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Mitigating Risks from Feller-Buncher Rollovers: Egress and Fire Suppression

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Contract report for the BC Forest Safety Council

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Abstract

The report fulfills a contract with the BC Forest Safety Council to analyze escape exits and fire suppression systems in feller-bunchers in relation to rollovers and develop recommendations for improvement. The report includes a review of safety incidents; discusses rollover and fire prevention; reviews fire suppression systems and provides best practices. Practical application of proposed changes to WorkSafeBC's Occupational Health and Safety Regulation, Part 16 - Mobile Equipment is discussed.

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Executive Summary

This report provides a resource package for logging contractors containing best practices to improve safety when feller-bunchers or other equipment rolls over and catches on fire. The report focuses on fire suppression and operator egress from the machine. It offers some guidance for implementing new provisions on rollover and fire to WorkSafeBC's proposed regulation Part 16: Mobile Equipment, of the Occupational Health and Safety Regulation.

Frequently it is loss of traction that causes a slide that precipitates a rollover. Preventing rollovers is the preferred solution but not always possible because of the complex interaction of factors that can cause a rollover including, operator competency, inadequate supervision, failure to identify and mitigate risks, complacency and risk tolerance. Improving operator competency through delivery of rollover prevention workshops to operators would be a good way of improving their knowledge and ability. Additional procedures for reducing the risk of rollovers are:

- Detailed LiDAR developed maps showing potential hazards.
- On the ground reconnaissance of recognized hazards.
- Comprehensive pre-work plans.
- Effective supervision.
- Eliminating a risk tolerance culture.
- Using winch-assist technology on steep slopes.
- Providing operators with best practices for operating on steep slopes.
- Regular equipment inspection and maintenance.

Technology can aid in preventing rollovers. A level gauge that displays the slope of the machine could improve operator situational awareness, or warn operators when they are in a hazardous situation. Winch-assisted machines have a lower risk of rollovers relative to untethered cutting machines due to improved traction. Technology could be developed to reduce wheel slip and improve traction. A track pressure sensor could also be developed to warn operators that a track is losing contact with the ground. Also, remote controlled machines with no operator in the cab could be deployed for use in high hazard areas. This technology is being developed in New Zealand but is still at the testing stage and has not been implemented.

However, no system is guaranteed to prevent rollovers. Therefore, provisions must allow for operators to quickly exit the machine after it has rolled over. Equipment manufacturers have indicated that there are limited options to re-engineer cabs to provide additional escape exits that meet WorkSafeBC regulations. However, there is usually enough window space that an operator could cut an escape hole through the cab window and guarding. Testing by an equipment manufacturer showed that a cordless powered metal cutting circular saw can be used to cut an escape hole through the cab steel bars and polycarbonate window in about seven minutes. Best practices would have to be rigorously followed for this option. These include, ensuring the cutting tool remains charged with a charged spare battery, it is easily accessible and secured, it is regularly inspected and maintained, and the operator has been trained and practices operating the tool. Carrying auxiliary cutting tools in all machines and pickups is also recommended.

There may be other potential engineered solutions for cab egress but they will likely be technically challenging and expensive to design and install.

Engine compartment fires following a rollover are often caused when combustible forest debris is dislodged or leaks of flammable fluid contact hot surfaces such as exhaust manifolds or engine components. Ensuring operators inspect and clean engine compartments to prevent the accumulation of forestry debris, oil, grease and other flammable materials is the most effective way of reducing the risk of a fire.

The proposed WorkSafeBC regulation will require fire suppression systems to be effective if a machine rolls over. Currently only one fire suppression manufacturer has stated that their system will work in any orientation. However, the system has not been tested and certified by a North American standards organization such as Factory Mutual. Factory Mutual is developing a new standard but it does not specifically address testing of fire suppression systems in the event of a rollover. Manufacturers will have to work at developing technical solutions so their systems will be able to meet the proposed regulation.

It is recommended that fire suppression systems have:

- Manual as well as automatic actuation.
- Audio and visual warning prior to agent discharge.
- Spot and linear heat detectors.
- Automatic engine shutdown when suppression system is discharged.
- System certification by an independent North American certifying agency. Preferably Factory Mutual.

Other points to consider in a fire suppression system are:

- Parts and service are easily available.
- The system is recognized by the equipment owner's insurer.
- The system is suited for rugged forestry conditions including high engine compartment temperatures and very cold winter temperatures.

Operators should be trained in using a fire extinguisher and fighting a machine fire. It is also recommended that there is an extinguisher in the cabs of all machines and pickups.

Installing a kill switch that shuts down the engine and de-energizes electrical power when a machine rolls over would prevent energized equipment acting as an ignition source. Gyro or level sensors could detect when a machine has rolled over and shut power off automatically through solenoids, or manually through a switch in the cab. Critical functions and cooling circulation should be maintained. Developing devices preventing fuel spilling through fuel venting systems after a rollover is technically feasible. However, due to the large number of forestry machines and their different venting systems it would not be practical to retrofit existing equipment.

Telematics offers potential for instantaneously notifying a central office and nearby equipment operators that a machine has rolled over. However, there are technical issues that have to be solved before this technology can be implemented.

Keywords: feller-buncher; rollover; egress; mobile equipment; fire suppression system; mechanized harvesting; safety.

1 Introduction

British Columbia's rugged terrain and climate poses challenges for safely operating mobile forestry equipment. Steep slopes and poor traction often due to weak soil conditions have caused incidents where machines have rolled over. Over the past nine years there have been two incidents where feller bunches rolled over, caught fire and the operators perished. This led WorkSafeBC to propose regulation changes to prevent similar accidents. The proposed regulations focus on operator egress and engine compartment fire suppression[1] and are a part of broader scope of proposed changes in mobile equipment.

The objective of this report is to provide a resource package for logging contractors containing practices to improve safety when feller-bunchers or similar equipment rolls over and catches on fire. The project analyzes escape exits, fire suppression systems, engineering controls, and other potential solutions. The report focuses on engine compartment fire suppression systems and operator egress from the machine. This report was contracted by the BC Forest Safety Council with funding from WorkSafeBC.

2 History of Incidents

Incidents of machine fires and rollovers are not high given the large number of timber harvesting machines. Although there have been fatalities, mechanized felling is a much safer alternative to hand falling. Detailed learnings can be referenced in safety alerts which are reviewed below.

2.1 Egress Problems

There have been rollover incidents where operators have been unable to get out of their machines because doors and escape routes were blocked.

At Mackenzie in 2017 a feller-buncher tipped over backwards and caught fire fatally injuring the operator. The incident is still under investigation. See BCFSC Alert 2017-10-16[2].

At Peachland in 2010 an operator contacted co-workers to tell them he needed the Butt N Top loader to assist him as he had rolled his machine. Approximately 5-10 minutes later he informed them that his machine was on fire and he could not get out. Two skidders tried to get the machine upright or move it away from the stump that blocked the emergency exit but were unsuccessful. The Butt N Top was able to upright the machine but it was too late to save the operator.

The Coroner's report (Noble 2011) concluded that the operator was unable to take corrective action after the machine reached the tipping point.

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[1] WorkSafeBC. (2018). *Proposed repeal and re-enactment of Part 16: Mobile Equipment in the Occupational Health and Safety Regulation*. Retrieved from https://www.worksafebc.com/en/resources/law-policy/discussion-papers/consultation-on-proposed-amendments-to-the-occupational-health-safety-regulation-july-18/part-16?lang=en

[2] BC Forest Safety Council (2017). *Fatality alert* [October 16, 2017, Feller buncher operator]. Retrieved from ttp://www.bcforestsafe.org/node/3026

The operator was unable to escape from the cab because the machine was lying on the operator's door, a stump blocked the single emergency hatch, and the front and rear windows had vertical steel bars. The investigation also concluded that the onboard fire suppression system was not suitable for the feller because:

- The agent cylinder in the engine compartment is exposed to operating temperatures above the maximum limit of 66^0C.
- The suppression agent did not reach accumulations of wood debris.
- If the agent cylinder is orientated more than 150^0 from vertical, the system will not work properly which is likely in a rollover.

Another fatality occurred at Haida Gwaii in 2009 when a loader fell into the water while being unloaded off a barge and the operator could not escape. See BCFSC Alert 2009-05-04[3].

Frequently, it is loss of traction that causes a slide that precipitates a rollover.

In 2010 a feller buncher operator was cutting a right-of-way when the machine slid about two meters down a bank and tipped over landing on its side blocking the side exit door. The escape hatch was also blocked by a stump. The operator called for assistance expressing concern the machine might catch fire and he would be unable to escape. Co-workers arrived and determined there did not appear to be a fire risk. They secured the buncher with another machine and then cut off the stump. The escape hatch could then be opened and the operator freed. See BCFSC Alert 2010-05-07[4].

In 2009 a feller-buncher operating on a steep slope lost traction, slid and then toppled over landing with the cab top on the ground (Figure 1). The impact caused the cab to twist and the operator could not exit the machine by the main door or the roof escape hatch. The operator was able to contact co-workers via radio and they arrived in approximately fifteen minutes with fire extinguishers and tools. They managed to open the front window escape hatch and free the operator. See BCFSC Alert 2010-10-01 .

[3] BC Forest Safety Council. (2009). *Safety alert: fatality* [May 4, 2009, Queen Charlotte Islands, BC]. Retrieved from http://bcforestsafe.org/files/2009-05-04%20Operator%20Fatality%20Unloading%20Barge.pdf

[4] BC Forest Safety Council. (2010). *Safety alert* [May 7, 2010, feller buncher rolled over trapping worker inside]. Retrieved from http://www.bcforestsafe.org/node/1678

Figure 1. Loss of traction led to rollover.

2.2 Rollovers

Most feller-buncher rollovers in conventional harvesting have occurred on relatively flat ground, but the risk of rollovers is increasing as the proportion of fibre harvested from steep terrain increases. While the reported number of incidents on steep slopes has been low and safety diligence is high, hazard levels may be increasing due to aging equipment, operator complacency and loggers pushing the limits of operability.

A fatality occurred in 1988 when a feller-buncher was heading down a trail and the lower track slipped off a stump. The operator was not wearing a seat belt and sustained fatal head injuries. See WSBC Alert 25-88[5]. Similar fatalities occurred in Idaho in 1994[6] and South Carolina in 1993[7].

[5] WorkSafeBC. (1988). *Logging fatal* [Operator feller-buncher]. Retrieved from https://www.worksafebc.com/en/resources/health-safety/hazard-alerts/forestry-fatal-operator-feller-buncher?lang=en&origin=s&returnurl=https%3A%2F%2Fwww.worksafebc.com%2Fen%2Fsearch%23q%3Dfeller%2520buncher%2520%26sort%3Drelevancy%26f%3Acontent-type-facet%3D%5BHazard%2520alerts%2520%2526%2520safety%2520bulletins%5D%26f%3Alanguage-facet%3D%5BEnglish%5D

[6] U.S. Department of Labour, Occupational Safety and Health Administration. (1994). *Inspection detail* [Employee dies of fractured neck in equipment rollover]. Retrieved from https://www.osha.gov/pls/imis/establishment.inspection_detail?id=107239196

[7] U.S. Department of Labour, Occupational Safety and Health Administration. (1993). *Inspection detail* [Employee killed when feller-buncher overturns]. Retrieved from https://www.osha.gov/pls/imis/establishment.inspection_detail?id=115689978

An operator died in Washington in 2017 when hoe-chucking. At some point while moving logs uphill, the momentum created by the swing or rotation of the boom caused the tracks to lose traction and it rolled. See Washington State 2017 Alert[8].

A hoe-chucker in New Zealand rolled while crossing the contour at 15-20 degrees. While slewing, the lower track sunk into a hole and the upper track slipped on a stump. See New Zealand 2014 Alert[9].

A hoe-chucker rolled after the operator pulled logs toward the machine and the machine pivoted on a small rock outcrop and then slid on thin soil over a rock bench. See BCFSC Alert 2010-01-07[10].

A tethered feller-buncher in New Zealand rolled after slewing the head around while positioned on a rocky outcrop. See New Zealand 2016 Alert[11].

A decking machine slid into a large divot that was covered by debris, hit a stump and overturned. See BCFSC Alert 2010-02-17[12].

Another decking machine flopped over when warm weather destabilized a windrow of snow underneath the machine track. See BCFSC 2010 Alert[13].

There are also many incidents where machines have slid but not rolled over.

While working on a slope in excess of 35 per cent, a hydraulic failure occurred causing a feller-buncher to freewheel out of control for about 20 metres to the bottom of the slope. See BCFSC Alert 2016-01-15[14].

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[8] Washington State Department of Labour and Industries. (2017). *Logging injury alert* [Shovel operator dies when shovel rolls down ridge]. Retrieved from http://www.lni.wa.gov/safety/research/face/files/shoveloperatordieswhenshovelrollsdownhill.pdf

[9] New Zealand Forest Owners Association. (2014). *Safety alert*. [Rolled excavator in shovel logging]. Retrieved from https://nzfoa-iris.com/SafetyAlerts/ShowSafetyPDF.aspx?id=109

[10] BC Forest Safety Council. (2010). *Western Forest Products Hazard Alert* [Hoe chucker rollover – medical aid]. Retrieved from http://www.bcforestsafe.org/files/2010-01-27%20Hoe%20Chucker%20Rollover.pdf

[11] Forest Owners Association of New Zealand. (2016). *Hazard alert* [Tethered felling machine rollover]. Retrieved from http://www.bcforestsafe.org/files/Safety_Alert-New_Zealand_Rollover-June%2015-2016.pdf

[12] BC Forest Safety Council. (2010). *Forest Industry Safety Alert* [Close call – serious incident, February 17, 2010, Chetwynd, BC]. Retrieved from http://www.bcforestsafe.org/files/2010-02-17%20Machine%20slides%20into%20obscured%20hole%20in%20the%20ground%20and%20overturns.pdf

[13] BC Forest Safety Council. (2010). *Forest Industry Safety Alert* [March 25, 2010, Decker machine tip over]. Retrieved from http://www.bcforestsafe.org/files/2010-02-17%20Machine%20slides%20into%20obscured%20hole%20in%20the%20ground%20and%20overturns.pdf

[14] BC Forest Safety Council. (2016). *Safety Alert* [January, 2015, Feller buncher runaway on steep slope]. Retrieved from http://www.bcforestsafe.org/files/Safety_Alert_Lime_Creek_Logging_2016-1-15.pdf

A feller-buncher working on 30% slope broke a track link so a track fell off the track frame. With no track on one side, the machine was riding on the idler, rollers, and sprocket, which caused it to free-wheel 10 m down slope before the operator could regain control. See BCFSC Alert 2009-10-13[15].

Wet compacted snow created slippery conditions which caused a feller-buncher to slide downhill. See BCFSC Alert 2012-02-01[16].

2.3 Engine Fires

Engine fires are commonly caused by a build-up of combustible materials. See BCFSC Alerts 2008-10-22[17], 2010-04-03[18]. Faulty wiring and leaking fluids are also contributors. In many cases the cause is unknown and the suppression systems failed to extinguish the fire (Figure 2). See BCFSC Alerts 2014-02-07[19], 2013-03-07[20], 2009-10-08[21], 2009-09-25[22]. Fires often occur following a rollover as combustible material and leaking flammable fuels come in contact with hot machine parts. See Minnesota Alert 2008[23].

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[15] BC Forest Safety Council. (2009). *Forest Industry Safety Alert* [October 13, 2009, Close Call/Serious Incident]. Retrieved from http://www.bcforestsafe.org/files/2009-10-13A%20Feller%20Buncher%20track%20link%20broke.pdf

[16] BC Forest Safety Council. (2012). *Forest Industry Safety Alert* [February 1, 2012, Buncher slides down slippery slope, operator bruised]. Retrieved from http://www.bcforestsafe.org/files/Safety_Alert_Canfor_2012-2-1.pdf

[17] BC Forest Safety Council. (2008). *Forest Industry Safety Alert* [October 22, 2008, Nazko Logging Close Call/Serious Incident]. Retrieved from http://www.bcforestsafe.org/files/2008-10-22%20Build-up%20of%20combustable%20material%20results%20in%20machine%20fire.pdf

[18] BC Forest Safety Council. (2010). *Forest Industry Safety Alert* [April 3,2010, Close Call/Serious Incident] Retrieved from http://www.bcforestsafe.org/files/2010-04-03%20Feller%20Buncher%20Muffler%20Starts%20Small%20Fire.pdf

[19] BC Forest Safety Council. (2014). *Forest Industry Safety Alert* [February 7, 2014, Engine compartment fire destroys feller buncher] Retrieved from http://www.bcforestsafe.org/files/Safety_Alert_Katchmar_Construction_2014-2-7.pdf

[20] BC Forest Safety Council. (2013). *Forest Industry Safety Alert* [March 7, 2013, Feller Buncher erupts in flames, cause unknown] Retrieved from http://www.bcforestsafe.org/files/Safety_Alert_Monte_Lake_FP_Inc_2013-3-7.pdf

[21] BC Forest Safety Council. (2009). *Forest Industry Safety Alert* [October 8, 2009, Serious Incident] Retrieved from http://www.bcforestsafe.org/files/2009-10-08%20Buncher%20Catches%20Fire%20While%20Operating.pdf

[22] BC Forest Safety Council. (2009). *Forest Industry Safety Alert* [September 25, 2009, N Three Contracting Ltd], http://www.bcforestsafe.org/files/2009-09-25%20Processor%20Catches%20Fire%20While%20Operating.pdf

[23] Minnesota Lumberman's Underwriting Alliance. (2008). *Lessons from losses*. Timber Bulletin March/April 2008. Retrieved from http://www.mlep.org/documents/lessonloss/fellerbunchtipoverburnmarapr08.pdf

An operator was fatally burned while attempting to extinguish an onboard fire when he was enveloped in a sudden release of ignited hydraulic oil. See North Carolina 2008 Alert[24].

Figure 2. Root cause of engine compartment fire is unknown (photo credit Katchmar Construction).

3 Egress

As indicated in section 2.1, safe procedures are needed to ensure that operators escape from cabs in the event of a rollover. Safety standards for emergency exits in other jurisdictions are reviewed in Appendix 10.1.

3.1 Escape Hatches

Alternate means of escape from the cab is well established among manufacturers.

Engineers at John Deere, Madill, Tigercat and Eltec were consulted on cab design and egress points. The four manufacturers' machines have a minimum of two access points plus an escape hatch on the cab roof. The Madill bunchers have five exits, the standard door, and escape hatch on roof, one behind the operator's seat and two others. Not all meet WorkSafeBC regulation because they can't be opened from the outside, but still provide a means of egress for the operator.

The manufacturers consulted indicated that solutions for additional escape hatches had been exhausted. This led a manufacturer to explore an alternative solution; using a handheld cutting tool to cut an escape hatch in the cab window. There may be additional engineering solutions that could be developed.

[24] U.S. Department of Labour, Occupational Safety and Health Administration. (2008). *Inspection detail*. [Employee fatally burned while fighting equipment fire] Retrieved from https://www.osha.gov/pls/imis/establishment.inspection_detail?id=311343164

Best Practices for Egress

The BC Forest Safety Council provides material on the RADAR system for identifying hazards and reducing risks. This is applied to mobile equipment escape hatches in the BC Forest Safety Council Alert 2010-08-01[25].

Recognize the risk – do pre-work orientations with operators and supervisors with checklists related to rollover hazards (e.g. high stumps, rock outcrops, debris, unstable material, bogs, etc). Look for upset conditions that deviate from the plan and could cause an incident.

Assess the situation – verify that all cab exits are functional. Escape hatches must be clearly marked and visible from inside and outside of the machine. Escape hatches must be inspected regularly to ensure they can be easily opened from inside and outside the machine. Bent or damaged hatches, corrosion, rotten rubber seals, over tight bolts, or even heavy repainting can make escape hatches difficult or impossible to open. Secure or remove all objects in the cab that could impede the operator from quickly exiting the cab. Inspect doors and escape routes each shift, remove all vandal locks before operations begin.

Develop a safe solution – select equipment with a third escape route. When modifying cabs for alternative escape routes ensure that guarding and rollover protection is not compromised and is approved by a professional engineer. Schedule regular maintenance for escape hatches.

Act safely to fix the problem – operators should regularly practice opening and exiting through emergency exits to ensure they can comfortably fit through. When working in hazardous conditions, e.g. steep slopes have other operators working nearby that can offer assistance. Increase check-in frequency. Check and maintain fire suppression systems. Crews should practise rescuing operators from equipment. This can be a challenging task as it may require specialized skills and tools to do the job quickly and safely.

Report and record the upset condition – report upset conditions or hazards to a supervisor. Share learnings from incidents.

[25] BC Forest Safety Council. (2010). *Safety alert of the month* [August, 2010, Hazards and risk: mobile equipment escape hatches]. Retrieved from http://www.bcforestsafe.org/files/August%202010%20Escape%20Hatch%20Alert%20of%20Month.pdf

3.2 Handheld Cutting Tool for Emergency Egress

The proposed changes to WorkSafeBC Part 16: Mobile Equipment OHS regulation indicate that harvesting equipment must have, *attached to the inside of the cab, a powered cutting tool able to effectively cut through steel guard bars and polycarbonate windows in a timely manner to provide an emergency means of escape.* It is likely that manufacturers will not provide equipment for this regional requirement so distributors or contractors will have to meet this proposed requirement if it is approved.

Tigercat Industries investigated the concept of the operator using a handheld cutting tool to cut an escape exit though the cab window. They tested a variety of tools for speed and efficiency in cutting through the polycarbonate windows and steel guard bars surrounding the operators cab. Testing found that the Milwaukee model M18 Fuel ™ 5-3/8”- 5-7/8” cordless metal cutting circular saw equipped with a Milwaukee Metal Tech Metal Ferrous blade and a Milwaukee M18 9.0 Ah battery cut a 51 by 74 cm (20 by 29 in.) egress hole through the 3.2 cm (1.25 in.) thick polycarbonate front window and two steel guard bars in approximately seven minutes and used half the battery charge. Cutting through the two steel guard bars was faster than cutting the hole in the polycarbonate window.

Figure 3. Hand held cutting tool Milwaukee model M18 and blade.

Tool specifications:

Milwaukee model M18 Fuel™ 5-3/8”- 5-7/8” metal cutting circular saw (part number 2782-20)

- Weight 4.8 (lbs)
- Height 8.5 inches
- Length 12.25 inches

Cost

The total cost for the Milwaukee tool and accessories is about $800.

- Milwaukee metal cutting circular saw $269
- Milwaukee Metal tech metal ferrous blade (part number 4840-4070) $86
- Milwaukee M18 9.0 Ah battery $229 (X2) (1 spare) =458

Tigercat examined and tested a variety of different cutting tool types to prove the concept. Further testing should be done as there may be a different cutting tool that provides similar or better cutting performance than the Milwaukee or there may be a more suitable alternative method for emergency egress.

Sparks will be generated from cutting through the metal bars. The flash point of diesel fuel is relatively high so the risk of igniting leaking diesel fuel from a spark is considered low compared to not egressing a machine that is at risk of catching fire.

Keeping the battery fully charged as well as the tool always available and ready to use and properly secured in the machine, is essential. There must be controls and procedures to ensure the tool is not used for other purposes. Hard wiring the battery pack to the machines electrical system would help ensure it is always fully charged.

Best practices

- Operators must check to make sure the tool is in good working condition at the start of the shift.
- The tool must be properly secured in an easily accessible location.
- It must not be used for other purposes.
- The battery should be fully charged with a charged spare.
- Ideally the battery charging unit should be hard wired to the machine's electrical power.
- The operator must be trained and should practise using the tool.
- The tool should be inspected regularly and have scheduled maintenance.
- There should be gloves and safety glasses/goggles with the tool.

Recommendation

It is recommended that auxiliary cutting tools be carried in all employee pickups and other forestry machines. Employees could use the tools to perform rescues and cut emergency exits from outside.

4 Vehicle telematics

Vehicle telematics is the use of GPS and onboard computers to track in real time machine movements and diagnostics. Data is transferred instantaneously by satellite or through cell phone networks to adjacent machines and a central location. Information such as vehicle location, fuel consumption, and operating hours can be transmitted. Telematics can also be used to contact help in the event of a motor vehicle collision. For example, eCall is European system that automatically calls an emergency center when an eCall equipped car is involved in a collision. All cars manufactures in Europe after April 2018 must be equipped with eCall technology. A North American system OnStar also provides automatic notification to a monitoring station in the event of a collision.

The application of telematics for improving harvesting machine operator's safety would be through the instantaneous notification of a machine rollover and or fire to a central office and nearby machine operators. Although this technology has potential there are technical issues that have to be overcome before this technology can be implemented. In most forestry operations there is limited cell reception so communication must be through satellite.

The satellite antenna must be externally mounted to receive and transmit and this presents design challenges as it must be protected from being damaged if a machine rolls over. Multiple antennae may be a solution.

Incorporating telematics may provide additional safety for operators in the future. However, this will not replace the contractor using diligent safety check-in procedures, proper communication devices and communicating with co-workers.

5 Prevention

Checklists for assisting operators and supervisors with safe practices to prevent incidents are included in Appendices 0 and 10.3

5.1 Rollover Prevention

Loss of stability can happen on all types of terrain, including steep slopes or flat ground, and many factors contribute to rollovers. Most equipment roll overs are caused by an initial loss of traction resulting in an uncontrolled gain in momentum (Visser & Stampfer, 2015). Boom configuration and reaching for trees along with unstable or uneven ground also lead to rollovers. Often it is complacency and accepting risk tolerance that are the biggest factors contributing to rollovers. Operators are usually skilled and competent and receive proper training on operating equipment. A workplace culture can develop that unintentionally rewards accepts, and promotes risk taking while working on steep ground. Felling trees on difficult hazardous ground is often something operators accept as a challenge and part of a ‘can do macho’ attitude. Reversing this attitude requires changing the culture through education, training and promoting safe work practices as the most important priority. Providing operators and supervisors with additional training and mentoring particularly when operating on operating on steep slopes would help in preventing rollovers. Delivering workshops focused on rollover prevention is one possible method. Workshops could be modelled after the ”Anatomy of a Rollover” workshops delivered to log truck drivers. While it is preferable to emphasize prevention of rollovers, this report focuses on mitigating risks once rollovers occur.

Technology can aid in preventing rollovers. Winch-assisted machines have a lower risk of rollovers relative to untethered cutting machines. Winch-assist improves traction by increasing the surface of track in contact with the soil. Technology could be developed to reduce wheel slip and improve traction. A level gauge that displays the slope of the machine could improve operator situational awareness, or warn operators when they are in a hazardous situation. Although these instruments are not commonly used in harvesting equipment they are used in off road recreational vehicles. A track pressure sensor could also be developed to warn operators that a track is losing contact with the ground. See Scion Youtube[26] video on a rollover incident.

[26] Scion. (2018). Scion rollover incident. Retrieved from https://www.youtube.com/watch?v=XO3vrMwwnVo&feature=youtu.be

There is potential to fully develop remotely controlled machines where there is no operator in the cab for use in high hazard areas. This technology is being developed in New Zealand but is still at the testing stage and has not been implemented.

Regulatory terms of reference for operating mobile equipment and many considerations for preventing rollovers are described in WorkSafeBC's (2016) document, *Understanding the Requirements for Mobile Logging Equipment in British Columbia*[27].

Some basic practices to prevent rollovers are summarized below.

- Adequate planning and standard operating procedures
    - Provide adequate visuals (maps).
        - LiDAR-derived terrain models provide highly detailed information of the terrain that aid in identifying hazards. Accurate slopes and grade changes are easily identified; rocky outcrops and hollows as well as landslide scars can be discerned; deactivated spurs, landings, and access points could also be recognized.
        - On-the-ground reconnaissance of the block, especially steeper areas, spots with thick understory vegetation, shallow soils or rocky ground as well as any other applicable risks/hazards (overhead hazards, excessive old stumps or downed large material, etc.) should be carefully examined and embedded into the maps/ visuals.
    - Provide detailed work plans
        - If slopes exceed WorkSafeBC limitations for the equipment, develop and provide a site-specific steep slope plan and operating procedure.
        - Weather-affected changes should be included in the visuals – e.g. a significant rain event can dramatically reduce soil strength at any given site.
        - Develop a site-specific emergency response plan for each worker and machine.
    - Effective instruction, communication and supervision
        - Conduct pre-work meetings to clearly communicate the details of the harvesting block, the maps/visuals, the hazards and risks identified as well as the preventative measures addressing those. Ensure everyone involved clearly understands expectations about safety and acceptable operating standards.
        - Mark "no-go" areas that are too steep in the field and on the maps/visuals. Operators should be cautioned about developing complacency when operating on flat ground.
        - Observe and record operating procedures and implement timely measures to correct any unsafe behaviour.

[27] WorkSafeBC. (2016). *Understanding the Requirements for Mobile Logging Equipment in British Columbia*. Retrieved from https://www.worksafebc.com/en/resources/health-safety/information-sheets/requirements-for-mobile-logging-equipment-in-bc?lang=en

        - Emphasize to every operator that they should know their personal and equipment limitations and work accordingly; frequently revisit the topic to prevent complacency and risk tolerance.
        - Ensure there is always a supervisor on site.
- Provide adequate training to operators performing more challenging tasks
    - Provide training material and resources on the hazards and risks of working on steep, rough, or otherwise challenging ground; implement a staged gradual transition into steeper and more challenging operation once satisfactory competency has been achieved at moderate and easy terrain.
    - Provide best practices when working on slopes:
        - When travelling downhill face direction of travel and place head on the ground to stabilize machine when required; if facing uphill, extend boom out and up the hill and lower the felling head to the ground to act as a counterweight.
        - Be aware of ground conditions and clear a path with felling head if needed.
        - Tracks to be straight up and down slope where possible.
        - Extra care needed when slewing as momentum can be altered jeopardizing machine stability.
        - When shovelling or hoe-chucking from above and throwing downhill, ensure that the machine tracks fully contact solid stable ground that will not cause them to shift or slide.
        - Avoid having tracks on stumps/logs/loose rock that may shift and result in an upset condition and loss of control.
        - Operators must regularly stop and reassess their work area to ensure they have a good plan and are aware of any upcoming hazardous situations.
        - If operators encounter ground conditions that they feel are unsafe, discontinue work and consult supervisor.
        - When backing down realize vision is limited and hazards may be obscured.
- Ensure that equipment is inspected and maintained regularly.
    - Inspect undercarriage regularly for wear, pay close attention to track links, track tension, grousers and pads.
- Implement robust continuous improvement culture.
    - After each completed harvesting block, review current procedures to assess whether they have fully addressed the identified hazards involved including procedures for reviewing changing conditions such as weather.
    - Review emergency response plan for each new worksite. Practice emergency response regularly. Promptly communicate any changes to all stakeholders.

5.2 Fire Prevention

5.2.1 Fire Risks

The number of potential ignition sources and combustible materials to sustain a fire once it starts puts timber harvesting machines at risk. A prime ignition source is the very hot exhaust system including, mufflers and pipes as well as turbo chargers and hydraulic pumps. Electrical shorts due to an overloaded system or improper modifications also create potential ignition sources. Malfunctioning brakes and accumulation of flammable materials around rotating components could cause ignition.

Timber harvesting equipment manufacturers are designing machines that are more powerful and productive. However, these improvements have also increased the risk of fire. New Tier 4 engines run hotter than conventional engines increasing the engine compartment temperature which creates a greater risk. Ultra-low sulfur diesel is more flammable than conventional diesel fuel.

Once a fire ignites it can be fed by many combustible materials, including forest debris such as needles, leaves, branches, bark and sawdust. The large volumes of hydraulic fluid under pressure create a potential fire hazard when hydraulic hoses rupture or leak. Diesel fuel, engine oil, anti-freeze, electrical wiring insulation rubber and plastic hoses are all flammable. The engine fan can fan the flames increasing fire intensity.

Engine compartments are usually located at the rear of the machine out of sight of the operator which makes early detection difficult. The fire can become well established before the operator realizes there is a fire. Timber harvesting machines work in isolated conditions and so support for fighting a fire is not quickly or readily available. In the early stages of a fire the operator is likely to be the only person available to fight it.

5.2.2 Machine Engineering Controls

Most fires are preventable and fire prevention should be a major focus. Equipment manufacturers have incorporated fire prevention features through engineering design and controls. Timber harvesting machines have sloped external surfaces so branches, needles and other forest debris will slide off the machine. Machines are designed to prevent forest debris from entering the engine compartment. However, dust and combustible debris gets sucked into the radiator and if it accumulates creates a fire hazard. Standard practice is to remove this material with compressed air during regular maintenance. Reversible radiator fan blades enable the operator to blow the debris out of the radiator by reversing the fan pitch while the machine is running. Debris can be purged frequently (i.e. every hour) which can be beneficial when operating in areas where there is a large amount of debris entering the radiator but may not be necessary in normal conditions. Cleanfix North America Inc. and Flexxaire manufacture reversible radiator fan blades that can be retrofitted to existing equipment. To help prevent an ignition source caused by the battery being displaced in a rollover it should be well secured by clamps or housed in a metal box.

5.2.3 Fire Resistant Hydraulic Fluid

Most oil-based hydraulic fluids have relatively high temperature flash points of 150 - 315°C. However, a small leak in a high-pressure system can produce a finely atomized spray that can travel significant distances and if it contacts an ignition source complete ignition of the spray envelope can occur. The alternative is to use fire-resistant hydraulic fluids (FRHFs) that significantly reduce this hazard. Lubricant manufactures have developed specially formulated hydraulic fluids that are difficult to ignite and do not spread flame. However, they are not fire proof as they will still burn under the right conditions. They can generally be classified in three categories, oil and water emulsions, water polymer solutions, and anhydrous synthetics. Water based products can be susceptible to freezing at cold temperatures, and evaporation at high temperatures so they are not an option for mobile equipment operating in B.C. Anhydrous synthetics are not used in mobile forestry machines because of concerns about lower performance and higher cost compared to oil based fluid.

5.2.4 Preventing Spillage from Fuel Tanks

Fuel venting in harvesting machines is provided through vent lines, breather tubes, or the fuel tank cap. In a rollover, fuel from the fuel tank can leak through these devices. There are devices that could potentially prevent fuel from leaking such as rollover vent valves but these devices are not used in forestry machines. The vast variety of machine types each with a different venting system would require designing and manufacturing a device for each unique application. Therefore, retro-fitting machines with leak prevention devices is likely impractical.

5.2.5 Potential Engineering Controls

A running engine and energized electrical system are potential ignition sources. Additionally a running radiator fan can fan the flames of a burning fire. When a machine rolls over machines shut down from loss of oil pressure. Although the shutdown may not occur as soon as the machine rolls over and the electrical system could remain energized. A system that immediately shuts down the engine and "kills" electrical power could help prevent fires from starting. Electrical power for running emergency systems such as lighting, communication (radio) and cooling circulation to prevent heat soak, would have to be maintained. Employing gyro or level sensors to detect when a machine has tipped over and a solenoid to turn off the power are potential solutions that could be developed.

5.2.6 Inspection and Cleaning Practices

Good housekeeping that prevents the accumulation of forestry debris, oil, grease and other flammable materials in the machine is one of the most effective ways of reducing the risk of a fire. Following daily, weekly and monthly housekeeping procedures to keep equipment free of flammable debris will prevent fires. The frequency of housekeeping would depend on the working conditions and the accumulation of combustible material. A comprehensive list of fire prevention practices has been developed by Tigercat[28].

Periodically

- Remove forest debris and blow out dust, sawdust and lichen from the air intake doors, radiator and charge air cooler, hydraulic oil cooler, diesel fuel cooler and air conditioning condenser to prevent overheating.
- Remove forest debris and blow out organic material from around exhaust components. Diligence is required where small pockets allow material to accumulate and ignite.
- If the machine is working in areas with excessive amounts of combustible forest material then conduct cleaning more frequently. Always visually inspect to ensure material is removed.
- Remove forest debris from inside the machine belly pans, lower machine structures, and areas close to the engine and fuel and hydraulic systems.

[28] Tigercat. Fire Prevention. Retrieved from: https://www.tigercat.com/wp-content/uploads/2014/08/safety_fire_prevention.pdf

The engine exhaust system can be a primary ignition source if exhaust gases leak, exposing combustible materials to high temperature gases. A change in the engine exhaust noise level is often a sign of an exhaust leak. A machine must be shut down immediately and not put back into to service if an exhaust leak is found. Exhaust system parts should be replaced before they fail.

- Inspect engine exhaust components for leaks during daily lubrication and maintenance periods. Specific items to address are:
    - cracked manifolds
    - loose or missing bolts
    - loose clamps
    - leaking gaskets
    - loose or missing debris guards and shields
    - broken mounting brackets
    - rusted or cracked pipes and mufflers
- Detach the belly pan and side shields to remove debris, grease, oils, and spilled fuel from the engine compartment.
- Steam clean the engine, transmission, brakes, fuel and hydraulic tank compartments. If operating where there are excessive amounts of combustible forest debris clean frequently.
- Other fire prevention practices include:
    - Regularly inspect electrical cables, exhaust components and hydraulic cables for damage.
    - Maintain protective shields, covers, screens and belly pans to prevent the accumulation of debris.
    - Immediately clean, grease, hydraulic fluid, lubricating oil and fuel spills.
    - Check for worn or eroded fuel and hydraulic lines.
    - Use non-flammable solutions for cleaning machine components.
    - Store rags and other combustible material in a fire proof location.

6 Fire Suppression

Under the proposed WorkSafeBC regulation, a feller buncher, timber harvester or a processor working on a sloped forest worksite with a significant hazard of rollover (not a road or landing) must have an externally mounted fire extinguisher in good working order, and an effective engine fire suppression system that activates when needed, despite a rollover.

A list of suppliers that provide fire suppression systems is provided in Appendix 10.4.

6.1 External Portable Fire Extinguishers

A handheld fire extinguisher is used to control or extinguish small fires. Typically it consists of a pressured tank that stores a fire suppression agent that is dry chemical, wet chemical, water or CO^2. Extinguishers are classified according to the fuel type they can extinguish.

The proposed WorkSafeBC regulation indicates that a portable fire extinguisher must be attached to the outside of the cab in good working order with a UL Rating of at least 40B:C. The 40B means that the extinguisher provides 40 square feet of coverage. The C means the suppressant agent does not conduct electricity when applied on electrically energized equipment. Some consideration will be required for placing the external fire extinguisher so it is readily accessible, but protected from harvesting hazards.

In addition to an externally located portable extinguisher it is recommended that there should also be a portable extinguisher in the cab of all harvesting machines and pickups.

It is commonly perceived that a fire extinguisher must be periodically maintained by turning it upside down and striking it with a mallet to "fluff" the agent. This practice is unnecessary. All extinguishers must go through a compaction test with various testing labs and authorities in order to be marketed in North America and internationally. Within a short time after "fluffing" the dry chemical will go back to the same state as it was before performing this unnecessary task. Striking the shell with a mallet can dent it requiring the extinguisher to be scrapped. Also the gauge can be damaged and paint can be chipped off of the extinguisher shell, allowing corrosion to set in.

A common myth is that stainless steel extinguishers will not corrode. However, they will corrode but are less susceptible to corrosion compared to non stainless units. Corrosion on stainless steel shells looks different than on mild steel shells. Instead of spreading out in a pattern and then flaking away layers of metal (such as on dry chemical extinguishers), corrosion on stainless steel shells will not spread out or flake. Instead it will bore through the shell creating a pinhole at each spot where corrosion has developed a foothold. Anything that looks like aged line corrosion on a stainless steel shell should inspected by a professional.

Best Practices

Maintenance - follow the manufacturers' maintenance requirements.

Inspect monthly to confirm:

- The fire extinguisher is not blocked or hidden.
- The fire extinguisher pressure gauge shows adequate pressure.
- The pin and seal is in place.
- The extinguisher shows no visual sign of damage or abuse.
- The nozzle is free of blockage.
- The extinguisher is securely fastened.

6.2 Engine Fire Suppression Systems

Hand held fire extinguishers are not effective at suppressing engine compartment fires in harvesting machines because of the enclosed compartment, challenges in early detection, volume of agent required, and the type and amount of flammable materials.

A typical fire suppression system for mobile equipment has systems for detection, control, agent storage delivery and discharge. The system contains fire detectors, actuation systems and suppression agent storage containers, discharge valves for manual or automatic control, piping and discharge nozzles. Systems are designed to either flood the entire area with suppressant (i.e. the engine compartment) or apply suppressant to a localized area. The systems are one-time use as they discharge the entire agent at once and must be recharged after use. Figure 4 shows the components of a fire suppression system.

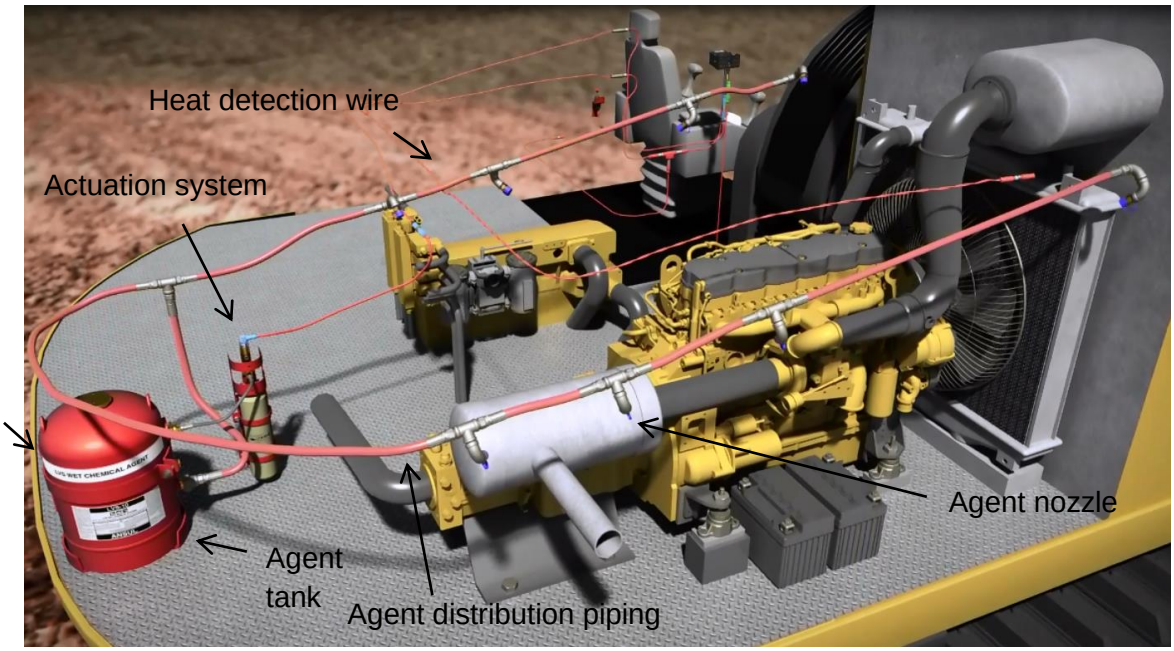

Figure 4. Fire suppression system (photo credit Ansul/Johnson Controls).

Fire suppression systems in mobile forestry machines are exposed to harsh operating conditions which must be considered when evaluating a system. These include vibration, temperature extremes and potential accumulation of forest debris, dirt, sawdust, oil, grease and, hydraulic fluids in the engine compartment. Additionally the machines often work on steep slopes. A crucial requirement is the system must be operational at any angle so that in the event of a machine rollover the system will function. Additional performance factors that should be met include quick fire detection and actuation, effective coverage, automatic machine shutoff, design simplicity, and ease of cleanup after discharge.

6.2.1 Detection Systems

Common electronic detection systems are linear heat detectors (Figure 5), spot heat detectors and optical flame detectors.

Linear

Linear heat detectors often use braided wire (twisted) that is installed throughout the area requiring fire protection. Braided wires are separated by a temperature sensitive material.

When a section of the braided wire reaches the threshold temperature, the material separating the wires disintegrates and the wires touch, activating the system. Some manufacturers of linear detectors include Ansul, Amerex and Kidde.

Figure 5. Linear heat detector (photo credit Amerx Corp.).

Advantages

- Provide systematic continuous coverage as it detects heat anywhere along the length of the wire.

Disadvantages

- More exposed to potential physical damage compared to spot detector.

Spot

Spot heat detectors use a temperature switch (~250F) to detect a fire (Figure 6). Typically a number of these are positioned throughout a machine in high fire risk areas.

Figure 6. Spot heat detector (photo credit Amerex Corp.).

Advantages

- Robust, dependable and widely used.

Disadvantages

- Must be carefully deployed to ensure effective coverage over the complete hazard area.

Infrared (IR)

Infrared sensors are also capable of measuring the heat being emitted by an object and detecting motion. Infrared detectors shine a light beam across to a reflector plate. When a flame disrupts the light beam an electrical signal is sent to the control panel activating the suppression system. An example of Infrared systems manufactured by Amerex is shown in Figure 7.

Figure 7. Infra-red heat detector (photo credit Amerex Corp.).

Advantages

- Instantly senses fire.

Disadvantages

- The infrared sensor and source must be kept very clean which is hard to do in an engine compartment of a harvesting machine. False alerts can activate the system when there is no fire.

Recommendation

Spot heat and linear detectors are considered the most reliable and rugged. They are likely the best option to withstand the vibration, jarring and harsh operating environment found in the engine compartment of forestry machines. The optimal solution is to use both linear and spot detectors.

6.2.2 Propellant and Delivery Systems

Many fire suppression systems use compressed nitrogen to distribute the suppression agent. There are two ways of storing the nitrogen. It is either stored in the same tank as the suppression agent or it is stored in a separate tank. A major drawback of the one tank system is pressure can leak through the pressure gauge particularly where there is significant vibration as is the case with mobile forestry machines that operate off road. This can cause poor performance or even complete system failure. The two tank system where the nitrogen is stored in a separate sealed tank is more to resistant to pressure leaking from the tank. The two tank system is likely a better option for mobile forestry equipment given the harsh operating environment.

Advantages of a two tank system

- Prevents moisture from entering the agent cylinder and contaminating the agent.
- More resistant to pressure leaking from the tank though the pressure gauge compared to the one tank system.

Disadvantages

- More space required for the two tank system.
- More complex and expensive.

Suppressant is delivered to a target area thorough piping. Nozzles affixed to the piping distribute the suppressant over the target area. Stainless steel piping or hydraulic hose is considered superior to rubber or plastic because they are more robust and have a longer lifespan. Nozzle caps keep the nozzle head clear of foreign material from that could inhibit or prevent suppressant distribution Figure 8). Nozzles caps are either spring loaded or blow off.

Points to consider when choosing a delivery system:

- Nozzle should be protected by either blow off or spring loaded nozzle caps.
- Stainless steel piping or high quality hydraulic hose is robust and has a long lifespan.

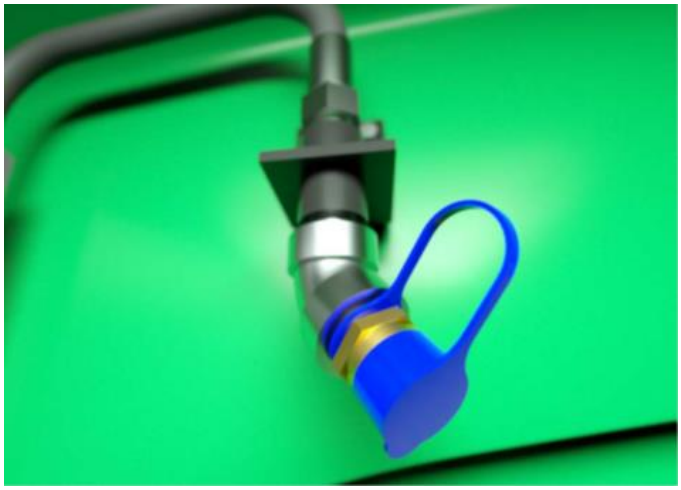

Figure 8. Nozzle with cap (photo credit Amerex Corp.).

6.2.3 Actuation Systems

There are two types of actuation systems manual and automatic. In a manual pneumatic actuation system the operator pushes a button to discharge the agent (Figure 9). Some manual suppression systems allow the operator to manually release the agent through a function on the control panel (Figure 10).

Figure 9. Manual activation device (photo credit Amerex Corp.).

Figure 10. Manual actuation through the control panel (photo credit Ansul/Johnson Controls).

Under an automatic system there is no human intervention. The electrical detection system detects a fire and the system discharges.

Manual release usually results in a slower reaction to a fire as the operator may not be aware there is a fire until it is well established. However, if the operator sees a fire before it is automatically detected manual discharge will be faster. The automatic system may not function if the electrical system is compromised. Therefore the best solution is to have both an automatic and manual system.

Recommendation

The system must have automatic actuation and should also have pneumatic manual actuation

Typically an alarm sounds and there is a visual display on the control panel indicating a fire. On some systems there is a 10-30 second delay before the agent is discharged providing the operator a short time window to stop the system from discharging.

Some dual suppression agent systems have a simultaneous discharge or a time delay between the dry chemical release and wet agent creating an extended discharge period. The delay between the two suppression agents can be beneficial particularly for larger vehicles which where there is potential for larger hotter fires.

There is potential for reducing fire intensity by having the engine shutdown when the suppression system actuates. This will prevent the fuel pump from continuing to pump fuel through possibly compromised lines and stop the radiator fan from fanning the flames. Temperatures can still rise when fans are turned off so cooling circulation should be maintained with other critical functions such as radios and lights.

A non-electronic detection system that can detect, actuate the system and also distribute the suppressant is a pressure tube system. The pressure tube system can be either indirect or direct release. In an indirect system when threshold temperatures are reached the tube bursts and the drop in pressure actuates the suppression system. The suppressant is delivered through piping and nozzles. The pressure tube only acts as a detection and actuation device. In a direct release system when the tube ruptures due to heat, the rupture point acts as the distribution nozzle for the suppressant. Pressure tube systems usually communicate to the control panel when the tube bursts. Control panel alarms notify the machine operator there is a fire and the system has discharged. FireTrace Ltd. is a company that manufacturers a pressure tube system.

Advantages

- Electrical current is not required to detect a fire.

Disadvantages

- Not as robust and sturdy as linear or spot detectors.
- The break in the tube acts as the nozzle so suppressant direction and flow will not be as accurate as an actual nozzle.

Points to consider when choosing an actuation system:

- There must be automatic actuation (proposed regulation requirement).
- It should also have manual actuation.
- Engine should automatically shut off when suppression system activated. Critical functions and cooling circulation should be maintained.
- System should have an alarm when system is about to discharge. There should be a 10-30 second delay after alarm sounds before discharge occurs.

6.2.4 Suppression Agents

6.2.4.1 Dry Chemical

Dry chemical agents are very effective at quickly knocking down a fire. A fine powder is released that floods an area suffocating the fire. It works well in confined spaces such as an engine compartment because it fills space in all three dimensions, flows around obstructions, and penetrates all areas. Dry chemicals are powders typically composed of sodium bicarbonate, potassium bicarbonate, or ammonium phosphate with added supplements to provide proper flow and prevent packing and moisture absorption. It is effective against Class A, B, and C fires. They function at temperatures of -54 C^0 to 66 C^0. A major limitation of dry chemical is that it does not provide cooling of hot surfaces, which can allow fires to reignite. Manufacturers of dry chemical systems include Amerex, Affex Ansul and Kidde.

Advantages

- Provides a quick "knockdown" of a fire.
- It fills spaces in three dimensions flows around obstacles and penetrates all areas.
- Effective against Class A, B, C fires.

Disadvantages

- Does not provide cooling of heated surfaces which can allow fires to reignite.
- Can be more difficult to clean up after discharge compared to wet chemical or water mist.

6.2.4.2 Wet Chemical

Wet chemical is usually a foam based solution, but it also includes aqueous solutions that are discharged in a liquid state. Wet chemical systems suppress fire by cutting off the oxygen supply and then coating the surface of combustible material with foam which prevents reigniting. Wet chemical is not as effective at quickly knocking down a fire compared to a dry chemical. However, it is very effective at cooling heated surfaces which can be a re-ignition source. Wet chemical requires direct application and "line of sight" to the to the target area. It does not flow around obstructed areas or provide three dimensional coverage areas as well as dry chemical. This means more piping, nozzles and agent is required for the same coverage. Wet chemical systems typically have a longer discharge period compared to dry chemical. They are effective in suppressing Class A and B fires but not very effective on Class C. Wet chemical systems operability range is -40^{0}C to 93^{0}C. Manufacturers of wet chemical systems include Amerex, Afex Ansul and Kidde.

Advantages

- Provides cooling of hot surfaces that helps prevent re-ignition.
- Offers easier to clean up after discharge compared to dry chemical.

Disadvantages

- Generally does not "knockdown" fire as quickly as dry chemical.
- Does not flow around obstacles and penetrates areas as well as dry chemical.
- Not effective on Class C fires.

6.2.4.3 Dual Agent

These systems use both a dry and wet chemical. The agents are released either simultaneously or serially and discharge is controlled by the same detection and actuation system. They are considered to be more effective than single systems as they combine the quick fire knock down of the dry chemical with surface cooling from the wet chemical that helps prevent re-ignition and flare up. Dual agent systems are typically more complex to install and more expensive compared to a single agent system. Amerex Corporation and Ansul manufacturer dual systems

Advantages

- Provides the advantages of dry chemicals quick fire “knockdown” and wet chemicals cooling of hot surfaces.

Disadvantages

- More expensive and complex to install compared to a single agent.

6.2.4.4 Water Mist

Water mist systems produce very fine water droplets (mist) that suppresses fire and cools hot surfaces. The mist is generated from nozzles that are supplied with agent from pressurized tanks. The effectiveness of water mist system is dependent on the droplet size distribution, flux density and spray dynamics. The water mist is mainly water but usually an AFFF (aqueous film-forming foam) is added to help coat surfaces and improve suppression. The agent is primarily water so it is environmentally friendly and can be easily cleaned in the event of a discharge. Antifreeze is added to the water mist agent if it is to be used in below freezing temperatures. Fogmaker (FMDC Watermist Canada Ltd) (Figure 11) and Fike Corp. are two manufacturers of water mist systems.

Figure 11. Water mist system (photo credit Fogmaker - FMDC Watermist Canada Ltd.).

Advantages

- Cooling of hot surfaces.
- Easily cleaned after discharge.

- Manufacturer states it will operate at any angle.

6.2.4.5 Suppression Agent Toxicity

Suppression agents have a low order of acute toxicity. Short term exposure to skin and eyes may cause irritation. The risk is higher for people with medical conditions such as asthma. Suppression agents are not hazardous to the environment if used in approved concentrations and following manufacturer procedures.

6.2.5 Control Panel

Suppression systems usually have a control panel (Figure 12) that displays the suppression system status, controls actuation (automatic systems) and provides audible and visual warnings to the operator prior to agent discharge. Control panels are powered through the machine's electrical power with a battery as a backup.

Some control panels have a time and date stamped event log that is downloadable and provides for easy trouble shooting and incident investigation. Automatic maintenance testing mode is another feature on some control panels. Manual system actuation is a beneficial feature.

Recommended features of a control panel

- Audio and visual warning prior to agent discharge.
- Downloadable time and date stamped log.
- Automatic maintenance testing mode.
- Manual system actuation capability.
- Battery backup.

Figure 12. Control panel (photo credit Amerex Corp.).

6.2.6 Non-Conventional Suppression Systems

Devices that burst and release a fire suppressing agent when they contact flame could have potential as a fire suppression system for mobile forestry machines. Typically these devices are ball shaped with

a hard foam shell exterior and contain a small explosive charge. When heat or flame contacts the device it bursts dispersing a cloud of dry chemical. A New Zealand equipment dealer is installing this type of device in their machines and indicates they are one tenth the cost of a conventional system. A manufacturer is the Elide Fire Ball Pro Co. Ltd.

Aerosol fire suppression systems use very fine (micro) particles and gas to extinguish a fire. The particle and gas are generated by an exothermic reaction when the device is actuated. The fire suppressing aerosol typically contains potassium carbonate which suppresses fire by interfering with the combustion process. Actuation can be manual, thermal release or electronic. A pressured agent storage vessel and distribution system is not required which is a major advantage. Effectiveness would also be compromised if the engine fan was operating when they discharged. Aerosol systems do not provide cooling of hot surfaces which is a major source for reignition of forestry debris. Aerosol systems are not usually used in mobile forestry machines.

Advantages of an aerosol system

- No pressured tank or distribution system required.
- Less maintenance compared to conventional systems.

Disadvantage of an aerosol system

- Does not provide cooling of hot surfaces.
- Not effective in deep seated fires where there is wood or plastic materials.
- They have not been certified by an appropriate third party (Factory Mutual or equivalent).

6.2.7 Installation

Many harvesting equipment manufacturers offer a suppression system that is a factory installed option. For example John Deere offers AFEX fire suppression systems on their harvesting equipment and Tigercat will soon be offering Fogmaker. Dealers for suppression system manufacturers also provide system installation services on harvesting machines.

The install is usually done in a shop but some systems can be installed in the field. Installation time varies with the type of machine and the complexity of the suppression system. A quality installation can take 30-40 hours. Prior to purchasing and installing the system the installer should conduct a detailed assessment of the machine. The assessment should consider:

- What are the dimensions and volume of the area to be protected?
- Is the hazard in an open area or closed compartment? In an open area the nozzles must be aimed directly on the hazard.
- Are there obstructions? Obstructions can limit the force of the agent discharge for direct application on a fire and it may be necessary to use additional nozzles.
- Is there airflow? Airflow can adversely affect the aim of nozzles and dispersion of dry chemical requiring additional nozzles to compensate for air flow.
- What is the potential for the hazard to spread to other areas of the vehicle/machine which may require protection?

- Does the vehicle/machine have additional hand portable extinguishers? Hand portable fire extinguishers are necessary to be used as a backup to an automatic fire suppression system. Appropriate type and rating of hand portable fire extinguishers must be considered.
- Where are the ignition, heat and fuel sources?
- Where does debris accumulate?
- Potential mounting locations for agent and pressure tank.
- Locations for manual actuation points.
- Location of special hazards.

6.2.8 System Cost

There are many factors affecting cost including machine size, system complexity, suppression agent, labour rates installation location and delivery system. Therefore there is a wide range in the estimated cost. The approximate costs of installing a system on a large feller-buncher (35 tonnes):

- Wet chemical $12,000 - 20,000
- Dry chemical $10,000 - 15,000
- Dual (wet and dry) $15,000 - 20,000
- Water mist $12,000 - 15,000

6.2.9 Maintenance

Maintenance periods vary widely from system to system and by manufacturer. Some systems require six month checks; some require one year check and others can go several years between inspections. All manufacturers have recommended maintenance schedules and procedures. Typically maintenance on most systems is done every six months and requires testing of the heat detection circuits, control panel functions wiring, battery connections and cleaning the nozzles. The inspections must be conducted by qualified technicians.

Best Practices

Daily

- Confirm the fire detection system is operating through the system control panel.
- Visual inspection of the system ensuring the piping has no defects.

Monthly

- All components are present and in their original location and securely fastened.
- Ring pins are in place and secured with proper break away tamper indicator seals.
- Mechanical actuation devices are unobstructed by vehicle modifications or clutter.
- Maintenance tag or certificate is in place and up to date. Date of inspection and initials of inspector are recorded.
- Physical condition of all components. Inspect for damage or conditions that may prevent operation.
- Tank pressure gauges show tanks are in the operable stage.
- Protective nozzle caps are in place and nozzle outlets are unobstructed and properly aimed at the hazard(s) which are intended to be protected.

6.2.10 Certification

Fire suppression system manufacturers usually seek independent third party certification of their systems. A certifying authority tests the system to ensure it meets a defined set of standards and then it is given a seal of approval. Canadian organizations that test and approve fire suppression equipment include UL Underwriters' Laboratory Canada (ULC), and Factory Mutual. Factory Mutual (FM) is considered the premier testing and certifying authority for fire suppression systems for heavy duty mobile equipment used in mining and forestry. They developed the only standard specific to heavy duty mobile equipment used in the demanding conditions found in mining and forestry. FM is currently developing a new standard for heavy duty mobile equipment that is expected to be completed in 2019.

Recommendation

It is recommended that the fire suppression system has FM certification.

6.2.11 Discussion

The proposed WorkSafeBC regulation will require suppression systems to be effective if a machine rolls over. Only one fire suppression manufacturer Fogmaker Canada (FMDC Watermist Canada Ltd.) has stated that their system will work in any orientation. However, the system has not been tested and certified by a North American standards organization such as Factory Mutual. Manufacturers will have to improve their systems so they will work in a rollover and meet the proposed requirement. There must also be a test standard developed by an independent agency to verify the systems can meet the rollover requirement. Some manufacturers have expressed concern that the proposed implementation date does not allow enough time to improve their suppression systems and for an independent third party to develop testing protocols. Factory Mutual is developing a new standard but it does not specifically address testing of fire suppression systems in the event of a rollover.

6.2.12 Points to Consider When Evaluating a Fire Suppression System

- Will the system operate in any orientation (i.e. if machine is tipped over)?
- Is the system approved by a third party testing and certifying agency (ideally Factory Mutual)
- Are parts and service easily available?
- Is the system recognized by the equipment owner's insurer?
- Is the system suited for the challenging operating conditions found in a forestry harvesting engine compartment?
- Will the system operate in the very high temperatures found in the engine compartment and very low winter temperatures (-40^0C)?
- Ease in recharging the system.
- What are the installation and maintenance cost and requirements?
- Are the system component manufacturer, installer and maintenance provider knowledgeable, skilled, experienced and do they have a good track record?

6.2.13 During a Fire

Exit the machine immediately if there is a direct hazard

If there is time and no immediate hazard, the operator can:

- Lower the boom to the ground.
- Shut off the engine.
- Radio or phone for help.
- If it is safe to do so, shut off the battery disconnect switch.

Best practices

- Only if it is safe and the operator has received proper training should the fire be fought.
- When deciding whether or not to fight a fire be sure:
    - The fire is small and will not spread rapidly.
    - There is an escape route.
- Don’t fight a fire if there is risk. Instead stay clear and wait for help.
- Operators must be trained in using a fire extinguisher. Training should be done when first hired and annually thereafter.
- Use the PASS system:
    - Pull the extinguisher pin.
    - Aim the nozzle at the base of the fire.
    - Squeeze the trigger.
    - Sweep from side to side at the base of the fire.
- Operators should be familiar with the location of machine extinguisher portals.
- Ensure that the fire extinguisher nozzle fits in the machine extinguisher portals.
- The access panels should not be opened when fighting a fire. The extinguisher nozzle should be inserted in the extinguisher portals (Figure 13).

Figure 13. Fire extinguisher portals, (photo from Youtube[29]).

6.2.14 Procedures after Discharge

Dry chemical, wet chemical and water mist agents are not toxic to humans or the environment. After a system discharges the affected area must be thoroughly cleaned. Dry chemical is generally considered to be more difficult to clean than wet chemical. Water mist systems are considered to be the easiest because the main component is water.

Recommended procedures for cleaning dry chemical agent

- Workers cleaning the affected areas should wear protective clothing, safety googles and fine particle dust masks as agents are an irritant.
- Electrical systems must be de-energized before starting the cleanup.

Areas where powder remained dry

- First, clean areas that were not subject to heating and stayed dry. This will help ensure the residual dry chemical powder does not obtain moisture through the air or from direct contact. Remove the powder with air, dusting or a vacuum with a HEPA filter. Wipe all surfaces with a damp cloth.

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[29] Timber Equipment Applications Management and the NC Association of Professional Loggers. (2013). *Logging equipment fire safety.* Retrieved from https://www.youtube.com/watch?v=zKgi6S1HGGs

Areas where the powder was exposed to moisture

- The powder will form a mild acidic paste if it combines with water. To neutralize the acidic paste wash the affected areas with a solution of 3 parts water to 1 part baking soda. Allow the solution to stand for several minutes and then wipe off, wash with soap and water, rinse thoroughly and blow dry.

Areas where the powder was exposed to heat

- Where the powder was exposed to hot surfaces it will have melted forming a coating that cakes the surface. These areas should be washed with a solution of 50% hot water and 50% isopropyl alcohol. The solution should be allowed to stand on the affected area for several minutes to breakdown the crust. Then wash with soap and water, rinse thoroughly and blow dry.

Cleaning electrical contacts

- Electrical contacts should be cleaned with a non-corrosive non-conduction cleaner such as CRC Contact Cleaner 2000.

More detailed instructions on actions to take when a fire is discovered, fighting a fire and agent discharge cleanup have been summarized by Tigercat[30].

[30] Tigercat. Fire Prevention. Retrieved from https://www.tigercat.com/wp-content/uploads/2014/08/safety_fire_prevention.pdf

7 Conclusions

Incidents of feller-buncher rollovers are not uncommon and there is an associated risk of machine fire from combustible material contacting hot surfaces. Fatal incidents have occurred where emergency exits have been blocked following rollovers and fires. This report reviews rollovers and machine fire incidents, and presents findings from these incidents to help prevent rollovers. It also analyzes escape exits, fire suppression systems, engineering controls, and other potential solutions for mitigating rollovers and fires.

Preventing harvesting equipment rollover is preferred but very challenging to accomplish. Usually it is a combination of complex factors that cause rollovers, including operator error, inadequate training and insufficient supervision, failure to identify and mitigate risks, complacency and accepting risk tolerance. Improving operator competency through enhanced training should be considered. Delivering rollover prevention workshops to operators would be a good way of improving their knowledge and ability. Detailed LiDAR developed maps showing potential hazards, comprehensive work plans including potential impact of weather changes, effective supervision, and eliminating a risk tolerance culture are all practices that would also help prevent rollovers.

Operators must be able to exit the machine after it has rolled over. Equipment manufacturers have indicated that there are few options to re-engineer cabs to provide additional escape exits that meet WorkSafe BC regulation. However, there is usually enough window space that an operator could cut an escape hole through the cab window and guarding. Testing by Tigercat showed that a cordless powered metal cutting circular saw can be used to cut an escape hole through the cab steel bars and polycarbonate window in about seven minutes. Best practices would have to be rigorously followed for this option to work reliably. These include, ensuring the cutting tool remains charged with a charged spare battery, is easily accessible and secured, it is regularly inspected and maintained, and the operator has been trained and practices operating the tool. Carrying auxiliary cutting tools in all machines and pickups would help in a rescue.

There may well be other potential engineered solutions for cab egress. But they will likely be technically challenging and expensive to design and install.

Technology can aid in preventing rollovers. A level gauge that displays the slope of the machine could improve operator situational awareness, or warn operators when they are in a hazardous situation. Winch-assisted machines have a lower risk of rollovers relative to untethered cutting machines due to improved traction. Technology could be developed to reduce wheel slip and improve traction. A track pressure sensor could also be developed to warn operators that a track is losing contact with the ground. There is potential to fully develop remotely controlled machines where there is no operator in the cab for use in high hazard areas. This technology is being developed in New Zealand but is still at the testing stage and has not been implemented.

Preventing equipment fires is the most effective way of ensuring operators are not endangered by fire. Ensuring operators follow good housekeeping practices to inspect and clean engine compartments to prevent the accumulation of forestry debris, oil, grease and other flammable materials in the machine is one of the most effective ways of preventing a fire. Tigercat has a comprehensive list of best practices on fire prevention and actions to take after a fire is discovered.

Further technology development could also improve fire prevention by adapting devices and systems used in other applications. Installing a kill switch that shuts down the engine and de-energizes electrical power when machine rolls, would prevent energized equipment acting as an ignition source. The power could be shut off automatically through gyro or level sensors when a machine has tipped over or manually through a switch in the cab. However, critical functions and cooling circulation should still be maintained. Developing devices preventing fuel spilling through fuel venting systems after a rollover is feasible. However, due to the large number of forestry machines and there different venting systems it would not be practical to retrofit existing equipment.

The proposed WorkSafeBC regulation will require fire suppression systems to be effective if a machine rolls over. Currently only one fire suppression manufacturer has stated that their system will work in any orientation. However, the system has not been tested and certified by a North American standards organization such as Factory Mutual. Factory Mutual is developing a new standard for large mobile equipment but it is not certain that the standard will be able to include all the testing procedures necessary to ensure a suppression system will be effective in rollover. Manufacturers will have to work at developing technical solutions so their systems will be able to meet the proposed regulation.

Telematics offers potential for instantaneously notifying a central office and nearby equipment operators that a machine has rolled over. However there are technical issues that have to be solved before this technology can be implemented.

8 Recommendations

Prevent rollovers through planning, supervision, and operator training.

- Planning
  - Use LiDAR to produce detailed maps showing, grade changes, rocky ground, and other potential hazards.
  - Mark “no go” areas on maps.
  - Utilize winch-assist systems on steep slopes.
  - Conduct on the ground reconnaissance of hazardous areas.
  - Provide site specific work plans
- Supervision
  - Ensure there is always a supervisor on site.
  - Prevent operator complacency and acceptance of risk tolerance.
  - Observe operating practices and correct any unsafe behaviour.
  - Implement a staged transition from gentle to more challenging terrain for operators.
  - Implement a robust continuous improvement culture
- Operator training
  - Provide operator with best practices and coaching for working on slopes.
- Ensure equipment is regularly maintained. Pay particular attention to the undercarriage.
- Prevent fires by thoroughly inspecting and removing any accumulated forest debris, and spilled flammable fluids in the engine compartment.

- Inspect the engine compartment daily.
- Pay close attention to the exhaust components and immediately correct any malfunctions.
- Periodically steam clean the engine.

Emergency egress

- Ensure operators frequently practice using the escape hatch.
- Implement the hand-held cutting tool and ensure operators follow best practices on training, inspection, maintenance and testing.
- Equip all other forestry machines and pickups with an auxiliary hand-held cutting tool.

Fire suppression

- Keep a hand held fire extinguisher in cabs of machines and pickups.
- Ensure all operators are trained in using an extinguisher and fighting a machine fire.
- Fire suppression systems should have:
    - Manual as well as automatic actuation.
    - Audio and visual warning prior to agent discharge.
    - Spot and linear heat detectors.
    - Automatic engine shutdown when suppression system is discharged.
    - System certification by independent North American certifying agency. Preferably Factory Mutual.
- Improve fire suppression systems. Manufacturers of fire suppression systems will have to further develop technology to ensure systems are effective in rollover conditions.

Technological innovations

- Improve telematics technology to automatically signal other machines and central locations when there is a rollover.
- Design kill switches that quickly shutdown the engine and de-energize electrical systems but maintain emergency power for communication. The switches could be activated in the cab by the operator or automatically through gyro or level sensors for suitable equipment.
- Develop devices to prevent fuel leaking from fuel venting systems.
- Install slope gauges in cabs.
- Explore technology to reduce wheel slip and the development of track pressure sensors.
- Continue development of remote control technology

Workshops

Deliver rollover prevention workshops for operators and supervisors. Workshop would focus on factors influencing machine stability and best practices for maintaining stability and traction, including winch assist. Workshop would be modelled after Anatomy of a Rollover workshops delivered to truck drivers.

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10 Appendices

10.1 Regulations and Standards for Egress

10.1.1 British Columbia

WorkSafeBC has detailed requirements for emergency escape exits under 16.7 (1) of the OHS regulation. Requirements for machines manufactured after Jan.1 2000, indicate that emergency exists cannot be located on the same surface as the cab entrance door, can be opened inside and out without the use of tools and the dimension size of the opening. The opening size can be either as stated in the regulation or the dimensions comply with ISO Standard 2867-Earth-Moving Machinery-Access systems. Section 16.17 also allows a purpose-built window breaking device as an alternate means of escape.

10.1.2 US Occupational Safety and Health Administration (OSHA) Regulations

(9) Access to machine operator cabs and protective structures manufactured on or after July 1, 2004, must comply with SAE J185-1988 or ISO 2867:1994.

(10) Each fully enclosed cab installed on machines manufactured on or after July 1, 2004, must have a second means of egress which can be opened from both the inside and outside without tools.

10.1.3 Washington State

Washington State Regulations come under Washington Administrative Code Title 296-54-573 Logging Machines General[31]. The regulation states:

(21) A safe and adequate means of access and egress to all parts of logging machinery where persons must go must be provided and maintained in a safe and uncluttered condition. Machine access systems, meeting the specifications of the Society of Automotive Engineers, SAE J185, June 1988, "Recommended Practice for Access Systems for Off Road Machines," must be provided for each machine where the operator or any other employee must climb onto the machine to enter the cab or to perform maintenance

(22) Enclosed-type cabs installed on mobile logging machines must have two means of exit. One may be an emergency exit and be available for use at all times regardless of the position of the side arms or other movable parts of the machine. An easily removable window is acceptable as the emergency exit if it is large enough for an employee to readily exit. EXCEPTION: Cable yarders manufactured before July 1, 1980 are not required to have two.

[31] Washington State Legislature, Washington Administrative Code, Chapter 296-54, Section 296-54-571

10.1.4 Oregon

Machine egress under Oregon Occupational Safety and Health states:

(10) Each fully enclosed cab installed on machines manufactured on or after July 1, 2004, must have a second means of egress which can be opened from both the inside and outside without tools. [32]

10.1.5 New Zealand

- Regulations on egress are under Worksafe New Zealand Approved Code of Practice for Health and Safety in Forest Operations. Emergency egress is addressed under 6.4.6 of the code: All winch-assisted mobile plant shall be constructed to provide adequate emergency access and egress points that can be activated internally and externally[33].

[32] Oregon Occupational Health and Safety, Divison 7, Subdivision H Machines Used in Forest Activities,. 437-007-0775 Protective Structures For Operators, Machines Manufactured On Or After July 1, 2004 . H-10.
[33] Worksafe New Zealand, Approved Code of Practice for Health and Safety in Forest Operations.

10.2 Operator Checklist

Egress

- All cab exits are functional including the escape hatch.
- You are comfortable fitting through the escape hatch and you have practised practiced exiting from it.

Handheld cutting tool

- The tool is in good working condition.
- The battery is fully charged and there is a charged spare.
- You know how to use the tool and have practised using it.
- The tool is well secured and there is eye protection and gloves.

Planning

- Detailed work plan.
- Map showing any site specific hazards including “No go” areas.
- Steep slope work plan if working on steep slopes.
- Discussed with your supervisor any site specific hazards shown on the map.
- Had a pre work meeting where you have received information on any potential hazards.
- Know the emergency response plan for the block.
- Be aware of how a change in weather conditions could affect working conditions i.e. heavy rainfall could reduce soil strength.
- Understand and take steps to prevent complacency and risk tolerance.
- Ensure there is a working in isolation or working alone plan following the B.C. Forest Safety Councils’ Procedures.

Operating

- Follow best practises for working on steep slopes:
    - When travelling downhill face direction of travel and place head on the ground to stabilize machine when required; if facing uphill, extend boom out and up the hill and lower the felling head to the ground to act as a counterweight.
    - Be aware of ground conditions and clear a path with felling head if needed.
    - Tracks to be straight up and down slope where possible.
    - Extra care needed when slewing as momentum can be altered jeopardizing machine stability.
    - When shovelling or hoe-chucking from above and throwing downhill, ensure that the machine tracks fully contact solid stable ground that will not cause them to shift or slide.
    - Avoid having tracks on stumps/logs/loose rock that may shift and result in an upset condition and loss of control.
    - Regularly stop and reassess your work area to ensure you have a good plan and are aware of any upcoming hazardous situations.
    - If you encounter ground conditions that you feel are unsafe, discontinue work and consult supervisor.

    - When backing down realize vision is limited and hazards may be obscured.

- Know the limitations of your machine and your skill level and work accordingly.
- Know the procedures when a fire is discovered when it can be fought:
    - Lower the boom to the ground.
    - Shut off the engine.
    - Radio or phone for help.
    - If it is safe to do so shut off the battery disconnect switch.
- Know when it is safe to fight a fire and how to use the fire extinguisher and the location of the extinguisher ports.

Machine

- Check the machine's final drives, paying close attention to track links, track tension, grousers and pads.
- Check the fire suppression system is operable through the system control panel.
- Inspect the engine compartment to ensure it there is no accumulated forest debris, oil, grease or other flammable materials.
- Inspect the exhaust system for leaks.
- Ensure rags and other combustible material is stored in a fire proof container.
- Ensure fire extinguishers are in working order.
- Ensure your machine meets the mobile equipment regulations Parts 16 and 26 of the Occupational Health and Safety Regulation.

10.3 Supervisor Checklist

Egress

- Test the escape hatch.
- Train operators to ensure they can exit through the escape hatch and ensure they practice exiting.

Handheld cutting tool

- Ensure there is a handheld cutting tool in each pickup:
    - The tool is in good working condition.
    - The battery is fully charged and there is a charged spare.
    - The tool is well secured and there is eye protection and gloves.

Planning

- Provided accurate maps showing site specific hazards including "No go" areas.
- Provided a detailed work plan.
- Provided a steep slope work plan if working on steep slopes. The work plan must be done by a qualified person and include a risk assessment and safe work practices acceptable to WorkSafeBC. Section 26.16(4) of the Regulation.
- Discussed with your crew any site specific hazards shown on the map. Made them aware of any changes in weather that could affect operating conditions.

- Assessed site hazards by on the ground reconnaissance.
- Had a pre work meeting where you have provided operators information on any potential hazards.
- Provided a site specific emergency response plan for each operator.
- Ensure there is an alternative supervisor available in your absence.
- Remind operators to avoid complacency and risk tolerance.
- Ensure there is a working in isolation or alone plan for each operator.
- Understand WorkSafe Regulation requires every person who has knowledge and control of any particular activity in a forestry operation must ensure that the activity is both planned and conducted in a manner consistent with This Regulation and safe work practices acceptable to the Board (Section 26.2).
    - Identification of work activities where there is a risk.
    - Be completed before work commences.
    - Be documented at the time of planning.

Operating

- Provide training for operators on the hazards of working on steep ground and challenging conditions. Operators must demonstrate to a qualified supervisor that they can operate the equipment competently.
- Know an operator's competency. WorkSafe BC regulation requires an operator must have received adequate instruction in the safe use and has demonstrated to a qualified supervisor competency in operating the equipment
- Implement a gradual transition for operator on steep challenging ground once satisfactory competency has been achieved at moderate and easy terrain.
- Implement a robust continuous improvement culture. After completing each block, review current procedures to assess whether they have fully addressed the identified hazards and procedures for reviewing changing conditions such as weather.
- Ensure equipment is well maintained particularly the undercarriage.

10.4 Suppression System Manufacturers

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https://www.flexxaire.com/company/

https://cleanfix.org/en

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