Prospects for Using Synthetic Rope in Logging: First Look and Future Research

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ABSTRACT - Describes the use of ultra high density molecular polyethylene (UHMWPE) fiber rope as a replacement for steel wire rope in logging applications. The rope characteristics are compared to wire rope. The research is supported by Oregon Occupational Safety and Health Administration grants to redesign work sites using ergonomic improvements. Potential ergonomic gains are shown as heart rate reductions for logging tasks and improved recovery after exertion. Issues are raised about end-connectors, abrasion, stored energy, spooling, and how to incorporate synthetic rope in logging planning. Some early gains in effectiveness are noted and potentials for improvements identified. Future research is funded to look at important issues in projects with industry cooperators and on synthetic rope properties.

Keywords: steel wire rope, cable harvesting, ergonomics, economics, payload analysis

INTRODUCTION

Steel wire rope is currently used in many logging applications. It has contributed to the advancement of cable logging and is used around the world in quantities of thousands of miles annually. Wire rope is also heavy per unit of length and helps make logging one of the most difficult jobs known (Astrand and Rodahl, 1986). Cable logging in steep terrain is near the top of the most difficult jobs in terms of energy demands. Consequently, fatigue is often present when serious accidents occur. When opportunities arise to replace wire rope in some logging applications, substantial ergonomic and efficiency improvements are possible. New synthetic fibers spun into ropes offer promise in various logging applications. The current OSU research projects described are funded by the Worksite Redesign Grant Program of the Oregon Occupational Safety and Health Administration (OR-OSHA, 2000).

Our project began from a trial by a logging contractor, Anderson Resources, of Washington (Anderson and Temen, 1999) reporting on the use of synthetic rope used for static guylines. Japanese researchers have also reported on synthetic ropes used for guylines on towers (Takumi, 1998). Earlier, Forest Engineering Research Institute of Canada (FERIC) researchers used synthetic ropes in ground-based logging in Eastern Canada (Golsse, 1996). One OSU project is nearing completion and two more are beginning to further address important developments with synthetic rope in logging.

SYNTHETIC ROPE

A number of synthetic ropes have been introduced into industrial use including ropes constructed from plastic fibers of nylon, polyester, polyethylene, and polypropylene. AMSTEEL-BLUE, a product of Samson Rope Technologies (formerly, The American Group) of Ferndale, Washington (www.samsonrope.com), is a member of a family of synthetic ropes constructed of polyethylene (lightweight thermoplastic) fibers. The polyethylene fibers are combined to yarns and the yarns are combined into strands that are formed into various rope constructions including twisted, plaited, and braided. AMSTEEL-BLUE is an ultra high molecular weight polyethylene (UHMWPE) 12-strand braided rope. This synthetic rope has a higher breaking strength to weight ratio than steel, by a factor of 9 to 10 (Figure 1). Other favorable characteristics include high flexibility, low stretch (other than the eye-splice), a specific gravity less than one (floats), and can be easily spliced. Coatings can be applied to increase resistance to abrasion, prevent contamination, and increase ease of splicing used ropes.

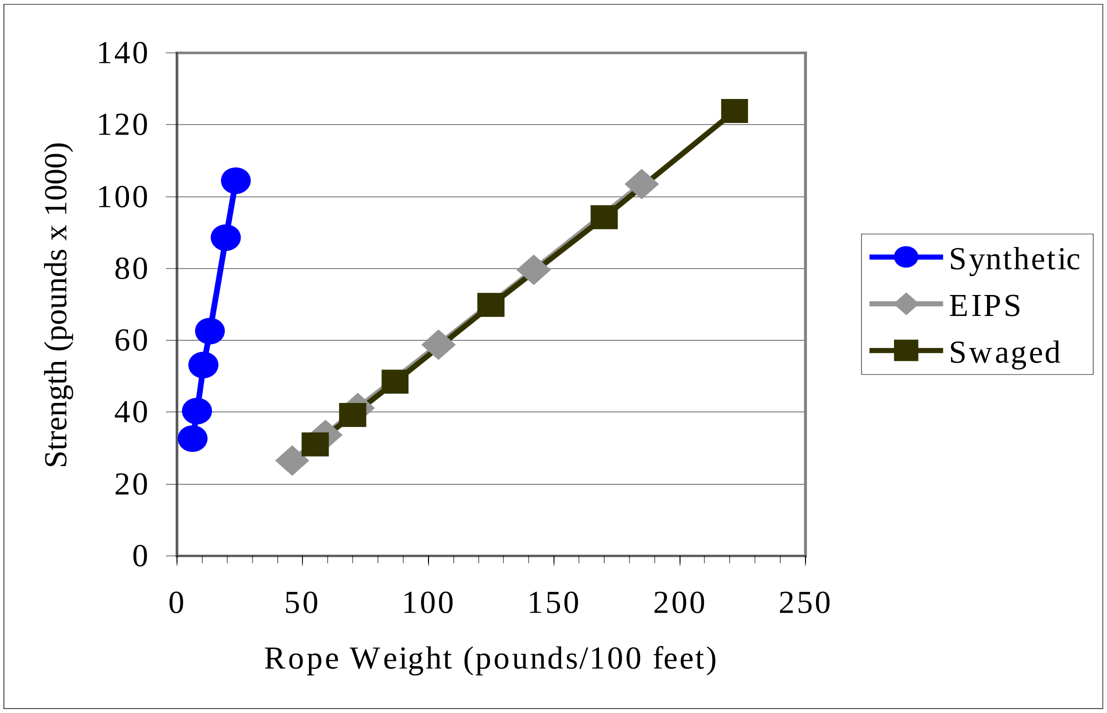

Figure 1. Nominal breaking strength as a function of rope weight for rope diameters 0.5 – 1. 0 inches.

This synthetic is generally the same material commonly used for fuel containers in logging. For a given diameter, steel wire rope is 7.5 (extra improved plow steel, EIPS) to 9 (swaged) times as heavy as a comparable length of AMSTEEL-BLUE rope. The synthetic rope is also flexible and does not produce "jaggers" (sharp, broken wires within a strand) as handling hazards common to wire rope. The cost is about four to six times that of wire rope in the specially-produced quantities now available. The off-shore drilling (anchoring) and towing industries use similar synthetic ropes in applications parallel to logging.

Figure 2 shows comparisons between published breaking strengths for some common logging wire rope grades and constructions (EIPS and swaged) and those published for AMSTEEL-BLUE. At medium rope sizes (0.5-0.625 inch diameter), synthetic strength exceeds both EIPS and swaged wire ropes. At larger diameters, the synthetic advantage diminishes to about equal EIPS strength at a 1-inch diameter. Rope elongation is also shown for AMSTEEL-BLUE under loads in Table 1. These elongation values are an increase of 0.3 feet per 100 feet of rope length at loadings shown (an absolute percentage difference of 0.3 percent more than steel constructed ropes).

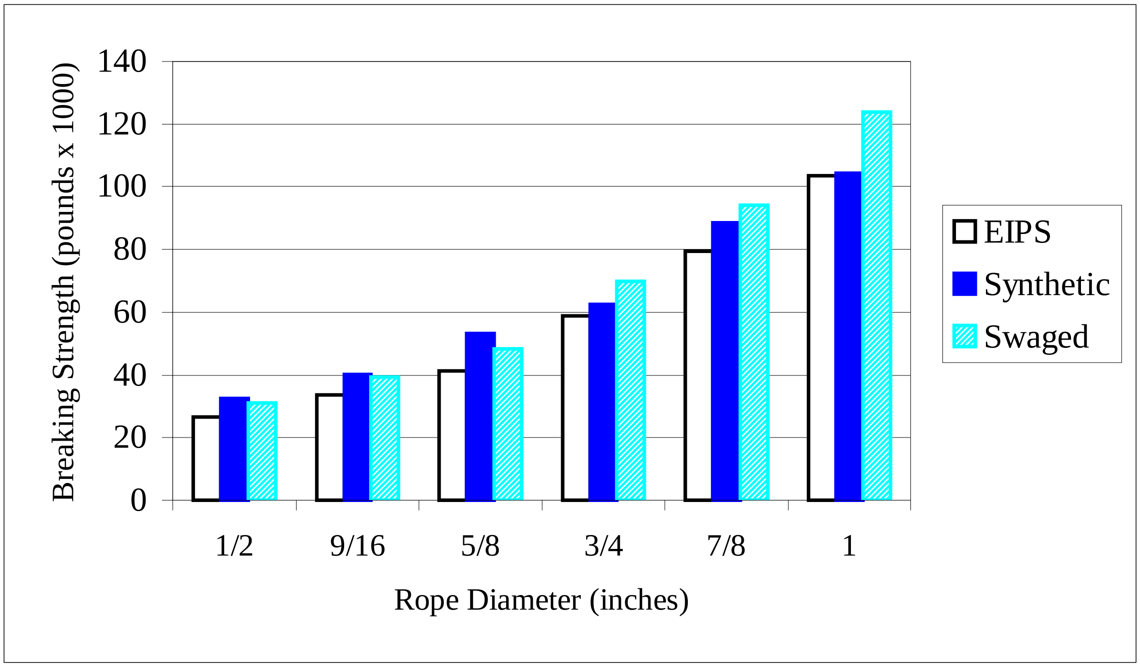

Figure 2. Ultimate breaking strengths of common diameter ropes used in logging applications: comparison of steel wire rope with AMSTEEL-BLUE (UHMWPE) synthetic rope.

Table 1. Elongation as a function of loading for AMSTEEL-BLUE UHMWPE synthetic rope.

LOAD (Percent of Breaking Strength)	ELASTIC ELONGATION (percent)	Tensioned Length of a 100-foot section (feet)
10	0.44	100.44
20	0.62	100.62
30	0.79	100.79

CURRENT PROJECT

The current project began in summer 1999 with field tests followed by laboratory testing. The OSU Student Logging crew used the synthetic rope and wire rope in tasks common to the work they do in cable logging and skidder logging using a winchline. The limited sample of workers was composed of generally fit young adults ranging in age from 19 to 44 years. Both males and female workers are included in the sample. The sample included two summers of work and the size of the sample ranges from 6 to 13 workers performing the standardized tasks. Such tasks included: pulling and carrying steel and synthetic ropes on roads and slopes, climbing and rigging intermediate support trees, and pulling winchline to logs for skidder logging.

Time-per-task was measured along with a heart rate profile during the tasks for each subject. Laboratory tests of rope breaking strengths were conducted in the Knudson Wood Engineering

Laboratory of Richardson Hall on the OSU campus. The small number of subject workers and limited breaking tests make the research a pilot study rather than a large-scale replicated research effort. Details of the testing apparatus and study procedures are available from the authors and are not outlined here to save space.

EARLY OBSERVATIONS

Our research and analysis are continuing but we can offer some insights on synthetic rope used in logging from three perspectives: laboratory tests, ergonomic implications, and economic potentials. Much more testing is planned and more refined analysis will help our understanding as the current project concludes and the other initiated projects produce results.

Laboratory Tests

Splicing of AMSTEEL-BLUE involves a buried eye-splice similar to the concept of the common children's finger puzzle where the harder the pull, the tighter the device grips the fingers. The rope is tapered and inserted into the middle of the twelve-strand rope with a "fid" to form an eye. The fid is an aluminum tapered needle-like rod with a hollow end to hold the rope and a pointed end to ease passage down the center of the strands. The American Cordage Institute (1997)* prescribes testing procedures to follow for standardize testing. We conducted a variety of tests to gain experience with the synthetic rope. Figure 3 shows a sample test for a 5/8-inch rope comprised of two eye-splices, cycle loaded ten times to 50 percent of breaking strength, then to failure. Based on a limited number of laboratory tests with 9/16, 5/8, and 3/4-inch AMSTEEL-BLUE ropes, we can make the following observations regarding the physical properties of these synthetic ropes:

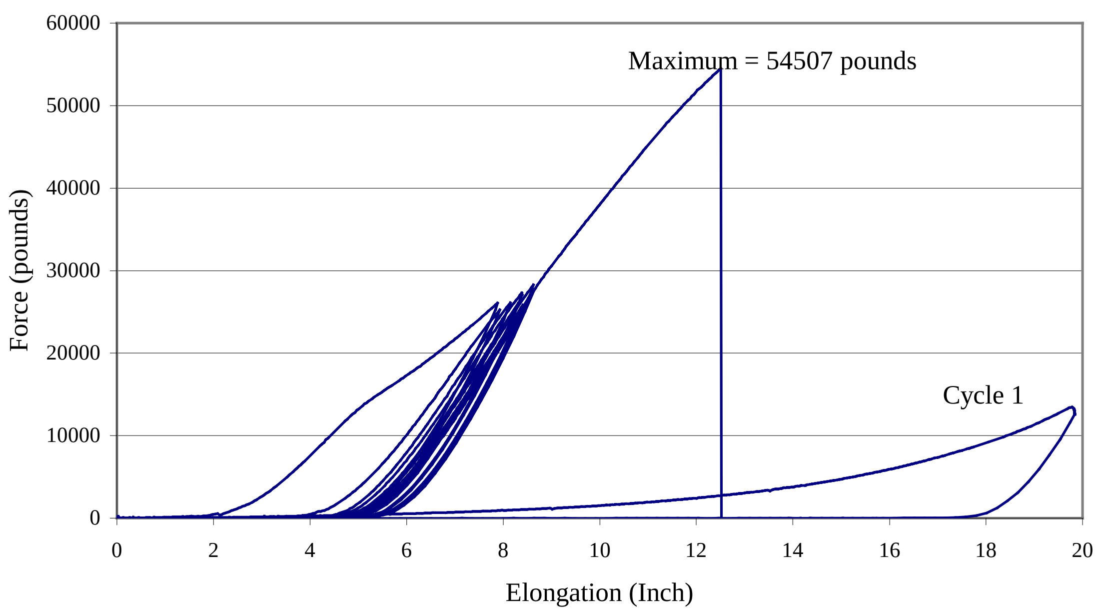

Figure 3. Ultimate load test for 5/8-inch diameter AMSTEEL-BLUE (UHMWPE) synthetic rope segment.

- The testing protocols allow for a buried eye-splice as the end connectors for the test samples and the ropes nearly always break at the end of the splice. Thus, the reported ultimate rope strength is the strength of the eye-splice end connector.

- Ropes break violently but with little lateral movement (snapback). Failures occur linearly and may leave one strand unbroken. See Figure 4 for testing apparatus and recoiled (spirally compacted) rope segment.

- Compressive fittings of any type (rope clips, pressed ferrules, etc.) are not possible with these ropes. However, we tested two low temperature epoxies in poured sockets to failure. Failure occurred at the rope not in the socket. More testing is needed.

- While the final elongation of rope sections at loads are similar to specifications, the test section has considerable elongation due to the buried eye-splice end connectors. These eye-splices would need to be pre-conditioned to about 50 percent of the rope's rated ultimate strength to take all of the "stretch" out of the rope segment.

- Tucked and buried long splices had ultimate strengths similar to specifications.

- Water (soaked overnight) had no effect on ultimate strength.

- Knots did not develop strengths as with other forms of rope and failed immediately or to a loading, at best, of 10-20% of the rated breaking strength. Knots are not recommended in logging.

- Pre-tensioning guylines or other lines with manual methods needs additional development, although we used "twisters" to pre-tension samples and did not find significant reductions in ultimate breaking strength.

- The ultimate strength of synthetic ropes above is comparable to steel wire rope but the exact breaking strength may depend on test procedures (rate of cycling to a prescribed percent of ultimate strength); quality of fiber materials, and the construction of the rope itself. Our cycled (per American Cordage Institute (1997)* test protocols) and uncycled tests produced similar breaking strengths. Design factors (formerly called Factor of Safety) may need to be developed for synthetic ropes.

The current project did not plan to test abrasion or degradation in synthetic ropes, but we did obtain a sample of AMSTEEL 815 synthetic rope used three years as a guyline for tail trees and intermediate support trees. The 9/16 inch rope was markedly increased in diameter (more than double) and had dirt and debris among the fibers and strands. Yet the residual strength of the test sections was more than 65% of the original specifications.

Ergonomic Potentials

Logging is one of the most difficult jobs in terms of workloads and cardiovascular demands (Durnin and Passmore, 1967). Synthetic rope offers potentials to lighten workloads in various ways for cable logging. The obvious lower weight per unit of length is important but synthetic rope produces no "jaggers" and may be more easily carried over difficult terrain, possibly reducing slips and falls.

Figure 4. Failed test segment showing break at the end of splice (far end), spiral compaction of recoiled rope segment (original length about 10 feet between failure and pinned eye shown), and testing apparatus.

We have compared synthetic rope to steel wire rope on various standardized tasks of pulling, carrying, climbing and rigging, and as a skidder winchline using the OSU Research Forest Logging Crew as they worked on the McDonald and Dunn Research Forests for two summers (1999, 2000). Subjective measures of difficulty, time per task and heart rates (Polar Electro Oy, 1998) were taken as workers (male and female) performed the tasks with steel wire rope or AMSTEEL-BLUE rope. Ropes were in static applications, e.g. guylines, straps, etc. or used at slow winch speeds compared to running lines on cable yarding operations.

Not surprisingly, the subjective views of the workers favor synthetic rope over steel wire rope. The heart rate measures are still being analyzed; however, an example chart provides some insights on the differences in task duration, maximum heart rate, and heart rate recovery. Figure 5 is the chart of a 25 year-old, male subject, weighing 200 pounds, carrying steel wire rope and synthetic rope for 150 feet. The task was conducted on a 25% slope with a 150-foot rope, 5/8-inch in diameter. Weight of the steel was 111 pounds while the comparable length of synthetic rope, with steel thimbles, was 18 pounds.

Studies of heart rate measurement in logging tasks are not common so exercise physiology provides indicators of task relative intensity in endurance training as a percent of maximum heart rate for individuals, taken as 220-minus the age of individual (American College of Sports Medicine, 1990). The table below correlates with maximum oxygen uptake (VO_{2max}) levels and some perceived exertion scales.

Heart Rate (maximum)	Intensity Classification
≥90%	VERY HEAVY
80-89%	HEAVY
60-79%	MODERATE (somewhat hard)
35-59%	LIGHT
<35%	VERY LIGHT

(adapted from American College of Sports Medicine, 1990)

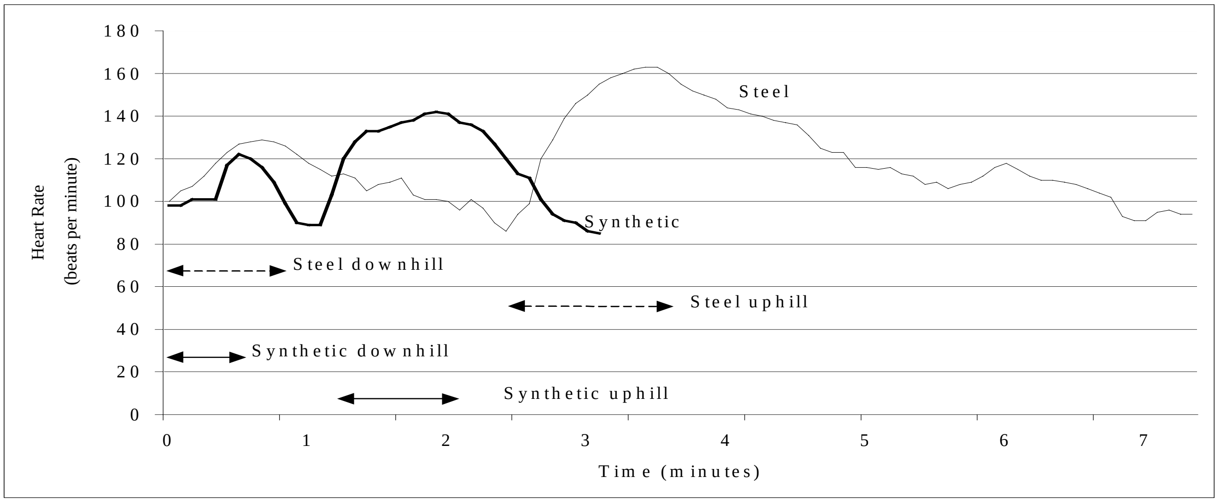

Figure 5. Heart rate and task duration for a 25 year-old male to carry a 150-foot coil of rope 150 feet on a 25 percent slope. Rope diameter 5/8-inch, steel wire or AMSTEEL-BLUE synthetic construction.

For the 25 year-old male worker shown, the heart rate traces for steel and synthetic ropes suggest differences both in the levels reached and perhaps more importantly, in the heart rate recovery for the tasks which can be classed as HEAVY and VERY HEAVY. We are looking at all our workers to assess the heart rate levels reached. Logging tasks often drive heart rate levels in fit workers to high levels so levels themselves may not show differences for ropes. The heart continues pumping at high levels until body chemistry signals indicate sufficient recovery has occurred to lower heart rates. Exercise physician Dr. Donohue suggests a 12 beat per minute reduction after one minute of rest and a return to close to resting heartbeat rate after three minutes (Donohue, 2001). We will see how our workers fit these values for synthetic versus steel wire rope.

Fatigue is implicated in many logging accidents, serious disabling injuries, and fatalities. Synthetic rope may provide the marginal benefit for logging crews at the critical times when tired workers are trying to rig the tail tree to keep logging, carrying guylines and rigging to the back of the unit, or climbing the intermediate support tree while the yarder waits on the crew. More research is needed to document the potential benefits of synthetic rope in skyline logging.

Economic Potentials

Everyone who handles the synthetic rope is curious to know how much it costs. Compared to steel wire rope of the same breaking strength or diameter, AMSTEEL-BLUE costs from four to six times that of steel. Current markets for synthetic ropes are for specialty applications and in produce-to-order quantities. It is unclear what price structure will evolve if substantial quantities of synthetic ropes are incorporated into the logging and forestry sector as well as other sectors currently using steel wire rope.

However, it is clear that gains in effectiveness can offset the costs of synthetic rope at current prices. For example, based on initial results from the skidder winch line trials (5 turns per worker), it is projected a 10 percent increase in productivity on a daily basis might be possible for a single machine operator setting his own chokers. Coupling this result with a recent skidder productivity study (Kellogg, et al, in review), this could amount to an additional 4 turns per day for 400-500 foot skids. While load size is an important factor, this could be about 1000 board feet (1 Mbf) additional production per day, at a benefit of $ 50 – 100 per day to the contractor.

If synthetic rope could increase payloads for cable systems or allow access to difficult terrain, substantial benefits might be attributed to the synthetic rope through reduced costs by replacing the need for more expensive harvest systems or additional roading. Gains might also come during cable equipment set-up, faster manual work, use in helicopter logging, balloon logging and many applications not yet considered.

The light weight and high strength of synthetic rope provides the potential to increase skyline payloads. The benefits will be greatest at low deflections where the ratio of total line weight to net payload is greatest. Table 2 illustrates 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-ft span, zero chord slope, where a load is fully suspended at midspan. The maximum payload that brings each rope up to its 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-inch wire rope and 31% for the 1-inch rope. The percentage increase declines as the deflection increases.

Table 2. Percent increase in maximum midspan payload at 4, 8 and 12 percent deflection for 5/8-inch and 1-inch diameter ropes, EIPS steel wire rope and AMSTEEL-BLUE synthetic rope.

	5/8-inch diameter rope			1-inch diameter rope		
Deflection (percent)	Steel Payload (pounds)	Synthetic Payload (pounds)	Percent Increase	Steel Payload (pounds)	Synthetic Payload (pounds)	Percent Increase
4	1645	2743	67	4096	5373	31
8	3779	5512	46	9450	10814	14
12	5824	8177	40	14581	16052	10

Planning programs such as LOGGERPC (Jarmer and Sessions, 1992) can be modified to include the option of using synthetic rope. For standing skylines, technical information relating to the elastic properties of synthetic rope will need to added to calculate pretensions (skyline tension without log load) and skyline ground clearances with load.

FUNDED FUTURE RESEARCH

Based on promising results to date, OR-OSHA has funded two additional research projects on using synthetic rope in logging at about the same level each as the current project. The projects commenced July, 2001 and will run for two years.

Project 1: Field Applications Of Synthetic Ropes

The Synthetic Rope Research Team will now take the ropes to the field for trials with industry in the following applications.

- Static lines as guylines, etc. with 3 industrial logging contractors

- Establish wear and damage criteria for users
- Verify ergonomic potentials with ground-based logging with Student Logging Crew and logging contractors
- Test new rope formulations with different coverings and braiding construction
- Test the use of synthetic ropes to replace wrappers on log trucks with three firms including one woman log truck driver
- Produce an illustrated user's guide for synthetic rope applications in logging
- Summarize ergonomic and workload reductions from using synthetic ropes.

Project 2: End Connectors And Running Line Applications In Logging
Several major areas from the first project suggest the need for further research and development on synthetic ropes in logging. We will also test, develop, and evaluate new products and uses.

- Evaluate end-connectors comparable to those now available for wire rope
- Use synthetic rope in running line applications and develop design criteria for cable harvesting software
- Conduct materials properties tests for running line applications
- Evaluate manufacturer's rope coverings for running line applications
- Assess winchline mechanics and spooling issues of synthetic rope
- Identify operating limits and procedures for running lines
- Work with a carriage manufacturer to develop slack-pulling and tensioning device for spooling
- Assess the ergonomic benefits from running line applications
- Estimate the economic benefits from using synthetic rope with running lines.

Both of the projects above involve the rope manufacturer, companies that make end-connectors, a carriage manufacturer, and many logging industry cooperators.

SUMMARY

We expect to learn a great deal about logging applications with synthetic ropes with exciting research in the next few years. Great promise exists for improvements in logging safety, worker ergonomics, and economic efficiency. Quantification and description of safe applications, limitations, and useful life/replacement criteria may lead to industry-wide implementation and benefits. These areas of research, with foundations in the wire rope and cable harvesting research of the 1960's and 1970's, will advance the field with 21st century materials and applications. As with the case of many logging activities, innovation can then be advanced further once the rope is in the hands of practitioners.

Mention of trade names does not constitute an endorsement. Research funded through OR-OSHA Worksite Redesign Program Grant.

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