

Research on synthetic rope and its future in timber harvesting

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Abstract

Steel wire rope is used for many logging applications. It has served the industry well in terms of strength, durability, and longevity. However, steel wire rope is difficult to use because it is stiff, heavy, and unyielding. These characteristics can lead to fatigue and exhaustion, and may contribute to worker injuries. Ultra-high molecular weight polyethylene synthetic rope has the potential to replace steel wire rope for selected logging applications. Research shows ergonomic gains and other operational effectiveness with its use. This paper presents research results, potentials, and issues in improving economic and ergonomic performance of ground-based and cable logging. Potential social and environmental benefits are also discussed. Further training, research and promotion are necessary to put this new technology into the hands of users and assure adoption in the forestry sector.

Keywords: *synthetic rope, timber harvesting, ultra-high molecular weight polyethylene, steel wire rope, environmental impacts*

Introduction

Currently, steel wire rope (SWR) is used universally in timber harvesting for skylines, guylines, winchlines, support lines, truck wrappers, chokers, and running lines (Hartter and Garland, 2006). Wire rope has advanced ground-based and cable logging technology and continues to be used heavily annually around the world. Its versatility, durability, and strength continue to meet the demands of logging. However, the properties of SWR including weight, stiffness, and bending-failure characteristics create problems during use.

Logging is one of the most difficult jobs in terms of workloads and cardiovascular demands (Durnin and Passmore 1967). The difficult nature of work combined with handling SWR can cause fatigue and may contribute to worker injuries (Leonard, 2004). In the period 2000-2004, Oregon logging disability claims totaled 2,365 claims (Oregon Department of Consumer & Business Services 2005). Thirty two percent of these claims came from chokersettlers, rigging slingers, and hooktenders while 22.7% of claims were from occupations using wire rope

daily. Within the logging group, 41.9% of such claims were related to overexertion, slips and falls, and bodily reactions (9.4% from pulling, pushing, lifting, carrying and throwing objects). Replacing wire rope could produce worker health and safety benefits.

Of the synthetic rope types available, braided rope constructed of ultra-high molecular weight polyethylene (UHMWPE) fibers has potential to replace SWR in timber harvesting. It is lightweight, has a strength-to-weight ratio that is approximately eight times that of wire rope of the same diameter, floats, and is stronger than extra-improved plowed steel (EIPS) wire rope of the same diameter up to 1" (25mm). UHMWPE braided ropes do not kink, corrode, nor absorb chemicals or water.

Uemura (1998) assessed synthetic rope guylines for a mobile tower yarder. Ropes in this study made of aramid fibers with a nylon core (Technora™) were found to have sufficient strength and fatigue life to be used as guylines. Studies from the Forest Engineering Research Institute of Canada (FERIC) on aramid fiber (Kevlar™) ropes for all-terrain vehicle skidding proved to be a viable alternative to steel wire rope (Dunnigan 1993). Golsse (1996) tested two different synthetic ropes for wheeled skidder winching applications and reported synthetic rope was a suitable candidate for replacement of SWR. Winching distance increased up to three times that of steel wire rope, significantly decreasing operator fatigue. Lapointe (2000) found synthetic rope easy to use for winching applications on skidders. Ewing (2003) reported on a reduction for machine travel time into riparian zones with the use of a synthetic mainline.

In 1999, Oregon State University (OSU) recognized the potential of synthetic rope and began field trials and laboratory testing (Garland et al. 2002). Funding was provided by Worksite Redesign Grants of the Oregon Occupational Safety and Health Administration (OR-OSHA). According to Pilkerton et al. (2001), AmSteel®-Blue synthetic rope (manufactured by Samson Rope Technologies of Ferndale, Washington) meets the strength requirements for logging applications. The forest operations applications were described in Pilkerton et al. (2001) and Garland et al. (2002). Research progressed with the development of end

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Table 1. Forest operations tasks evaluated for substituting synthetic rope for steel wire rope.

JOB	ACTIVITY DESCRIPTION	TASK	ERGONOMIC IMPACT WITH SWR
Hooktender	Onsite supervisor, rigs yarding roads and climbs and rigs trees	Carries guylines, blocks (pulleys), gear to anchor tree or support tree, carries and pulls/rigging line for next road (1000-5000 feet or 323-1613m)	Multiple trips over steep slopes, climbs trees Loads 60-100 pounds (27-45 kg) Pulls 30-60 pounds (133-267N) force
Skidder Operator Setting Chokers	Drive vehicle, positions, pulls winchline and sets chokers, winches logs to machine, returns to landing	Pull winchline 75-125 feet (24-40 m) through slash & obstacles, uphill/downhill	With leg drive and arms pulls 60-80 pounds (267-356N) force, more than 40 times/day
Cable yarding crew	Pull line through carriage to logs to set chokers	Walk and pull line on slash covered slopes of 50-70% occasionally 100% with lines 3/8-3/4" (10-19mm) distances 30-100 feet (9-33m)	40-80 times daily pull lines 30-60 pounds force (133-267N)
Log truck driver securing loads	Attach wrappers and binders at the landing and re-tighten enroute, loosen at destination	Throw 4 wrappers over load 10-15 feet (3.22-5m) high. 25-30 foot (8-9m) 3/8" (10mm) wire rope with 4 feet (1.3m) chain on both ends	3-5 loads per day, throws steel wrapper weighing 11-14 pounds (5-6.4kg)

connectors for synthetic rope (Hartter 2004, Hartter and Garland 2006). Field trials were conducted with static and running line applications (Leonard et al. 2003, Pilkerton et al. 2003, Leonard 2004). Research on ergonomic benefits and operational effectiveness is reported for static lines in cable yarding (Leonard 2004) and skidder winch lines (Pilkerton et al. 2003). This paper summarizes research and addresses the future of synthetic rope for improved ergonomic, economic, and environmental performance of logging operations.

Ergonomic Potentials

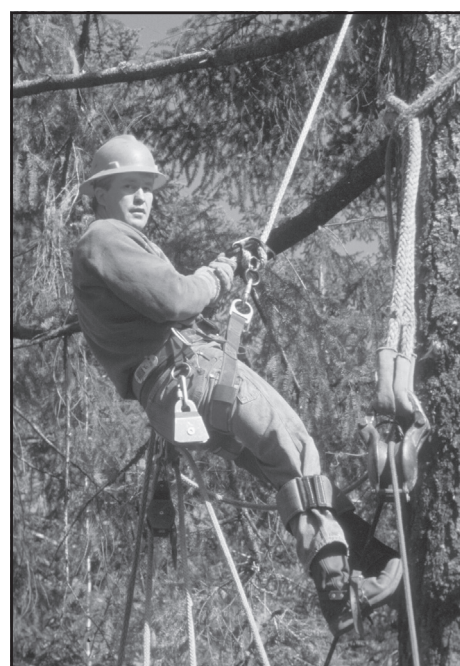
While much of prior research focused on material properties and breaking strengths, Pilkerton et al. (2001) were the first to quantify the ergonomic potential of the synthetic rope in forest operations. The lower weight and lack of stored torsional energy are significant differences from SWR. These properties translate into ergonomic benefits. Synthetic rope may be pulled or carried more easily over difficult terrain with and logging slash, can reduce fatigue, and possibly reduces slips and falls (Pilkerton et al. 2004). Key tasks in forest operations are described in Table 1 using SWR where potential benefits exist to substitute synthetic rope.

Ergonomic Results from Field Trials - Pilkerton et al. (2001) compared synthetic rope to SWR on selected standardized tasks of pulling, carrying, climbing and rigging, and pulling a skidder winchline by the OSU Student Logging Training

Crew. Time per task, heart rates, and subjective measures were taken as workers (male and female) performed the same tasks with either SWR or AmSteel®-Blue rope.

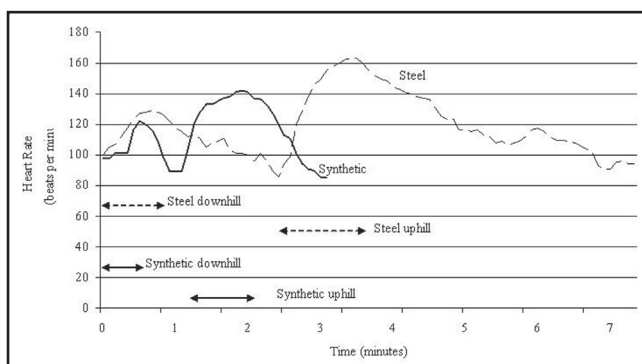
Within the small sample studied, the seven individuals favored synthetic rope. Pilkerton et al. (2004)

Hooktender descending tree rigged with synthetic rope.



reports that heart rate and time relationships showed lower heart rates, faster completion of tasks, and a reduction in the time required for the heart rate to return to initial (pre-exertion) rate with synthetic rope. Figure 1 compares the heart rate and time per task for a 25 year-old, 200 pound (91kg) male carrying steel wire rope and synthetic rope uphill on a 25% slope for 150 feet (46m). The weight of the SWR was 111 pounds (50kg), while the comparable length of synthetic rope, with steel thimbles, was 18 pounds (8kg). For a 24-year old skidder operator pulling the 3/4" (19mm) synthetic winch line and setting his own chokers, 80% of the work time is in the heavy or more strenuous work intensity categories of Rodahl (Astrand and Rodahl, 1986). We would expect even higher levels of exertion with SWR.

Figure 1. Example heart rate and task duration from a 25 year-old male to carry a 150 foot (46m) coil of rope a distance of 150 feet on a 25% slope; 5/8" (16mm) diameter SWR and AmSteel®-Blue synthetic rope (Garland et al. 2002).



Fatigue is implicated in many logging accidents involving serious disabling injuries and fatalities (Pilkerton et al. 2001). Synthetic rope may benefit logging crews at the critical times when tired individuals are trying to rig the tail tree, carrying guylines and rigging to the back of the unit, or climbing intermediate support trees to allow the operation to continue. Therefore, any potential gains to reduce workloads and cardiovascular recovery time may reduce overall worker fatigue and improve safety.

Nonindustrial Landowner Trial - A trial was conducted with a small Farmi® winch attached to a tractor used for winching small-diameter trees (Pilkerton et al. 2004). This short duration time study quantified operational efficiencies with the synthetic winch line. Twenty-five turns (winching cycles) were timed for both the steel and synthetic winch line. The outhaul and hook times were half the time with the synthetic versus the steel winch line.

Log Load Securement - Log truck wrappers were also candidates for replacing wire rope with synthetic rope. At the beginning of our research, Oregon law did not allow synthetic rope to be used as a log truck wrapper. That law changed on January 1, 2004 when the OR-OSHA Division 7 Forest Activities Code and the Oregon Department of Transportation (ODOT) Load Securement rules were harmonized by ODOT's adoption of the Federal Highway Safety Standards rules for load securement. Synthetic rope

could then be used for load securement. OSU's tests of breaking strengths produced mean breaking strengths of 15,310 pounds (68,102N), exceeding OR-OSHA's minimum requirement of 15,000 pounds (66,723N) (Hartter 2004).

If log truck drivers throw four wrappers for four loads per day and work a full year, the number of wrapper tosses over a 30-year driving career approaches the number of pitches for a short career of a major league baseball pitcher (Garland et al. 2004). Not surprisingly, the injuries to log truck drivers are similar, with rotator cuff and shoulder injuries the most common ailments (Garland et al. 2004). One difference is that pitchers get rest days from pitching duties while drivers throw wrappers everyday and chronic inflammation is not allowed time to heal. Such injuries cause drivers to seek other types of work or stop driving log trucks. Other injuries to drivers from load securement include arm and shoulder damage from overtightening binders, slips and falls, and being struck by the binder handle. For five-year period (2000-2004) log truck drivers reported 111 claims relating to load securement covered by the Workers Compensation System (Oregon Department of Consumer & Business Services 2005); however, many log truck operators are sole proprietors and are not covered by the statistics. In addition, the State Accident Insurance Fund collected yearly statistics from one of its Oregon districts for driver injuries and found 32 injuries relating to load securement, costing \$276,000 (SAIF 2003).

Field trials were also completed with log truck wrappers (Garland et al. 2004). Twenty-one log truck drivers, (22 years average experience) were given synthetic rope wrappers in Oregon and Washington. At the end of a six month trial period, drivers were surveyed. Results are summarized below.

- More than 60% of the drivers had experienced complaints in shoulders, elbows, backs or arm from their work at the start of the trial
- All 21 found the synthetic rope wrappers easier to throw
- 7 of 21 drivers found the synthetic wrappers more difficult to coil and store
- 18 of 21 drivers preferred synthetic wrappers over steel wrappers after using them

Logging Field Trials - Field trials of synthetic ropes as static lines in logging applications were the next research interest. Applications for synthetic rope include rigging straps, lift tree (intermediate and tail tree) guylines, and intermediate jack support/lift lines. Four trials were completed with logging contractors for periods of three to six months in static applications (Garland et al. 2004, Leonard 2004). Seven field trials were also completed in running line applications: five skidder winch trials, one mainline trial on a yarder, and one dropline test on a mechanical slackpulling carriage (Leonard 2004, Pilkerton et al. 2003). Contractors reported a substantial increase in start-up cost with the synthetic rope - approximately two to four times that of similar diameter steel wire rope - but felt that the benefits of health and safety outweighed this cost.

Workforce Benefits

- Has 1/8th weight of comparable steel wire rope (SWR)
- Rope usually fails linearly and does not have “whiplash” common with SWR.
- Stores less energy under high tension because the rope only has significant mass in the end connection.
- Discarded synthetic rope can be recycled.
- Does not corrode and thus does not need to be lubricated.
- Does not conduct electricity.
- Rope will float.
- Reduces cardiovascular recovery time compared to SWR.
- Could reduce or prevent injuries.
- Can reduce set up time because workers have to take less hardware into the field with them, make fewer trips, can rig trees faster and set up rigging safer with lighter materials.
- Less residual stand damage when the rope is wrapped around trees for support lines, guylines, etc.
- Less fire hazard as the synthetic rope does not produce sparks when pulled over rocks.
- More line can be spooled on a winch drum to reach logs at greater lateral yarding distances. Therefore, fewer skid trails could be required.
- Could increase payloads because a larger load could come to the landing in cable and helicopter operations.

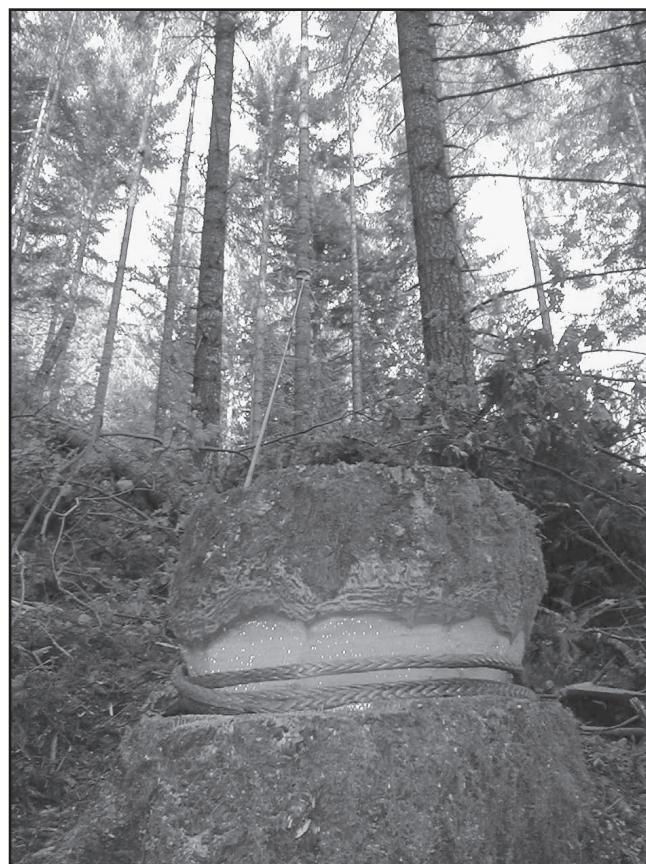
Timber harvesting work has a reputation for being “difficult, dirty, and dangerous” compared to work in urban occupations. Logging is among the top three industries for fatalities and injuries almost every year and rates as the most hazardous when all factors are considered (Garland 2005). At the same time, financial benefits, autonomous work environments, and the satisfaction of overcoming challenges seem to compensate for the negative aspects of logging work. Using new technologies like synthetic rope to reduce workloads is seen as a positive consideration for worker health and safety. Several benefits are possible.

- New recruits to the sector experience lighter workloads in entry-level tasks
- Existing workers see the shift to lighter materials as a firm’s commitment to their well-being
- The accumulated knowledge base of older workers in key positions may be extended if workloads are more in line with capacities of older workers (e.g. the hooktender position).

While new technologies cannot fully compensate for negative aspects of forest work (steep terrain, weather, job hazards, etc.), synthetic rope offers a positive result for forest workers. Other potential benefits of synthetic rope adoption are found in Box 1.

Environmental Benefits

Synthetic rope guyline anchor stump.



Improvements in environmental performance with ground-based skidding and cable logging activities are also likely (Ewing 2003). Guidelines for minimizing area impacted by skid trails are dependent on operators pulling winch line laterally a designated distance. In practice, SWR is a physical and mental barrier to achieving desired lateral outhaul distance. Garland and Pilkerton (2005) show synthetic rope allows operators to physically achieve desired skidtrail spacing with economic benefits to the landowner. Use of synthetic mainlines and winch lines increases the likelihood of meeting environmental objectives.

Synthetic rope applications in cable operations allow for improved environmental benefits when used as skyline extensions that allow lifting logs over the top of streams and riparian areas (Pilkerton et al. 2004). Also, the ability to pull lines a greater lateral distance may minimize the number of cableways through riparian areas and stream corridors. Finally, for cable operations with limited deflection, synthetic rope mainlines or even skylines could improve the payloads and the ability of the operation to lift logs free of the sensitive areas needing protection.

Cost of Synthetic Rope

Cost is an important consideration in the evaluation of synthetic rope in forest operations. The cost of synthetic rope in logging applications runs two to five times that of domestic SWR depending on the application (Upton, S. personal communication March 3, 2006). For rigging straps and prepared rigging, the cost is about three

times that of steel. A winchline of 150 feet (36m) might cost five times more. Small diameter lines in long quantities like those used for rig-up (called strawlines - e.g. 3/8" [10mm]) may be only twice as expensive. Leonard (2004) reported that the initial cost of synthetic rope is a major determinant in choosing materials for static and running line applications. Synthetic wrappers for log trucks may be three times as expensive as wire rope wrappers (McCorkle, E. personal communication March 6, 2006). Synthetic rope costs per hour or production unit over time have not been developed. However, one contractor, independent of our studies, estimated a cost of US\$ 1.00 per operating hour for his synthetic winchline (Pilkerton et al. 2004).

Increased Productivity

Synthetic rope offers a host of benefits, but many times these benefits are difficult to assess in monetary terms. However, gains in efficiency, production, and lower unit costs may be estimated. These gains in effectiveness may offset the costs of synthetic rope at current prices. Pilkerton et al. (2004) estimated from skidder winch line trials a 10% increase in daily productivity might be possible for a single machine operator setting his own chokers. Coupling this result with a recent skidder productivity study (Kellogg and Davis in press), four additional turns per day are possible on a sample harvest unit. Increased volume production could be about a thousand board feet (6m³) per day, at a benefit of US\$50-100 per day available to the contractor.

Anecdotal evidence from contractors suggests they would rather pull additional line than take the extra time to position the machine closer. In addition, reductions in time and physical effort associated with carrying rigging (straps, blocks, and guylines) have been documented as well. A SWR guyline of 5/8" (16mm) diameter, 150 feet (46m) in length weighs approximately 111 pounds (50kg). A similar guyline made of synthetic rope may weigh only 18 pounds (8kg) (Leonard 2004). Workers can increase the amount of line taken into the woods to set up guylines and decrease the number of trips. For example, the hooktender can make one trip to the next tail tree with all the synthetic gear on a packboard, as contrasted with three to four trips with steel.

Other productivity gains have been seen when rigging a synthetic skyline extension in cable logging. Several operators have successfully used a synthetic skyline extension (not for carriage travel) noting the ease of manual

layout. There is no need for mechanical power to assist in rigging the extension or making cable road changes. The result is a substantial reduction in rigging time. Savings in time and effort are also seen when raising a synthetic line used for intermediate support jacks in cable logging. Synthetic jack lines can be raised by hand eliminating additional rigging required to raise a steel line. Gains accrue both during rig-up and de-rigging the trees.

Perhaps the most striking gains are from using synthetic rope to replace steel strawlines (rigging lines for cable operations). In order to use the heavy steel cables, lighter steel rigging lines are commonly used to rig up the cableways. Typically 100 foot (33m) sections are carried and then strung along the 1000-3000 feet (322-968m) needed to make the layout. Each section weighs about 26 pounds (12kg) and three to four are carried at a time. Rigging lines must be strung uphill and downhill depending on the topography. Hooktenders work ahead of the yarding crew readying the layout so delays are minimized. In contrast, 500 foot sections (161m) of synthetic rope can be easily carried in a backpack and strung at the same pace as walking on the terrain. Many times the synthetic rigging line can be strung with the aid of a pickup rather than using the drum on the expensive yarder. Rigging time can be cut to less than a quarter of that of steel and the wear and tear on the Hooktender is dramatically reduced.

Garland et al. (2004) argue that the light weight and high strength of synthetic rope provide the potential to increase skyline payloads. Benefits will be greatest at low deflections (a ratio [percent] of the sag in the line from a chord slope divided by the horizontal span) where the ratio of total line weight to net payload is greatest. Table 2 shows the potential benefits of using synthetic rope (AmSteel®-Blue) and wire rope (independent wire rope core, EIPS). Two rope diameters are compared for a 1500-foot span, level chord slope, where a load is fully suspended at midspan. The maximum payload that brings each rope up to a design load (1/3 of breaking strength) is calculated. At low deflection (4%) the synthetic rope provides a 67% increase over the fully suspended payload for the 5/8" (16mm) SWR and 31% for the 1" (25mm) SWR. The percentage increase declines as deflection increases.

Leonard (2004) also reported that spooling capacity increased on the drum due to better layering of the synthetic line. The Koller K300 mainline drum capacity is rated at

Table 2. Percent increase in maximum midspan payload at 4, 8 and 12% deflection for 5/8" and 1" diameter ropes - EIPS steel wire rope and AmSteel®-Blue synthetic rope.

Deflection (%)	5/8" (16mm) diameter rope			1" (25mm) diameter rope		
	SWR payload (lbs.)	Synthetic rope payload (lbs.)	% increase	SWR payload (lbs.)	Synthetic rope payload (lbs.)	% increase
4	1,645 (746kg)	2,743 (1,244kg)	67	4,096 (1,857kg)	5,373 (2,437kg)	31
8	3,779 (1,714kg)	5,512 (2,500kg)	46	9,450 (4,286kg)	10,814 (4,905kg)	14
12	5,824 (2,642kg)	8,177 (3,709kg)	40	14,581 (6,613kg)	16,052 (7,281kg)	10

1150 feet of steel line. Approximately 1300 feet of synthetic rope was installed and the drum appeared to have capacity for additional line. Based on our operational installations, it is possible to spool approximately 35% more synthetic rope compared with manufacturers' spool capacity equations for wire rope (Pilkerton and Garland 2004).

Disadvantages of Synthetic Rope

Even with benefits to the workforce, safety and health improvements, and potential productivity gains, synthetic rope has drawbacks. Some drawbacks are due to the properties of the rope while others are from the process of introducing a new material in the forestry sector. Cost of synthetic rope is greater than comparable steel wire rope by two to five times. Operators must first purchase the rope and then collect the economic benefits over time and usage of the rope. The payback period is usually not known and may discourage first time rope purchasers.

Synthetic rope can be cut with a knife or sharp object. SWR can create grooves or sharp edges on equipment that will instantly sever a replacement synthetic rope during operation. The longevity of synthetic rope depends on the application and may be unknown for the new material. For safety considerations, synthetic rope should be replaced before failure in specific applications. At the same time, visual conditions may not indicate excessive wear and early replacement of rope highlights the need to educate users in wear and replacement criteria to avoid unnecessarily replacing synthetic rigging. Samson Rope Technologies (2003) provides limited criteria, but this information is too general for forest operations (Pilkerton et al. 2003). Synthetic rope should not be considered a direct one to one replacement for SWR.

There are a limited number of suitable end connectors for synthetic rope compared to SWR, and SWR connections many times will not work. The most common end connection of an eye splice and shackle covers many needs for synthetic rope as a replacement for wire rope. Hartter's 2004 study on end connections determined that some SWR end connections could be modified, but others had to be developed for synthetic rope use. Despite this research, some logging contractors may opt for SWR because of limited experience with synthetic rope connectors and the inconsistent and low breaking strengths of some configurations.

Synthetic rope may also require equipment modifications and new designs. In the OSU Boman™ carriage dropline trial (Leonard 2004), we found several failure modes. Crews lacked both training and experience with synthetic rope. The adage "you can't push a rope" was confirmed with this carriage winch design for spooling off the skidding line. The two-speed winch caused backspooling hang-ups on the drum because the carriage design depends on the stiffness of steel wire rope to push out the slack. The lack of stiffness in synthetic rope caused the Boman™ winch to backspool, but when the rigging crew applied constant tension during lateral slackpulling, backspooling was eliminated. Other failure modes on this

carriage were from synthetic rope coming into contact with sharp edges on the carriage fairlead. That carriage has been redesigned to accommodate synthetic rope usage (Smith, L. personal communication February 2, 2006).

Finally, synthetic rope is a recent introduction to the forestry sector although it has been widely used in other industries. Many applications are unique to logging and therefore, some of the technology is not directly transferable. Presently, there is a small infrastructure and limited expertise in the rigging shops that supply contractors. Contractors and their crews must largely depend on their own training for onsite trouble shooting. Synthetic rope has been rigorously tested in relatively few applications and environmental conditions. Although it too has considerable drawbacks, the performance of steel wire rope is known under varied conditions and crews have experience working with it.

The Future of Synthetic Rope

Synthetic rope has significant advantages relative to SWR such as a higher strength to weight ratio, weight savings, and enhances safety and productivity. However, synthetic rope is also costly and cannot take abuse like SWR. Synthetic rope may face an uphill battle for adoption into logging. Technology transfer involves bringing discoveries, inventions or innovations from research organizations, laboratories, industries or government agencies to the marketplace. Over the years, evidence shows quality technologies do not often sell well by themselves (Gibson and Smilor 1991). Developers of technology have a difficult time reaching loggers and other forest operators. Operators themselves may need to change mental attitudes (i.e. "steel is good") and change behaviors to avoid abuses to synthetic rope. Effective technology transfer is needed to sustain synthetic rope adoption.

Adoption of synthetic rope in the forestry sector may follow the process of Rogers (1995) through stages of interest, evaluation, trial and adoption by groups of early adopters, early majority, late majority and laggards in a more or less normal distribution over time. At present, early adopters may be individual owner-operators who purchase the rope, use it properly and physically benefit from the ergonomic improvements. However, one bad accident or a fatality could set back the use of synthetic rope dramatically. Bad news travels quickly throughout the forestry sector and misidentification of the accident causation may wrongly point at the new technology. Designed studies with synthetic rope would help evaluate safety improvements with training (Hale 1984) and document the relation of training to accident frequency (Cohen et al. 1979). Rummer (1997) challenges the industry to approach safety not only through generalized training programs, but also through the incorporation of new technologies. A designed, competency-based training program would educate contractors and crews on the use of synthetic rope (after Garland 1990). Learning modules could include end connections, spooling techniques, static line rigging, and general handling to avoid abuse.

Further research is needed as well on synthetic rope in several areas:

- Empirical trials of a skyline extension to determine the mechanical stress/strain relationships for cable payload programs such as LOGGERPC (Jarmer and Sessions, 1992)
- New material developments for blocks and rigging to further lighten loads
- Alternative rope materials, types and constructions
- Rope applications for use with a traction carriage which eliminates the expensive yarder
- Evaluations on a wide variety of applications under variable operating conditions to develop wear and retirement criteria
- Additional physiological monitoring of workload differences for workers along with documentation of economic and environmental performance

Conclusion

It may not be possible to show that the accident (injury or fatality) that “did not happen” was due to replacing wire rope with synthetic rope. However, with the diminishing logging labor pool and an aging, but highly experienced workforce, the forest industry needs to take steps to attract, retain, and protect its workers. Synthetic rope appears to be on the way to adoption within the forestry sector. Over 200 operators throughout the US and Canada are using it in various applications. Research and field trials are underway around the United States, Canada, New Zealand, and Europe. The Oregon Occupational Safety and Health Administration Division 7 Forest Activity Code provides for the use of synthetic rope and adjacent states will soon adopt similar provisions. Various applications are now chronicled in trade journal articles as further indication of increasing use. Synthetic rope research has shown logging contractors they have a choice in materials and an opportunity to improve worker health, safety, and productivity.

Literature Cited

Astrand, P-O. and K. Rodahl. 1986. Textbook of Work Physiology: *Physiological Bases of Exercise*. McGraw-Hill. New York City, NY. 756p.

Cohen, A., M.J. Smith, and W.K. Anger. 1979. *Safety Program Practices in High v. Low Accident Rate Companies*. An interim report. Health Education and Welfare Publication. 185p.

Dunnigan, J. 1993. Braided KevlarTM Cable: Trials in Skidding Wood With an ATV. Field Note FN-022. Forest Engineering Research Institute of Canada. Pointe Claire, QC, Canada. 2p.

Durnin, J.V.G.A. and R. Passmore. 1967. *Energy, Work and Leisure*. William Heinemann, Ltd., London, UK. 167p.

Ewing, R. 2003. Harvesting Riparian Zones Using Cable Skidders with Spectra Synthetic-Fiber Mainlines. Advantage 4(20). Forest Engineering Research Institute of Canada. Pointe Claire, Quebec, Canada. 6p.

Garland, J.J. and S.J. Pilkerton. 2005. Use of Synthetic Rope as a Skidder Winchline for Designated Skid Trails USDA Forest Service Gen. Tech. Rep. PSW-GTR-194. in Proc. of Council On Forest Engineering. Annual Meeting, July 11-14.. Fortuna, CA.

Garland, J. 2005. Who Does the Work in the Forest? Connections Between Foresters and the Forestry Workforce. in Proc. of Society of American Foresters Annual Meeting, Oct. 18-22. Ft. Worth, TX.

Garland, J., Pilkerton, S., and J. Leonard. 2004. Field Testing of Synthetic Rope in Logging Applications to Reduce Workloads. Oregon Occupational Safety and Health Administration Worksite Redesign Grant Final Report. Salem, OR. 67p.

Garland, J., Sessions, J, Pilkerton, S., and B. Stringham. 2002. Using Synthetic Rope to Reduce Workloads in Logging. Final Report, Oregon Occupational Safety and Health Administration Worksite Redesign Grant Final Report. Salem, OR. 28p.

Garland, J.J. 1990. Assessing Gains from Woodworker Training. *Int. J. Industrial Ergonomics* 5: 227-242.

Gibson, D.V. and R.W. Smilor. 1991. Key Variables in Technology Transfer: A Field-Study Based Empirical Analysis. *J. Engineering and Tech. Mgt* 8: 287-312.

Golsse, J-M. 1996. Initial Tests of Synthetic-Fiber Mainlines For Cable Skidders. Field Note FN-033. Forest Engineering Research Institute of Canada. Pointe Claire, Quebec, Canada. 2p.

Hale, A.R. 1984. Is Safety Training Worthwhile?. *J. Occupational Accidents* 6: 17-33.

Hartter, J. and J. Garland. 2006. Synthetic Rope End Connections For Use in Timber Harvesting. *Int. J. For. Eng.* 17(1): 39-51.

Hartter, J., Garland, J., and S. Pilkerton. 2004b. Synthetic Rope Properties and End Connector Concepts for Use in Timber Harvesting Applications. in Proc. of International Mountain Logging Conference June 13-16. Vancouver, BC Canada.

Holthusen, D. 2005. Rigging and Other Trials. Conference presentation. Synthetic Rope: Research, Developments, and Applications. December 2-3, 2005 Forest Engineering Department. Corvallis, OR.

Kellogg, L.D. and C.T. Davis . in press. Tractor thinning productivity and costs: Experience from the Willamette Young Stand Study. Research Contribution, Forest Research Laboratory, Oregon State University, Corvallis.

Jarmer, C. and J. Sessions. 1992. Computer Based Skyline Analysis: LOGGERPC 3.0 - A New Tool for Logging Planning. in Proc. of Workshop on Computer Supported Planning of Roads and Harvesting. August 26-28, Feldafing, Germany, Sessions, J (ed.). Corvallis, OR.

Lapointe, M. 2000. Development of Methods to Minimize the Breakage Frequency of Synthetic-Fibre Rope Mainlines Used on Cable Skidders. B.Sc. Thesis, Forestry and Environmental Management, University of New Brunswick, Fredericton, Canada. 32p.

Leonard, J. 2004. Applications for Synthetic Rope in Logging. MF Paper. Oregon State Univ. Corvallis,

- OR. 90p.
- Oregon Department of Consumer & Business Services. 2005. Occupational Safety and Health in Oregon's Forests: Logging and Forestry Services CY 2000-2004. Information Management Division, Research & Analysis Section. Available at www.cbs.state.or.us/imd. Salem, OR. 90p.
- Pilkerton, S., Garland, J., and J. Hartter. 2004. Applications of Synthetic Rope for Improved Ergonomic, Economic and Environmental Performance in Mountainous Logging. in Proc. of 2004 International Mountain Logging Conference June 13-16. Vancouver, BC, Canada.
- Pilkerton, S. and J. J. Garland. 2004. Rigging and Operations Guide: Use of Synthetic Ropes as Alternatives to Steel Wire Ropes in Logging Applications. Oregon Occupational Safety and Health Administration Worksite Redesign Grant Final Report. Salem, OR. 56p.
- Pilkerton, S., Garland, J., Leonard, J., and J. Sessions. 2003. Synthetic Rope Use in Logging Winching Applications. in Proc. of Council On Forest Engineering. Annual Meeting, September 7-10. Bar Harbor, ME. Council on Forest Engineering, Corvallis, OR.
- Pilkerton, S., Garland, J., Sessions, J., and B. Stringham. 2001. Prospects for Using Synthetic Rope in Logging: First Look and Future Research. in Proc. of International Mountain Logging and 11th Pacific Northwest Skyline Symposium, December 10-12. Seattle, WA.
- Rogers, E.M. 1995. *Diffusion of Innovations*. 4th Ed. The Free Press. New York City, NY. 507p.
- Rummer, B. 1997. Safety and Health Concerns in Forestry Operations. Technical Paper 97-P-4. American Pulpwood Association Inc. Rockville, MD. 5p.
- State Accident Insurance Fund (SAIF). 2003. Internal Report of Injuries to Log Truck Drivers for Mid-Willamette Valley District. State Accident Insurance Fund. Salem, OR.
- Samson Rope Technologies. 2003. Industrial Catalogue. Samson Rope Technologies. Ferndale, WA. 59p.
- Uemura, T. 1998. Application of Super Fiber Rope as a Guyline for a Mobile Tower Yarder. in Proc. of IUFRO/FAO Seminar on Forest Operations in Himalayan Forests with Special Consideration of Ergonomic and Socio-Economic Problems, Heinemann, H.R. and J. Sessions (Eds.). Kassel University Press, GmbH. Kassel, Germany.