatively, a purpose-built harvester with an on-board integrated winch can be used alone, provided tree or stump anchors are available. In most conditions an untethered machine will slide before it reaches a slope that is steep enough to cause it to tip. In slippery conditions the added traction due to a tether can extend the limit of the machine’s working slope closer to its stability limit. The stability of cutting machines is enhanced by adding a tether, especially for tracked machines working when facing downhill. A tether also adds a level of security that allows a machine to be used closer to its stability threshold.

3.4.2.2 Conditions that many increase or decrease a machine’s slope limit

While equipment choice is important for determining operating limits, other factors such as site conditions, operator skill, and operator techniques will have equal or bigger effects.

It can be difficult or impossible to accurately indicate slope limits for machines. A feller-buncher that is technically capable of operating on slopes of up to 50%, may, for example, be operated by an inexperienced operator whose limited skill means he can only operate safely up to 30% slope, or the machine may be operated by a very competent operator who might be able to work safely up to 60% under the same conditions. A 40% slope can be more dangerous than a 55% slope if the conditions are unfavourable.

Examples of site conditions that can affect a machine’s slope limit:

- **soil / surface type** – Fine-textured soils like those with high clay content have much lower traction than coarse-textured soils. Rock surfaces have low traction, especially with steel tracked equipment. Thin soils over rock can easily be displaced, leaving only lower-traction rock. Soil-bearing capacity (strength) can also affect slope operability. As the slope increases, more of the machine weight shifts to the downhill sections of the tracks or to the downhill tires. This increases the pressure (PSI) of the machine on the soil, which can reduce its operability if soil strength is insufficient. Using brush mats can reduce machine pressure.

- **soil / surface moisture** – All soils and surfaces have lower traction when they become wet; they can eventually reach a moisture level where safe equipment operation cannot be sustained on a particular slope.

- **ground roughness** – The greater the surface roughness of the slope, the greater the difficulty of working on it. Travel options become more limited as roughness increases, and a machine’s stability can be compromised when repositioning on rough terrain is required. Rough ground can also have varying surface types, which can translate into unexpected changes in the machine’s traction levels. Travelling into/onto hollows, stumps, rocks, or other obstacles will increase the machine’s slope and reduce its stability. Using brush mats or debris to fill in holes...
may help to establish a continuous grade, but may also reduce traction. Recontouring the ground with the machine’s blade or head can also be used to improve operability on rough ground. Using stumps to level the machine can improve machine stability. To improve the travel route, the operator can use the grapple to remove small obstacles from the machine’s path.

**tree size** – Larger trees will place higher demands on the equipment; they can affect the machine’s balance and stability. Even smaller trees can become hazardous if a feller-buncher’s accumulated load becomes too large. Feller-directors and harvester heads can cut trees without fully supporting the load, so they can be better suited to cutting large trees on slopes.

**weather, season, snow, and ice** – The weather conditions will greatly affect machine traction. Steeper areas should be harvested when the ground is dry. Dry snow can also provide good traction, while ice is treacherous on steep ground. Chains, spikes, band tracks, and ice lugs can help.

**long, smooth slopes vs undulating ground** – Undulating ground that includes small, flatter micro terrain can be used by a skilled operator to reduce machine slope and improve machine stability on steep ground. Long, smooth slopes pose a higher risk to the operator because if a machine was to slide or upset in such conditions, the machine has a greater chance of commencing an uncontrolled descent. Lower slope limits should be considered in locations where the consequences of possible machine failure or operator error would be catastrophic.

### 3.4.2.3 Techniques and strategies that can increase or decrease slope limits

**extent of reach used** – A machine will be more stable when its boom or crane is extended uphill, but it will be less stable when the boom or crane is extended downhill or to the side. The heavier the load in the head, the greater the effect of extending the boom. When swinging to the side to bunch or unload or process, or when working downhill, the boom or crane should be kept close to the machine’s base to maximize stability.

**uphill-only positioning** – For excavator-style machines, slope limits can be increased substantially by cutting and travelling only while facing in the uphill position, returning to the bottom of slope by reversing or by an alternate route before beginning to cut the next swath of trees. Keeping the boom extended uphill when travelling up or down a steep slope will also increase stability.

**environmental concerns** – Environmental requirements can vary by jurisdiction and can effectively restrict the slope on which a machine type can work. In Europe, winch-assist systems are used to extend the slope limit of ground-based equipment while meeting high environmental criteria.
**day-shift-only operation** – Good visibility is critical when working in difficult terrain. Planning operations so that the steeps areas are harvested only during day-shift operations will increase operating range and reduce operator stress.

**lower productivity expectations** – Lowering productivity expectations on steep terrain allows more time for ensuring operations are conducted safely in the challenging conditions.

**operator skill and experience** – Operators who have gradually gained experience on steeper ground will have a better understanding of the machine limits and techniques that contribute to safe and effective operations on steep ground. Operators who have worked in untethered machines will have a better appreciation of their stability and sliding limits than operators who have tethered experience only. Operators with many hours of experience in a particular machine model will understand its limits better than one who has never used that model before. The less competent and experienced the operator is, the more the machine’s operating limits will be reduced.

**stump height** – Cutting lower stumps, sometimes by cutting a stump again after the tree has been felled, helps remove obstacles and improve machine mobility on slopes. Cutting higher stumps to hold the cut trees or logs in place on a steep hill can reduce the risk that logs will roll or slide.

**planning and layout** – The slope limit may be affected by a safe runout, or lack of a safe runout if a loss of traction occurs. A work plan that excludes operating a machine in its least stable positions (i.e., the machine can work or travel only when positioned facing uphill, no turning on the slope) could permit higher slope limits. Plan for handfalling where necessary, or exclude areas that cannot be safely harvested mechanically.

**Bladed or excavated trails** – can be used to extend the working range on slopes, or to provide access via a route that is too steep. Care must be taken to not redirect water onto these trails, nor to exceed any site-disturbance requirements; timely trail rehabilitation can also be an effective strategy.

### 3.4.3 Injuries and fatalities

Studies from around the world and more recent unpublished information were reviewed and analyzed in order to understand the hazards and risks associated with different tree-felling methods, and to understand the associated injury and fatality rates.

In mechanized harvesting, the highest accident rates are in maintenance and repair activities, not actual tree felling (Gerst, 2009; Jänich, 2009; Lindroos and Burstrom, 2010); manual tree felling in
inaccessible areas resulted in higher accident rates in Ireland (Nieuwenhuis and Lyons, 2002), and in the United States (Shaffer and Milburn, 1999).

In semi-mechanized operations, the great majority of accidents are caused by chainsaws (Albizu-Urionabarrenetxe et al., 2013; Axelsson, 1998; Neely and Wilhelmson, 2006; Nieuwenhuis and Lyons, 2002; Peters, 1991; Shaffer and Milburn, 1999). Contact with machinery when skidding and forwarding is also a frequent cause of accidents (Driscoll et al., 1995; Lindroos and Burstrom, 2010).

In motor-manual harvesting operations, felling trees is the most frequent cause of fatal accidents. Reasons vary from inappropriate felling direction (Axelsson, 1998; Bell, 2002; Driscoll et al., 1995; Lefort et al., 2003; Neely and Wilhelmson, 2006; Peters, 1991); tree roll-off after felling (Driscoll et al., 1995; Peters, 1991); rebound from another tree (Albizu-Urionabarrenetxe et al., 2013); slips, trips and falls (Tsioras et al., 2014); and other reasons. The most common situation that caused accidents was felling a tree into a hang-up with the plan of dislodging it (Peters, 1991; Salminen et al., 1999; Thelin, 2002).

While injury and fatality rates are commonly reported separately for motor-manual harvesting and mechanized harvesting, it is more challenging to differentiate those rates for the different types of mechanized harvesting operations (e.g., harvester/forwarder cut-to-length vs feller-buncher/skidder whole tree). Enache et al. (2016) reported results from seven case study areas (CSAs) from representative European mountain ranges, where 632 harvesting operations were analyzed (Table 3). The focus was on road infrastructure, transport systems, harvesting methods, and extraction technologies. The CSAs were located in the main European mountain ranges which cover the most important forest types and harvesting methods in Europe:

- Iberian Mountains (CSA1) and French Alps (CSA2) – primarily semi-mechanized operations on gentle and moderately steep terrain (tracked and wheeled felling machines, cable skidders, agricultural tractors).
- Austrian Alps (CSA3) – primarily mechanized ( harvesters and forwarders, tracked and wheeled felling machines, grapple and cable skidders) except for very steep terrain (25% of forest area is on slopes greater than 60%) where manual felling and cable yarding is most common.
- Dinaric Mountains (CSA4), Western Carpathians (CSA6) – equally split semi-mechanized operations and motor-manual ones on gentle to moderately steep terrain (mostly manual felling, few tracked and wheeled felling machines, cable-skidders, agricultural tractors)
- Scandinavian Mountains (CSA5) – fully mechanized harvester-forwarder operations.
Rhodope Mountains (CSA7) – almost exclusively motor-manual operations with agricultural tractors, horses, and cable skidders used for extraction.

Table 3. Summary of the analysis of harvesting operations in seven case study areas (CSAs) in European mountain ranges, from Enache et al. (2016).

<table>
<thead>
<tr>
<th>Harvesting system indicators</th>
<th>CSA1</th>
<th>CSA2</th>
<th>CSA3</th>
<th>CSA4</th>
<th>CSA5</th>
<th>CSA6</th>
<th>CSA7</th>
<th>Mean CSA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Productivity (m³ h⁻¹)</td>
<td>9.5</td>
<td>13.0</td>
<td>12.0</td>
<td>13.5</td>
<td>34.3</td>
<td>16.2</td>
<td>4.0</td>
<td>14.6</td>
</tr>
<tr>
<td>Cost (€ m⁻³)</td>
<td>33.8</td>
<td>23.0</td>
<td>44.9</td>
<td>29.8</td>
<td>15.8</td>
<td>21.9</td>
<td>15.3</td>
<td>26.4</td>
</tr>
<tr>
<td>Consumption (l m⁻³)</td>
<td>2.7</td>
<td>1.8</td>
<td>2.0</td>
<td>1.9</td>
<td>1.7</td>
<td>1.6</td>
<td>3.1</td>
<td>2.1</td>
</tr>
<tr>
<td>Accidents (N mill. m⁻³)</td>
<td>87.0</td>
<td>87.0</td>
<td>111.0</td>
<td>83.1</td>
<td>22.0</td>
<td>85.7</td>
<td>126.0</td>
<td>86.0</td>
</tr>
<tr>
<td>CO₂eq emissions (kg m⁻³)</td>
<td>6.7</td>
<td>4.5</td>
<td>5.3</td>
<td>5.2</td>
<td>5.3</td>
<td>4.2</td>
<td>8.0</td>
<td>5.6</td>
</tr>
<tr>
<td>Mean SDI (%)</td>
<td>26.5</td>
<td>26.5</td>
<td>44.0</td>
<td>25.9</td>
<td>17.0</td>
<td>27.4</td>
<td>24.1</td>
<td>27.3</td>
</tr>
</tbody>
</table>

In all scenarios, CSA5 (Sweden) reported the highest productivity, the lowest number of accidents, and the lowest stand damage index, thus highlighting the benefits of using fully mechanized harvesting systems (Table 3). Similarly, Klun and Medved (2007) demonstrated the benefits of mechanization on very steep terrain, with fatality rates in Switzerland and Austria dropping from more than 2/M m³ harvested in early 1980s to less than 0.8/M m³ harvested in mid-2000s. In Australia, where terrain is mostly gentle and harvesting systems are generally fully mechanized (both harvester/forwarder cut-to-length and feller-buncher/skidder whole tree), Ghaffariyan (2016) reported an accident rate of 14.4/M m³ harvested. In New Zealand, serious harm incidents were reduced from an average of 15/month in January 2013 to 4/month in November 2015, with the greatest contributing factor being increased mechanization (Garland, 2017).

3.4.4 Research reports about winch-assist technology

FPInnovations has investigated a number of new machine technologies that have high potential for felling trees on slopes and reducing the use of hand fallers. We have conducted field evaluations of these technologies in New Zealand, Europe, the PNW of USA, and, as machines have been introduced, here in British Columbia. FPInnovations’ reports on these evaluations and a comparison report are included in Appendix 8.2.
3.5 Review of existing science and research needs for developing international standards for safe winch-assist operations

Existing science on winch-assist operations is limited because the concept is still very new. Research from other applications such as cable yarding, shipping, and snow-cats could be applied. SCION in New Zealand conducted early studies (Evanson & Amishev, 2010; Evanson & Amishev, 2013; Evanson et al., 2013) on the first ClimbMax machines. FPInnovations and John Deere have carried out tilt-table (Boswell & Parker, 2015) and center-of-gravity testing (Petch & Parker, in review) to model machine stability. The University of Canterbury and FPInnovations have done research (Schaare et al., in press; Amishev, 2017) measuring tensions on different winch-assisted machines. Oregon State University and FPInnovations are conducting research on the track/soil interface with load cells placed on the ground (Leshchinsky et al., 2017; S. Parker, pers comm). Oregon State University is also researching the physiological responses of machine operators working on steep slopes.

Industry members and manufacturers around the world agree that any standards for winch-assist operations should be science-based. The New Zealand experience, with incidents involving broken ropes, couplings, loss of traction, and overturning, (R. Visser, pers comm) has been very instructive. Further research should address issues arising from incidents and any perceived or anticipated risks. Discussions with FPInnovations’ Steep Slope Initiative’s Steering Committees, and liaison with various local and international agencies have identified the following areas of priority research.

3.5.1 Tension monitoring and cable integrity

Research from the University of Canterbury has shown that spikes in cable tension have occurred, impacting cable integrity and life (Visser & Harrill, 2016). As a result of this research manufacturers are starting to add data loggers so that tension data can be analyzed. Further research is needed to understand the affects of operations on cable tension and how to prevent unsafe incidents from occurring.

3.5.2 Machine stability and traction

Some of FPInnovations’ early work on mechanization on steep slopes focused on machine stability. Subsequent research has led to modelling, and recently winch-assisted machines have been modelled. It is now recognized that loss of traction usually occurs before a loss of stability and can be more critical for machine stability. There is a need for greater understanding of the machine/soil interface. Coefficient of friction estimates can be used to determine traction limits on slopes for different machine weights and cable tensions. There are opportunities to improve safe practices by implementing traction-related tools from ongoing research.
3.5.3 Anchors

For systems with winches integrated onto the cutting machine, the strength of the anchor tree or stump is critical. Further information on stump strength is needed. Research and information from cable yarding, including guidelines for stump and tree selection, could be adapted to B.C.’s winch-assist operations.

3.5.4 Rub trees

Rub trees are used to avoid repositioning the anchor, to allow the cutting machine to remain in lead on sideslopes, and to provide winch-assist access in complex terrain. It is also referred to as ‘siwashing’. While there are many benefits to this technique, there are also many potential drawbacks. Researchers at the University of Canterbury have recorded high wire rope temperatures which could negatively impact wire integrity. Deflection angles of the cable around stumps can also affect rope tensions. Investigations are needed to ascertain how rub trees can be used safely or when they should be avoided.

3.6 The development of BMPs for winch-assisted, mechanized, steep-slope harvesting

The development of BMPs for winch-assist systems was identified as a high need by both industry and manufacturers that would expedite the adoption of these systems and bring safer tree falling. Although there are user manuals available from manufacturers and guidelines from landowners in other parts of the world, there are no comprehensive national or international standards for the technology and there is nothing that was specific for BC conditions. The deliverable for Contract Activity 6 is a stand-alone document that is a first draft of “Best Management Practices for Winch-Assist Equipment (Appendix 8.1) which includes the draft document “Wire Rope Integrity for Winch-Assisted Forestry Equipment – Draft Report” (Appendix 8.1.1). It draws on field observations of working machines, discussions with operators, owners, and equipment manufacturers, available documentation from manufacturers and landowners, and related research reports. As winch-assist is a developing technology, it is expected that this BMP draft document will evolve. Our understanding will grow as more system hours are logged, research is conducted, and more is learned about the technology in general. 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. The final document will be enhanced with photos and drawing to help illustrate the practices that are recommended in the text.
3.7 The physiographic conditions affecting the feasibility of adopting mechanical harvesting

When FPInnovations started the Steep Slope Initiative in 2015, one of the early questions was ‘How much steep ground is there?’. The Inventory and Analysis Branch of the B.C. Ministry of Forests, Lands and Natural Resource Operations was requested by FPInnovations to conduct a GIS analysis of B.C.’s Vegetation Resource Inventory by slope class for each Timber Supply Area.

The volume of timber in the Timber Harvest Land Base was distributed over slope classes. The results indicated that, for the province, 24% of the volume is on slopes greater than 35%. Coastal and Interior proportions are 56% and 14%, respectively. Timber Supply Areas with heavy mountain pine beetle infestations have 8% of the Timber Harvest Land Base volume on slopes greater than 35%.

The proportions of volume by slope class were prorated for the Allowable Annual Cut (AAC) for the province and Figure 2 shows the distribution of AAC volume by slope class for the Timber Supply Areas with greater than 300,000 m³ of AAC on slopes greater than 35%. The analysis indicates that much of the steep ground is between 40 and 60%, and the proportion of ground greater than 80% is relatively small. The operability lines in the Timber Harvest Land Base were likely drawn with steepness as a limiting factor. It is possible that marginal volume exists outside the Timber Harvest Land Base that could be utilized. The analysis suggests that a very low proportion of B.C. harvesting will occur on terrain that is as steep as the average slope in New Zealand where winch-assist operations on slopes greater than 100% are common. The analysis of B.C. slope classes also suggest that a large proportion of steep ground could be harvested by skilled operators using untethered equipment.

However, the suitability of mechanized harvesting to B.C. is also affected by areas with rock outcrops, shallow soils, soil moisture and texture concerns, gullies, and obstacles such as large stumps and boulders. Additionally, many high-elevation harvesting sites are above the road and beyond the limits of economical road construction. These areas have limited upper access for an anchor machine and are challenging to string with cables to reach tree and stump anchors.
Figure 2. Distribution of Allowable Annual Cut volume by slope class for Timber Supply Areas with volume >300,000 m³/year.

4 IMPLICATIONS FOR FUTURE OCCUPATIONAL HEALTH RESEARCH

Mechanized falling has already replaced hand-falling on conventional ground where slope and tree size are not limiting. Handfalling will still be needed for large trees like old-growth, and on steep rocky terrain not suitable for mechanized systems. The areas to be hand-felled will become concentrated in challenging conditions. Many hand fallers are in their late 50s and will be retiring over then next few years, and there are fewer than 100 trainees a year to replace them. Further research will be needed on how to refine safe practices for this increasingly hazardous job.

Mechanization is progressing up steeper slopes beyond the limits where cabs can self-level. Operators will be increasingly exposed to challenging ergonomic conditions. Operators are often strapped into 4-point harness and hanging over their controls. As machine cabs slew on slopes, operators are subject to forces, physical strain and fatigue. Further research will be needed to understand the ergonomic impacts and prevent associated problems.
Ingress and egress from forest machines is a common cause of injury which is likely to be exacerbated on steep slope conditions. Manufacturers are aware of this problem and will likely address it, but further occupational health research may be required for prevention.

Further research is required to address gaps in science and knowledge on best practices, for example, machine operability, cable safety and anchors.

Newer technologies that can replace hand-falling or allow safer mechanization on steep slopes such as remote control and automation should be researched.

5 APPLICATIONS FOR POLICY AND PREVENTION

This project provides an evidence based platform that could be used by practitioners and regulators for implementation of safer forest harvesting practices by encouraging more mechanization. While it is appealing to regulate where mechanization should be used as a safer alternative to manual falling, the practicalities of defining these limits are daunting.

North America currently has ten new types of winch-assist systems in operation. The rate of adoption and innovation in applying the new technology in BC is very fast. This is a very positive development as manual falling is increasingly being replaced by mechanization. As winch-assist technology becomes more wide spread, operability limits will be tested, creating potentially dangerous situations. Practices and systems will continue to evolve. The regulatory implications involve standards for manufacturing and importing equipment into BC, and safe operating practices.

Manufacturers are hoping for international, science-based standards so equipment can be produced for one market without adapting to standards for different jurisdictions. Standards should be performance-based rather than prescriptive so innovative solutions can be developed. The market for specialized harvesting equipment is small and if special standards are required for BC, then manufacturers may by-pass B.C., diminishing the competitiveness of the industry. It is recommended that WorkSafeBC work with the International Standards Organization (ISO) to develop B.C. winch-assist standards. If B.C. requires unique standards, then ISO should be urged to consider them.

Many of the existing regulations, for example, OHSR 26, 4, 16, 3 and the WCAct, as well as the ongoing review of the mobile equipment regulation, provide good guidance for mechanized harvesting on steep slopes. Safe operating practices for new winch-assist techniques will still need to be adapted to some of the unique regional conditions in BC. Since the technology is new and evolving, it is
recommended that WorkSafeBC carefully monitor work practices, keep field staff informed of developments, and work with industry to ensure that current due diligence is applied. WorkSafeBC should identify issues of concern and work with researchers, industry and manufacturers to find solutions and develop guidelines. FPInnovations is facilitating the ongoing development of a BMP document, and aims to direct research efforts toward addressing information gaps.

Operator training is very important for ensuring that mechanical harvesting is a safer alternative to manual tree falling. Government funding and policies should be developed to support operator training either through educational institutions or on-the-job training.

The economic implications of this project involve further implementation of mechanized harvesting systems which provide benefits from reduced injuries and claims paid. Mechanized tree falling is generally more productive and economical relative to manual falling. Each feller-buncher can replace up to four manual fallers, which alleviates the looming shortage of hand-fallers.

6 KNOWLEDGE TRANSLATION AND EXCHANGE

Pending approval from WorkSafeBC, FPInnovations will disseminate this report through our usual report distribution network to forest companies and governments. This report will be posted on the Steep Slope Initiative website which is publicly accessible. There will be a FPInnovations Solutions newsletter article on this work as well as social media posts on LinkedIn, Facebook and Twitter. This report will be made available to groups such as the BC Forest Safety Council and forestry Associations. The appendices of Technical Reports and Information Notes will be available through member access to FPInnovations’ library.

Further development of the BMP document will be a key focus of FPInnovations’ Steep Slope Initiative. The Steep Slope Initiative Steering Committee indicated that FPInnovations should work closely with contractors and provide operator aids. The BMP will be posted and shared with the steep slope harvesting community and input will be solicited from many stakeholders in BC and internationally. The aim is to capture continuous improvement and learnings from safety alerts, along with other research and developments.
7 WORKS CITED


8 APPENDICES

Appendices attached

8.1 Best Management Practices for Winch-Assist Equipment

8.1.1 Wire Rope Integrity for Winch-Assisted Forestry Equipment – Draft Report

8.2 Published FPInovations Reports and Info Notes

Appendix 2. Review of tethered equipment for steep-slopes operations – IR-2012-08-20
Appendix 3. The Summit Winch Assist System – Info Note No. 4; 2015
Appendix 4. Ponsse Synchrowinch Harvester and Forwarder Demo Results – Info Note No. 25; 2016
Appendix 5. HSM 208F winch-assist feller clambunk forwarder – Info Note No. 18; 2016
Appendix 6. Harvesting steep slopes with Ponsse and the Herzog Alpine Synchrowinch – Info Note No. 6; 2015
Appendix 7. COFE meeting, January 14, 2016: Winch assist developments in the U.S. Pacific Northwest – Info Note No. 5; 2016
Appendix 8. Remote Operated Bulldozer (ROB) traction-assist system for steep slopes in Coastal B.C. – Info Note No. 3; 2016
Appendix 9. T-MAR LC150 traction winch – Info Note No. 12; 2016

8.3 Survey Results on Operator Training