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Finding the Vertical Alignment of Forest Roads Using Several Heuristic Techniques

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ABSTRACT

Once the horizontal alignment of a forest road section between two known locations has been determined by establishing a series of intersection points, the most economic vertical alignment can be identified using heuristic techniques. In a previous research work, Simulated Annealing (SA) was used to locate the optimal vertical alignment for a preselected horizontal alignment, while subject to the geometric design specifications, environmental requirements, and driver safety. The feasible vertical alignments were generated by adjusting the intersection points using a neighborhood search procedure and acceptance criterion. For each alignment, the earthwork cost was minimized using linear programming. This study is a sequel to this earlier study. It employs various heuristic techniques for optimizing vertical alignment of a forest road section and compares their performances in a simple application. The results indicated that heuristic techniques may be useful tools for identifying the optimum vertical alignment at acceptable computational time.

Key Words: forest roads, vertical alignment, optimization, heuristics

INTRODUCTION

In order to locate the lowest total cost path subject to environmental requirements and driver safety, forest road designers should examine a sufficient number of alternative alignments to assure that they have identified a good one. Evaluating a large number of alternative paths considering the specified constraints is too complex a problem to solve with traditional road design methods (Akay 2003). Heuristic techniques can be used to solve such a problem with many solutions. These techniques systematically search for the optimal solution among feasible solutions at acceptable computational cost (Beasley et al. 1993).

In recent years, heuristic techniques have been applied to forest road design problems. To optimize vertical alignment for a forest road, Ichihara et al. (1996) developed an optimization model using a heuristic technique (Genetic Algorithm) for identifying the optimum combinations of intersection points and dynamic programming for locating the optimum longitudinal slope with minimum construction cost. The model was applied to a road section that had been located using traditional road

design methods. The results indicated that the optimization model took significantly less calculation time compared to an existing road designed using traditional methods.

Suzuki et al. (1998) also applied a Genetic Algorithm (GA) to a forest road design problem for recreation. In this study, scenic values, road slope, distance between roads, variation of the ground elevation, road length, and longitudinal slope were the evaluation factors. First, two intermediate points per one route were located to search between four points including the beginning point, two intermediate points, and the end point. Then, GA was employed to find an optimal solution by altering coordinates of the intermediate points. Comparison of the forest road profiles designed using GA and traditional method indicated that GA significantly reduced the calculation time.

Akay (2003) developed a forest road alignment model, TRACER. An initial alignment was located on a 3D view of the terrain generated based on a high-resolution DEM, considering the specified constraints. The constraints included geometric specifications, environmental requirements, and

driver safety. A heuristic technique, Simulated Annealing, was used to search for the best vertical alignment with minimum total cost of construction, maintenance, and transportation costs. For each alignment alternative, a linear programming method (Mayer and Stark 1981) was used to determine the economic distribution of cut and fill quantities. The model application indicated that development of a road design that incorporates computer graphics capability, advanced remote sensing technologies, and optimization techniques could significantly improve the design process for forest roads.

Aruga et al. (2004) developed a model to compare capabilities of two heuristic techniques, GA and Tabu Search (TS), in planning of a forest road profile. In the model, alternative profiles were generated by adjusting the heights and the location of the intersection points. The method of Akay (2003) was used to calculate total cost of construction and maintenance activities. Earthwork allocation was determined by using linear programming (Mayer and Stark 1981). The results indicated that the model using TS usually found a good quality solution in less time than using GA. However, both heuristic techniques found a near optimum/good quality solution in a reasonable computational time.

This study is a sequel to an earlier study conducted by Akay (2003) in which SA was used for optimizing vertical alignment of a forest road section. In this study, various other heuristic techniques were employed and their performances were compared in a simple application. The opportunities of using heuristic techniques for finding the optimal vertical alignment are presented to encourage other researchers to apply them in road design problems.

HEURISTIC TECHNIQUES

Four types of heuristic techniques were used to solve a vertical alignment optimization problem. The techniques include Simulated Annealing, Threshold Accepting, Record-to-Record Travel, and Great Deluge Algorithm. In this section these techniques were briefly described and the logic behind each technique was presented. In the optimization process, the initial vertical alignment (initial solution) was generated by manually establishing the intersection points on 3-D view of the terrain. The alternative vertical alignment (new solution) was automatically generated by changing the elevation at a randomly selected intersection point within the specified elevation range. For each feasible solution, the model calculates its "quality", which is the unit cost of sum of the construction, maintenance, and transportation costs. Then, heuristic techniques were used to

systematically search for the good quality/near optimal solution among the acceptable solutions.

Simulated Annealing

The idea of Simulated Annealing (SA) is based on a simulation of a metallurgical process known as annealing. In order to produce a good quality product, a solid material should be heated past its melting point and then gradually cooled back into an optimal state, subject to a reheating and cooling schedule. Kirkpatrick et al. (1983) suggested that this process could be basis of a heuristic technique for combinatorial problems. SA uses a local search where alternative solutions are generated by moving from one solution to a neighborhood solution. There are number of generic decisions to be made for implementing the algorithm. These decisions include the initial temperature (t), the temperature reduction factor, and the stopping condition (maximum number of iterations). In most of the combinatorial optimization problems, they are determined based on several trial and error runs of the search process. After an initial solution (old solution) is determined, the model generates a feasible random solution (new solution) and calculates its quality. If the new solution is feasible and better than the old solution, it becomes the old solution for the next step. If the proposed new solution violates any of the constraints, it is rejected by the model and another random solution is generated. To avoid being trapped in a local optimum, the algorithm will allow the acceptance of an inferior solution, with a decreasing probability. After a user defined number of iteration, the temperature is reduced by using temperature reduction factor. Therefore, the probability of accepting a worse solution is slowly lowered. The model records the "best" solution among the acceptable solutions during the running time. The algorithm stops once the stopping conditions is reached. The algorithm of SA runs as follow for minimization:

select an initial solution (old solution)
select an initial temperature t>0
    select a new solution
    compute E = quality of new solution –
                quality of old solution
     IF E < 0
       THEN old solution = new solution
     ELSE with probability exp(E/t)
       old solution = new solution
    IF too many iterations with the same t
      THEN reduce temperature t
    IF stopping condition is reached
      THEN stop

Threshold Accepting

Dueck and Scheuer (1990) first proposed the idea of Threshold Accepting (TA), which is very similar to SA. It has a slightly different set of acceptance rules than that of SA. TA accepts every feasible solution which is not much worse than the old solution, while SA accepts worse solutions only with rather small probability. Once an initial solution (old solution) is generated, the difference (E) between the quality of proposed new solution and the old solution is compared to a user defined initial threshold level (T). If the new solution is feasible and E is less than the threshold level, the new solution becomes the old solution. If the proposed new solution is not feasible with respect to the constraints, the model rejects it and generates another random solution. The best solution among the acceptable solutions is recorded by the model. If there has been no improvement in the quality of the best solution for a specified number of iteration, the threshold is reduced by threshold reduction factor. If the threshold level reaches the minimum threshold level or total number of process iterations exceeds the maximum number of iterations, the algorithm stops. The initial threshold, threshold reduction factor, minimum threshold level, and maximum number of iterations are determined by the user after a few experiments. If the quality of the best solution has not improved for a user-defined number of iteration, the search process also ends. The algorithm of TA runs as follow for minimization:

select an initial solution (old solution)
select an initial threshold level T>0
    select a new solution
    compute E = quality of new solution –
          quality of old solution
      IF E < T
        THEN old solution = new solution
      IF no improvement in quality for
        many iterations with the same T
        THEN reduce threshold level T
      IF no improvement in quality for too
        many iterations or maximum
        number of iteration is reached
        THEN stop

Record-to-Record Travel

The idea of Record-to-Record Travel (RRT) resembles the algorithms of SA and TA (Dueck 1993). The difference relies on their acceptance rules. In RRT, if the quality of any proposed new solution is not much worse than the quality of the best solution recorded so far, the new solution is accepted. In the search process, the designer first determines the initial solution (old solution) and the model records its quality (R). Then, the model generates a proposed new solution. If the new solution is feasible, its quality (Q) is compared to the quality of the old solution plus a user defined value of some deviation (D). If the quality of the new solution is less than $R + D$, the proposed new solution becomes the old solution. Moreover, if Q is less than R, R becomes Q for the next steps. If there has been no improvement in the quality of the best solution for a specified number of iteration or maximum number of iterations is reached, the algorithm stops. The user determines D and the maximum number of iterations based on several trial and error runs of the search process. The algorithm of RRT runs as follow for minimization:

select an initial solution (old solution)
select a deviation value D>0
set R = quality of the initial solution
    select a new solution
    compute Q = quality of new solution
      IF Q < R + D
        THEN old solution = new solution
      IF Q < R
        THEN R = Q
     IF no improvement in quality for too
       many iterations or maximum
       number of iteration is reached
       THEN stop

Great Deluge Algorithm

The Great Deluge Algorithm (GDA) is similar to SA with a slight change in deciding whether or not the proposed solution is acceptable as a new solution. GDA was introduced by Dueck (1993) and in a maximization process it searches for the highest elevation in a fictitious surface by simply walking around the surface, while it rains without end. Once an initial solution (old solution) is generated by the designer and its quality is computed by the model, the initial water level (WL) is determined by adding (subtracting in a maximization process) a user defined "rain speed" (RS) from the quality of the initial solution. Then, a feasible new solution is generated by the model, considering the specified constraints. If the quality of the new solution (Q) is less than the initial water level, the old solution becomes the new solution and water level becomes $WL – RS$. If the quality of the best solution has not improved for a user-defined number of iterations or maximum number of iterations is reached, the algorithm stops. Rain speed and the maximum number of iterations are determined by the user after

a few experiments. The algorithm of GDA runs as follow for minimization:

select an initial solution (old solution)
select a rain speed RS>0
set the initial water level WL>0
    select a new solution
    compute Q = quality of new solution
        IF Q < WL
          THEN old solution = new solution
          WL =WL - RS
       IF no improvement in quality for too
         many iterations or maximum
         number of iteration is reached
         THEN stop

RESULTS AND DISCUSSION

The solutions generated by the four heuristic techniques and their performance are compared in a simple application. The study area of 55 hectares was located in the Capitol State Forest, Washington. Soil, hydrology, and geology data were provided by Washington Department of Natural Resources. Road design specifications and economic data were obtained from the local sources (Kramer, 2001 and USDA Forest Service, 1999). The initial road path was located by establishing the intersection points on the 3D image of the terrain based on DEM data from LIDAR (Aerotec, 1999), while considering the specified constraints. Some of these constraints include minimum curve radius (18 m), minimum vertical curve length (15 m), minimum gradient ($\pm$ 2 %), maximum gradient (16%), minimum distance from a stream (10 m), and maximum cut and fill height (2 m). A sample forest road section (625 m)
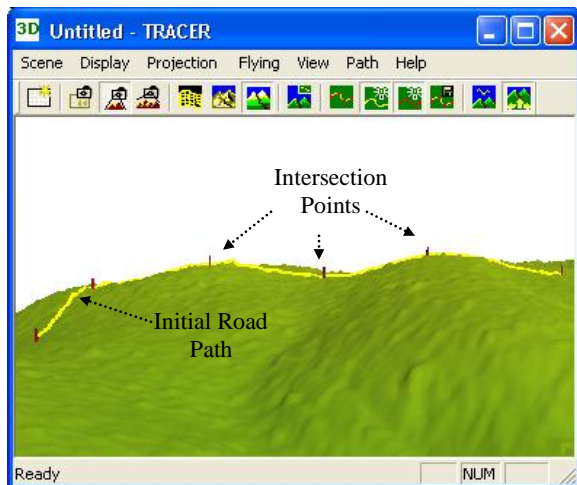

Figure 1. The initial solution generated by locating the intersection points on 3D image of the terrain.

was located by using six intersection points (Figure 1). The unit cost of the initial solution was $32.05/m. Then, the model generated the optimal vertical alignment using heuristic techniques.

The solution quality and computational times are presented in Table 1. The results from the example indicated that GDA and SA were better techniques than TA and RTR in terms of solution time. GDA was the fastest algorithm, while RTR was the slowest algorithm among the heuristic techniques. The good quality/near optimum solution ($28.61/m) for the problem was reached by each of the four heuristic techniques. Using the heuristic techniques, the unit cost of sum of the construction, maintenance, and transportation costs was reduced approximately 11%.

The heuristics were also compared in terms of complexity of the programming. GDA and RRT were very easy to implement because the success of these algorithms depends on a single parameter. However, in SA and TA, the quality of the solutions depends on two parameters; therefore, they are relatively difficult to implement into the computer programming.

In SA, when the initial temperature was too high, worse solutions were usually accepted in the process. Choosing the appropriate initial temperature and temperature reduction factor influence the success of the algorithm. In TA, the initial threshold and threshold reduction factor were the main parameters that reflected the quality of the results and computational time. When the initial threshold was too high, the algorithm produced low quality solutions. In RRT, when the value of deviation was too small, the algorithm ran very fast and produced low quality results. Therefore, a large value was chosen for deviation to generate excellent results. In GDA, when the rain speed was too high, the algorithm ran very fast and produced poor solutions. To produce high quality solutions, the rain speed was needed to be very low in this problem.

Table 1. The solution quality and times for the four heuristic techniques, using Pentium III 750 MHz processor.

Heuristic Techniques	Solutions ($/m)	Computational Times (min)
SA	28.61	5.6
TA	28.61	9.2
RTR	28.61	10.5
GDA	28.61	5.1

CONCLUSION

Finding an optimal vertical alignment of a forest road by evaluating all the feasible alternatives, considering economical and environmental constraints, is too large a problem to be solved by using the traditional road location methods. In recent years, heuristic techniques have been used to solve such complex problems at reasonable computational cost. In this study, four heuristic techniques (SA, TA, RTR, and GDA) were applied to a forest road location problem, where the objective function was to minimize the sum of the construction, maintenance, and transportation costs, subject to specific constraints.

The performance differences of these heuristic techniques in terms of solution quality, computational time, and complexity of programming were investigated. The results indicated here can not be generalized; however, this research can provide other researchers with insight information into using heuristic techniques for road design problems. Besides, it can be a guide to assist road designers in selecting the technique that is most appropriate for their specific problem.

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SPATIAL ANALYSIS OF TO-STREAM SEDIMENT DELIVERY IN CENTRAL APPALACHIAN FORESTED WATERSHEDS

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ABSTRACT

Some negative impacts inevitably occur from forest management activities. Non-point source pollution, which originates from dispersed sources across the watershed, is often the largest problem. Of all non-point source pollutants, sediment is the most common cause of water quality impairment from silvicultural activities, though most sediment typically originates from roads rather than across the general harvest area. A study is being conducted in the central Appalachia, in which sediment delivery to streams is being measured in two forested watersheds. Hill slope attributes have been measured and mapped, and these are being analyzed spatially in to identify those that control sediment movement in both undisturbed and roaded/harvested conditions. The findings will be applicable to future management activities to identify potential problem situations and sediment "hot spots" so they can be avoided during planning or mitigated before problems develop. The findings also will be used to improve targeting of best management practices (BMPs) within the watershed, thereby making BMPs more cost effective.

INTRODUCTION

Some factors that influence the amount of natural or geological soil movement in a forested watershed include slope length, slope percent, vegetative cover (Wischmeier 1976), presence of obstructions, geology, natural disturbances such as windthrows and deer trails, and the distance such a disturbance is from a stream channel. The amount of rainfall that a particular watershed receives and its intensity also helps to determine the amount of soil movement that could occur (Florida Department of Environmental Regulation 1988). The physical properties of the soil also have an effect on the level of soil movement. Soil texture and moisture will help to determine the amount of soil cohesion that is present, and less cohesion results in easier sediment movement. Adverse soil movement in a disturbed watershed can be contributed to many factors. These factors include the removal of existing protective vegetative cover, exposure of less pervious or more erodible geological formations, reduced capacity of exposed soils to allow penetration of rainfall due to compaction, prolonged exposure of unprotected areas, changing slopes and the altering of overland flow routes (Florida Department of Environmental Regulation 1988). Climate, soil, vegetation, and topography are the major variables that affect erosion. Some of these variables can be manipulated, but for the most part, climate and topography remain out of the reach of the land manager. Water erosion is also affected by other factors that have varying degrees of impact, depending on location and magnitude; these include soil moisture, soil properties, rainfall intensity, vegetative cover, slope of land, and length of slope (Copley et al. 1944). Forces in the forested watershed that helps to determine the amount of soil that is eroded are either attacking forces or resisting forces. Attacking forces help to dislodge and move the soil particles and resisting forces that help to prevent erosion by impeding soil detachment and particle transportation through hydrological processes such as rough surfaces as encountered with vegetation.

A 0.001 ton/ac/yr and a 0.003 ton/ac/yr average has been removed from weir ponds located at the outlet of two watersheds which are located in the Fernow Experimental Forest near Parsons, West Virginia (Patric 1976). This information is very useful on a watershed scale, but when trying to determine point

sources of pollution within the forested watershed, a better system of measurement is needed, and to locate weir ponds every 3-4 meters would be too costly and environmentally disturbing on a watershed scale. A method of sediment collection that is nearer to 100 percent and is more cost efficient is necessary. Renard et al. (1991) suggest that the most commonly used erosion prediction model is the universal soil loss equation (USLE). The USLE has six factors, (R) rainfall erosivity, (K) soil erodibility, (L) slope length, (S) slope steepness, (C) cover management, and (P) supporting practices. This soil loss equation was developed for agricultural purposes with slopes no steeper than 18 percent. The USLE was later updated to incorporate forested lands as well. In a mountainous region, with slope steepness of 25 percent, the L and S factors are speculative. The USLE estimates an average soil loss for an entire watershed, but bases this loss on linearity of slopes. In the real world, slopes lengths and steepness are nonlinear, and are not uniformly distributed over the entire watershed (Dissmeyer and Foster 1981).

Since the concepts for the USLE were intended for cropland and the erosion estimates from sheet and rill erosion were often predicted improperly for areas other than cropland, other modifications were made to the USLE. This allowed for an expanded use, such as rangeland erosion and road erosion. Two modifications of the USLE are the revised universal soil loss equation (RUSLE) and the modified universal soil loss equation (MUSCLE). The RUSLE incorporates more data than did the USLE from different locations and types of cropping systems, and also for rangeland and forest erosion. RUSLE is also more flexible than the original USLE and this factor alone allows modeling of significantly more complicated systems. The MUSLE was devised to model sediment delivery where deposition was expected down slope. The MUSLE equation makes an improvement over the USLE by considering surface runoff (Barfield et al. 1983).

Sediment that has been transferred across the forest floor and into a stream channel could lead to excessive sediment deposition when the energy of the water lowers and the sediment is deposited onto the stream bottom. This deposition in excessive amounts will result in damages to aquatic life, obstruct navigational abilities, and reduces available hydrological capacities of streams. This leads to a reduced amount of aquatic organisms and increased flood crests (Corbett et al. 1978). An estimated 3.6 billion metric tons of sediment is carried to streams, ponds, lakes and rivers each year in the United States, and an estimated 0.9 billion metric tons of this sediment is carried all the way to the ocean annually (Florida Department of Environmental Regulation 1988). For some watersheds, where the vegetative cover and the soil mantle have been drastically altered, 0.405 hectares may deliver 20000 to 40000 times more sediment than an undisturbed woodland area of the same size and makeup (Florida Department of Environmental Regulation 1988). By quantifying the amount of sediment that is delivered to streams in a watershed by discrete locations, it can help to determine the problem areas and allow for increased attention to help diffuse and/or eliminate the sediment travel from these locations. This will eventually lead to less sediment delivery to the stream channel.

MATERIAL AND METHODS

Two small watersheds were chosen in a central Appalachian mixed hardwood forest and the amount of soil that was delivered from the topological features to the stream channel from the two watersheds were collected and examined. This was done to quantify the amount of soil that was delivered to the stream channel and also to determine the topological attributes, such as slope percent, slope length, bare soil areas, windthrows, and other factors that were responsible for the origination and transfer of the soil that was delivered to the stream channel. Samples were collected over the entire length of the stream that originated in each of these watersheds. These sediment samples were collected along the backside (away from the stream) of silt fences that were installed adjacent to the stream channels for all perennial and ephemeral reaches of streams in each of the two watersheds. Stream channels were completely encompassed by the silt fence to ensure all sediment that was delivered from adjacent slope attributes was being collected. The silt fence was permanently installed with locust and oak post that were driven into the ground at irregular intervals, and then some of the posts were numbered when the first set of samples were removed from the silt fence. The base of the silt fence was installed differently than recommended also, instead of digging a trench for the lower edge of the silt fence to be installed into, the silt fence was lapped up the slope approximately 0.3 meters. This was done so that the trenching would not unnecessarily disturb the forest floor, and also to provide an area where sediment could collect and be removed by hand more easily. The area created by the rolled silt fence stays as a constant, so that all samples taken at later dates

will be removed from the same sample area. The silt fence was installed far enough away from the stream channel to prevent high flow water from undercutting the edges of the fence and displacing material that has been previously caught in the silt fence and also eliminating the formation of any new rills and gullies. Data were analyzed spatially to determine the effects that the topological attributes had on sediment delivery to the stream channel. The use of GIS mapping was used to develop a final land area with respect to the soil erosion processes and the amount and locations of soil collected in each of the two watersheds.

A 1:24000 topography map was used to find a suitable watershed in the Monogahela National forest. The watersheds that were used in this project were both located on the Left Fork of Clover Run, in Tucker County, West Virginia (figure 1). The soil series for the study watershed is Berks High Splint Complex, and the geology is Chemung. A 10-meter DEM (Digital Elevation Model) of the study area was obtained from West-Vaco Timber Company. This DEM had been created for private land next to the National Forest, and also covered the study area. Using the DEM, it was possible to create flow direction models and flow accumulation models for the studied watershed. This enabled a map to be created, which showed areas of water convergence, or places where ephemeral streams would flow. The flow accumulation model was then used to establish a stream network that showed stream convergence points. The two larger watersheds could then be divided up into sub-watersheds at the stream convergence points by using the watershed tool in ArcGIS. The sub-watershed boundaries were then used as analysis masks to derive slopes for each of the sub-watersheds in the treatment and control watersheds. A total of 7 sub-watersheds were delineated in the treatment watershed and a total of 5 sub-watersheds were delineated in the control watershed.
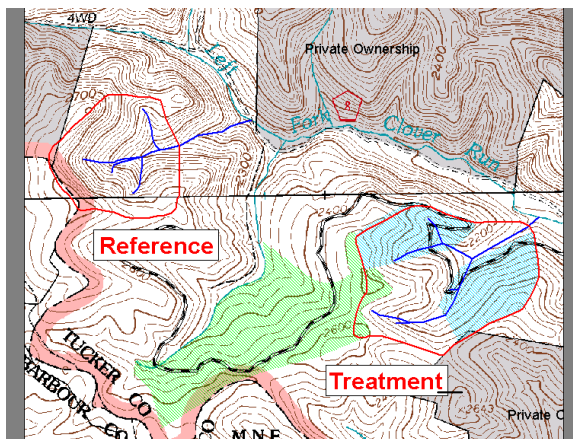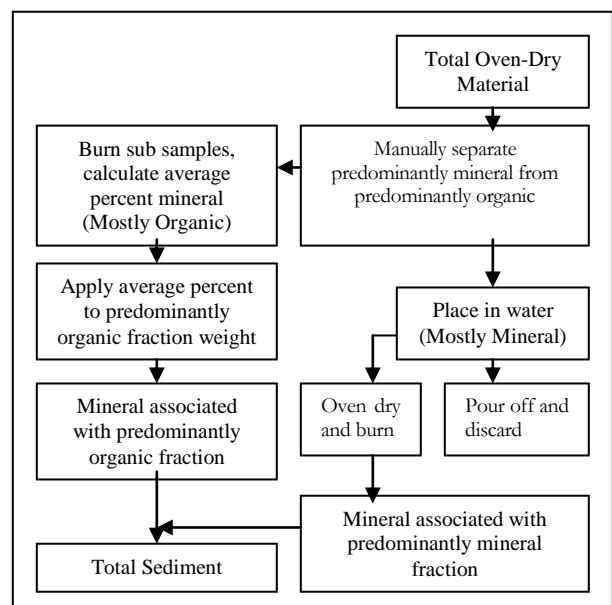

Figure 1. Location of the watersheds.

Figure 2. Separation processes to determine total sediment.

These pour points or sub-watershed outlets were entered on the watershed map and the sample collection that was performed above these points to collect soil erosion that had entered the silt fence was utilized in determining the erosion results of that particular sub-watershed. The silt fences were installed and were in place for one year. This allowed for one full year of soil erosion to occur and to be collected in the silt fences.

The total stream length in the watersheds is 1325 meters and 902 meters for the treatment and control watersheds respectively, and the total area for the watersheds is 31.46 hectares and 20.25 hectares also for the treatment and control watersheds respectively. The sediment samples collected were numbered with respect to the watershed and the location along the silt fence in each watershed where they were

collected. This kept a record of which sub-watershed the samples were collected in. The samples were then taken back to the lab to be sorted, dried, weighed and sieved.

Taking steps to separate the organic material from the mineral material is performed first after the samples have dried (figure 2). Twigs and leaves are removed by hand, and then the remainder of the mostly mineral sample is burned to remove any of the smaller organics that were not removed manually. The samples are then dried and weighed to determine the remaining mineral content. The remaining mineral sample is then sieved using an automatic shaker to get the distribution of particle sizes that are present. The sieve sizes used were 4mm (sieve A), 2mm (sieve B), 1mm (sieve C), 0.125mm (sieve D), and 0.063mm(sieve E). Material that is <0.063mm would be collected in the sieve pan. The 4mm and the 2mm sieve sizes were used to determine the amount of material that is fine sediment (<4mm) and the amount of material that is soil (<2mm). The 0.063mm size was used because this size of material has been found to be the size that affects brook trout in the streams of West Virginia. After the material has been sieved, it is weighed again for each of the sieve sizes.

RESULTS

The sub-watersheds are shown in figure 3, for the control and treatment watersheds. The watersheds are at different scales.
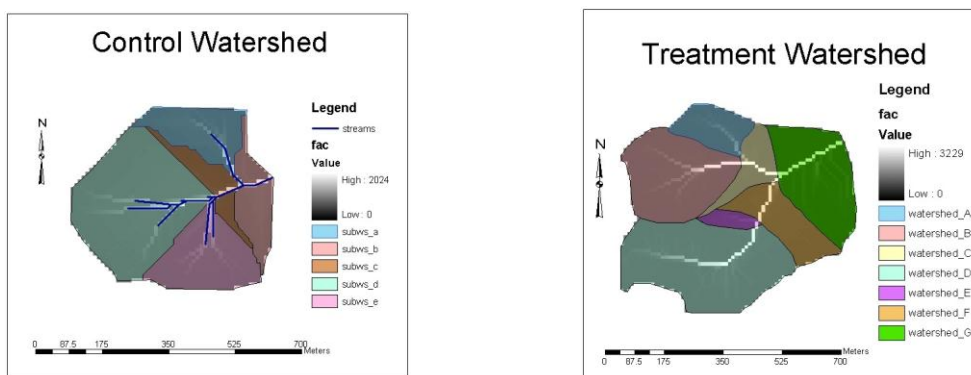

Figure 3. Sub-watershed delineations for the control and treatment watersheds.

The total weight of all of the material (both mineral and organic) that was collected in the treatment and control watersheds was 2376.75 kg and 526.79 kg respectively. The amount of those samples that were mineral only was 1258.65 kg and 163.14 kg for the treatment and control watersheds respectively. This amount is a combination of the mineral associated with the predominately mineral fraction and the mineral associated with the predominately organic fraction of the separated samples. This shows that an average of 0.040 mton/ha/yr (0.109 ton/ac/yr) of mineral eroded from the treatment watershed and an average of 0.008 mton/ha/yr (0.022 ton/ac/yr) of mineral eroded from the control watershed from the summer of 2001 to the summer of 2002, and was captured in the silt fence. The amount of erosion from the control and treatment watersheds was calculated using all of the samples collected for each watershed and then dividing that amount by the area calculated in ArcGIS by the watershed delineation tool. For the sub-watersheds, some of the identification tags were destroyed by the dampness of the samples, so the exact location of the sample is unknown. If less than 10 percent of the samples in an area were unidentified, then the averages of the samples that were known was used to fill in the missing information. Sub-watershed E in the treatment watershed was the only sub-watershed in which there were too many sample data missing, so the results of that sub-watershed were not calculated on a sub-watershed level, but the data from that sub-watershed were used in the treatment watershed calcuations. Table 1 shows the results of the mineral erosion from the sub-watersheds located in each of the two larger sampled watersheds. Table 1 does not have all of the sub-watershed listed because some of the sample identification information was destroyed by the dampness of the samples during the sampling processes.

Statistical analysis was run on the sieved mineral weights and the different slopes that were classified in the sub-watersheds. The slope classifications were defined as <30%, >=30%-<35%, >=35%-<40%, and >=40%. The slope classifications were listed as 30%, 35%, and 40% respectively for the three slope conditions that were used. Table 2 shows the resulting means for the sub-watersheds and their

respective weight distributions according to the different slope conditions. There were no significant differences in the weight distributions for the different slope conditions at the alpha=0.05 level.

Table 1. Sieve weights and slopes for sub-watersheds.

Subws	Weight (g)							Slope (%)				Area (ha)	Tons/ac/yr
	Total	Sieve A	Sieve B	Sieve C	Sieve D	Sieve E	Sieve Pan	Min	Max	Mean	Std. Dev.		
Trt a	56612	33500.5	4514.057	5386.076	9810.01	1527.335	1684.634	1.66	56.38	31.85	12.71	2.17	0.0711
trt b	119140	56303.07	14740.03	15020.23	22148.1	3726.367	4055.133	0.68	75.28	41.99	16.61	6.95	0.0467
trt c	68927	46496.47	4755.2	5018.5	7875.5	1629.9	1950.7	1.4	66.23	36.49	17.6	1.37	0.137
trt d	241916	142432.4	22908.65	23880.23	37309.7	6668.85	8337.275	0.32	80.64	39.86	18.17	10.39	0.0634
trt f	29846	20641.68	1806.362	1813.143	2771.152	498.2667	660.4286	2.09	66.26	39.38	14.91	3.84	0.0212
trt g	120244	98493.43	3897.15	4530	8162.233	1738.133	2139.817	0.53	72.3	44.79	16.35	5.99	0.0547
ctrl a	5454	4065	113	135	652	190	98	1.19	56.5	32.17	12.68	2.94	0.0051
ctrl b	14638	9699	507	762	2508	620	445	2.29	63.68	36.47	15.79	2.29	0.0174
ctrl c	13836	9348	359	627	2452	551	392	5.42	55.82	31.05	10.44	1.62	0.0233
ctrl d	50930	26613	2630	4116	12181	3194	1896	0.6	70.12	40.39	16.07	9.22	0.015
ctrl e	12658	10128	177	297	1326	335	204	1.58	60.15	34.79	13.06	4.18	0.0082

Table 2. Mean weight distribution in grams for the different sieve sizes, on a per hectare basis.

Watershed	Slope (%)	Total Weight	Sieve A	Sieve B	Sieve C	Sieve D	Sieve E	Sieve Pan
Control	30	3922.2	256.68	283.35	643.88	139.53	126.3	108.04
	35	43010.23	1701.81	1978.17	3564.29	759.01	934.42	194.32
	40	1051.95	54.99	82.65	272.02	67.25	48.26	205.64
Treatment	30	183547.71	24272.1	25684.41	40678.66	7285.65	8682.02	776.5
	35	22321.22	3559.8	3865.3	6336.11	1070.06	1263.71	799.46
	40	4341.95	276.46	434.38	1391.83	353.55	219.35	470.36

CONCLUSIONS

The resulting data shows that the slopes are not significantly responsible for the different amounts of materials that were eroded from the forest soils and collected in the silt fences. There were very different means calculated for the different particle sizes, but none were significant at the level tested. There seems to be strong differences present between the sub-watersheds,

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Evaluating the effectiveness of a logger safety training program

Jennifer Bell

Introduction

Many states have some form of logger training or certification, but they vary in type and length of training (MacKay et al. 1996, Reeb 1996, Egan et al. 1997, Kinard 2000). These programs often have multiple goals, including training in safe work practices for a variety of jobs, first aid, sound environmental management practices, and business practices. In many states= certified or licensed logger programs, only approximately 4-8 hours of training in safe work practices (primarily chainsawing) are required. Few, if any, of these program have been rigorously evaluated in a quantitative manner as to their ability to reduce injury. In general, even in other industries, there are relatively few examples of studies that have quantified injury reductions after training (Johnston et al. 1994, Sulzer-Azaroff and Austin 2000). Another challenge is that additional factors may be present, such as mechanization, that may confound training effects.

The state of West Virginia has a high rate of injuries as documented through the rate of workers' compensation injury claims (Bell and Helmkamp 2003). In 1992, the state of West Virginia passed the Logging Sediment Control Act stating that one Certified Logger must be present at each logging job for at least part of the day. The West Virginia Certified Logger program (also started in 1992) consists of a full day of best management practices training, a day of first aid/CPR training, and approximately one-half day of chainsaw safety training. Despite the increased number of Certified Loggers in the state, workers= compensation premium rates remained high. In order to address this, a group of concerned parties formed a task force and

started the West Virginia Loggers' Safety Initiative (Carruth 2000). The initiative was designed as a four year pilot project with annual premium rate reductions for participating logging companies. Specialized training is provided for all members of the logging crew. Fellers get four 8-hour hands-on training sessions on safe chainsaw use and directional felling practices. Participating logging companies were also expected to maintain safe work environments for their employees, which included safe work practices, use of personal protective equipment, ongoing training, and compliance with existing OSHA standards. An ongoing inspection program (3 times a year) was an integral component to encourage companies to maintain safe work practices. The program was open to any employer regularly engaged in timbering that was in good standing with the West Virginia Workers' Compensation Division. The objective of this research was to evaluate the effectiveness of the West Virginia Loggers' Safety Initiative (LSI) in reducing injuries to loggers.

Methods

The LSI covered a four-year period beginning July 1, 1999 and ending June 30, 2003. In general, new companies could enroll each July. Data from the program were obtained from the parties organizing and managing the LSI program, and from the West Virginia Bureau of Employment Programs. Injury rates were calculated using workers' compensation claims and employment data (days worked per employee). Poisson regression (using SAS software) was used to determine significance of injury trends over time, and between groups. Because of the potential confounding effect of mechanization (Bell 2000), additional information was included when assessing injury rates on a measure of mechanization (whether or not they were observed

using a feller buncher during any of the on-site inspections).

Results

A total of 88 companies enrolled in the LSI for at least part of the four-year program. Companies that joined in Year 1 of the program, and stayed through until Year 4 (Years 1,2,3,4) comprised the bulk of participants (64%) (Table 1). Over the course of the program, when looking at all companies that had been in the program for any length of time, there was a decline in total injuries, but the trend was not statistically significant (slope= -0.0088, P= 0.0837). When examining the subgroup of companies that had been in the program all four years (Years 1,2,3,4), there remained no significant trend in total injuries (Figure 1, slope= 0.0112, P= 0.0778).

Feller buncher use accounted for significant differences among groups. In general, companies with feller bunchers had a significantly lower injury rate (6.4 injuries per 100 workers) than did non-feller buncher (14.5 injuries per 100 workers) companies (rate ratio= -0.8132 , 95% CI 0.30-0.63).

Discussion

In this evaluation of a state logger safety training program, there is no strong evidence to suggest that the program was effective in reducing injuries in companies participating in the training. The bulk of the total person-time under study (64%) came from companies that were in the program all four years (Years 1,2,3,4), and this group showed no trend over the study period; essentially their rates did not change.

There is strong evidence that mechanization of harvesting tasks (as measured by use of a feller buncher during logging operations) is associated with a significantly lower injury rate in

companies using them. The effects seen from mechanization were much stronger than the training effect, which appeared to be modest to non-existent. It may be that high injury rates in the state of West Virginia would be best addressed by finding ways to encourage companies to become more mechanized in their harvesting practices.

Table 1. Injury rates by LSI participation group.

Years in LSI	Injury Rate per 100 workers	% of total person-time
1	5.2	1 %
2	2.7	2 %
3	0.0	0 %
4	12.8	2 %
12	20.0	6 %
23	3.2	2 %
34	10.7	2 %
123	23.7	9 %
234	6.2	12 %
1234	11.4	64 %

Figure 1. Injury rate per 100 workers for companies participating in all four years of the Loggers Safety Initiative Program
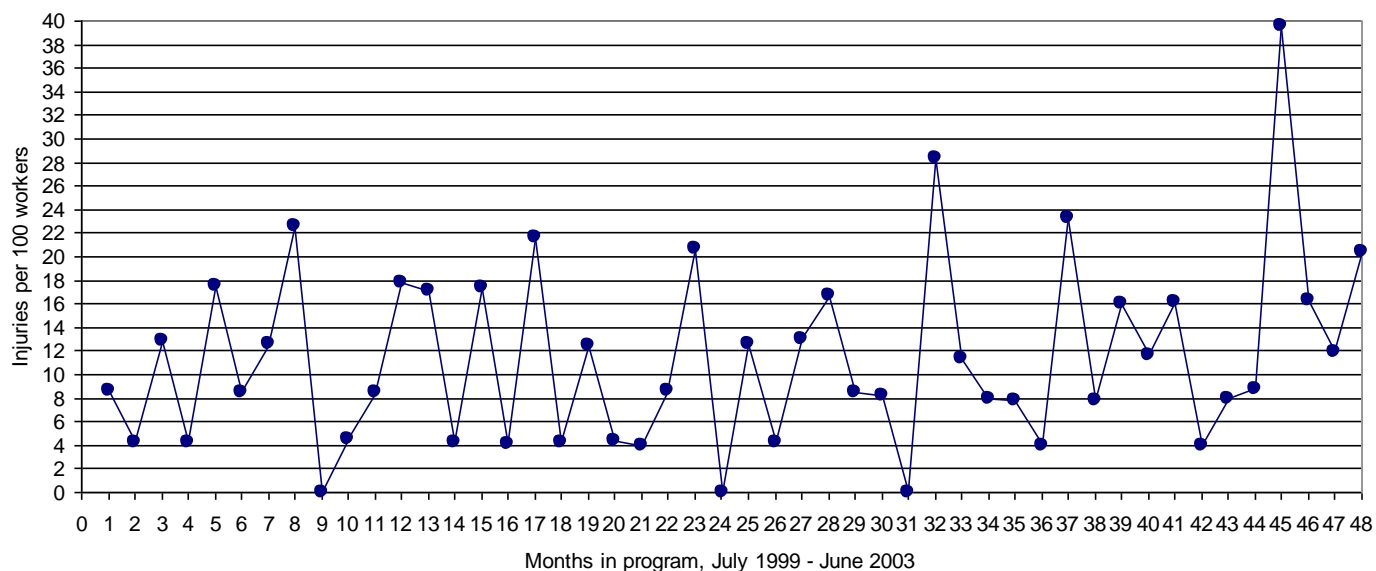
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Logging Machinery used in Wildland Fire Suppression

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Abstract

Catastrophic wildfires are now a common occurrence in the west. To battle these blazes, logging machines are used for constructing firelines (earthmoving), timber removal, and water transport. The research at Oregon State University is defining the issues at stake with three focus points: equipment, policy, and training. Standard and modified logging machines are used in multi-employer work arrangements for wildfire suppression scenarios and tactics. Wildfire suppression is a complicated system to comprehend, and the study identifies the pertinent issues, provides a problem definition, and identifies research needs to advance firefighting efficiency.

Introduction

Devastating fires have become a common occurrence in the western United States and Canada during recent years. Large fuel breaks have been the only effective way to stop some of these catastrophic wildfires, and without these interruptions, the fires commonly burn until the weather changes or the fuels simply run out. Trends in fire suppression equipment technology show little change over the last fifty years and logging equipment offers new potentials.

Increases in mechanization occurred in logging for two main reasons: to increase safety and efficiency. This justification can be logically extended to fire suppression. Bulldozers have long been the sole piece of heavy equipment used for firefighting; however, there has been success using logging machinery for various firefighting tasks.

The main goal of this scoping research is to improve the efficiency of wildland fire suppression through documentation of potentials and defining problems and related issues. Fire managers in the public and private sectors as well as the specialized operators of machines from the private sectors need to better understand how the new equipment can contribute to wildfire suppression. Three main focus points have been selected: the equipment, safety policies, and training requirements.

Equipment

Logging machinery has been used successfully on large and small wildfires occurring on both public and private lands. Tasks performed during Initial and Extended Attack scenarios include direct and indirect tactics, water delivery, mop-up, rehabilitation, and hazard reduction.

The ongoing logging operations were likely the first scenarios where logging equipment was deployed to fight fires. Accidental fires can be started from sparks or friction of moving tracks, blades, saws, and other parts—especially in the dry season. Thus, most logging crews are required by law to make special preparations for these emergencies. In addition to having a plan of action and assigned duties, many crews also keep a water supply and firefighting tools nearby. The heavy equipment suppresses the wildfire by digging lines and removing fuels. Furthermore, older machines are occasionally modified specifically for fire suppression purposes.

In southern Oregon, one logging contractor built "skidgines" to accompany feller-bunchers. The name skidgine is derived by combining a log skidder with a fire engine. These skidders were retired from logging but still had some value. Equipped with a 500 gallon water tank, pump, and hose the machines were parked near the operation and could be quickly driven to small fires that might occur from sparks caused by debris and the continuously spinning "hot saw" of the feller-buncher (Wampler 2003).

Contracts

Logging machines have also been used by wildfire contractors as money-making firefighting tools on agency fires. Federal contracting has increased dramatically, especially in wildland firefighting. As a result, many in the private sector have become employees of the government contractors. These contract workers consist of both logging personnel who lack work (especially during the fire season) and newcomers looking to make a career in forest activities.

On agency managed fires, both standard and modified machines have been used in contract firefighting. Interagency contracts have been built to serve two levels—regional and national—with the range of deployment depending on the type of contract used. An Emergency Equipment Rental Agreement (EERA) must accompany these contracts (Kuehn 2003). Pay rates and equipment classifications are provided with these contracts. However, determining pay rates can be complicated. Many rates are negotiable due to the unclear agency classification of equipment and the wide range of innovative machines available.

Modifications

Many machine modifications have been documented in addition to water tanks, water cannons, pumps, and hoses. Calcium chloride has been used to enhance rubber-tired machine stability when operating on steep ground. Chains are used to decrease the direct heat exposure to the tires, and on some machines, can also reduce site rehabilitation needs by decreasing ground pressure. To provide a necessary level of safety and performance, machines carrying large water tanks have also been equipped with additional braking systems on the rear axle and stronger driveshafts

Because many modified machines have not been properly designed to handle the fire conditions they will encounter, more assessments are needed on how capabilities are altered when machines perform tasks different than those for which they were originally designed. For example, a skidder will behave differently when carrying a full water tank than it would when dragging logs partially supported by the ground.

Safety
Operator safety has also been a reason for modifying machines. Pull-down fire screens are used on some machines to provide burnover protection. In contrast, some expensive logging machines are factory equipped with on-board fire extinguishing systems that use chemicals toxic to humans. Many other modifications are in consideration—some more sophisticated than others.

Despite having precautionary features, machine manufacturers may recommend evacuating the machine in a burnover situation because of flammable fluids, pressurized systems, and other possible dangers. Most manufacturers do not recognize firefighting as a designed use for the machine—even if it is performing the actual task for which it was designed but operating in a fire setting (e.g., a skidder skidding logs or a feller-buncher felling trees on a fireline). Only a limited number of logging equipment manufacturers advertise their machines for use in fire suppression.

Stability
To help analyze stability of an existing machine or machine design, a computer model is being constructed to assess machines modified with rectangular box-shaped water tanks. The model will include uphill, downhill, and side slope calculations. For this analysis, stability is defined as the ratio of restoring to overturning moments:

$$stability = \frac{\sum moments_{restoring}}{\sum moments_{overturning}}$$

The model is written in Visual Studio 7.0, and features an easy-to-use interface (Figure 1). The heuristic takes user inputs to first determine the center of gravity of the fluid in the tank and then calculates the overall machine stability. Because any ratio grater than 1 is computed to be stable, comparisons to machines involved with past accidents are being used to help determine an appropriate safety factor.

One such accident documented by the Forest Engineering Research Institute of Canada (FERIC) demonstrated how a modified skidder overturned on a 35% slope. The machine originally was driving uphill, then stalled, rolled backwards down the slope, and eventually overturned. Luckily, the operator was not killed; however, it was labeled as a serious "near miss" accident. In addition to its location dangerously high on the rear axle, the water tank also blocked the vision of the operator and prevented precautionary actions such as backing up the hill. Future incidents like this can be avoided by assessing the machine during the design stage and before operation.

Figure 1: Machine stability model user interface.

Manufacturers

A questionnaire has been distributed to the Society of Automotive Engineers (SAE) Forest Machinery sub-committee. This group consists of representatives from several logging machine and attachment manufacturers. The questionnaire attempts to gather knowledge from machine experts regarding the firefighting uses of machines. Although still in the works, questionnaires have been returned and there are some early findings. Liability is a major issue, and the manufacturers do not currently recognize firefighting as a designed use of the machine. Company warranties would be voided when the equipment is used for wildland fire suppression. There are also discrepancies in the correct procedure to be followed in a burnover situation. Questions about engine performance, tire and track vulnerability, operator protection, and other issues are still outstanding but will influence how machines are used in wildland firefighting.

Policies and Training

At the heart of the issues are the federal, state, agency, and company policies and regulations that dictate specific procedures to be followed. The Oregon Occupational Safety and Health Administration (OR-OSHA) has had regulations covering wildland firefighters since 1988. All forest activities workers who may be called upon to fight wildfires in Oregon must receive the minimum basic training as stated in the safety code (OR-OSHA 2003). This applies to both logging crews and professional contract firefighters. For fires resulting from logging operations, Oregon Revised Statutes (ORS) require logging contractors to provide a "reasonable effort" in suppressing fires occurring on the operation (ORS-477). Often this requirement is the justification for modifying older equipment to have at hand for fire emergencies.

Various other issues surface when private employees become involved with a government agency for firefighting. Firefighting for the agency requires more documented training, knowledge of fire behavior, and integrating into the Incident Command Structure (ICS). In order to coordinate fire suppression, government standards often required of private workers to maintain a level of safety across the complex fire organization. This may create confusion about responsibilities among those involved in the multi-employer work arrangement.

The Initial Attack situation is an emergency allowing agency management to bypass lengthy training and safety requirements to immediately utilize loggers as suppression resources. However, after a certain time—often the end of the first shift or beginning of Extended Attack— the logger is then required to meet the agency standards. This will involve additional personal protective equipment (PPE) such as *Nomex™* clothing and fire shelters. More demanding training standards must also be met. The actual requirements depend on the agency with jurisdiction on the fire. Rationally resolving conflicting requirements will determine whether the fire is extinguished or grows out of control.

Incorporating loggers and logging equipment for fighting wildland fires is slowly taking place within the government. The "Big Iron" project, in the Northern Rockies Region of the US Forest Service, has provided an inventory of machines including their rates and uses (Steele et al. 2003). There is also progress towards including the logging machinery and potential uses in fire suppression tactics courses. In addition, specific criteria have allowed better inspection of equipment offered for federal fire suppression contracts in the Northern Rockies Region.

Conclusion

Society needs more sophisticated tools and systems for suppressing both large and small wildfires. Recent trends indicate logging machinery potentials are becoming recognized to increase safety and efficiency. The government and private sectors are slowly learning how to work together, but more progress is needed to increase understanding and knowledge between the groups. Wildland fire suppression is a complicated system to comprehend. The study attempts to identify the pertinent issues, provide a problem definition, and identify research needs for advancing efficiency.

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Loggers and Bureaucrats: A Strategic Partnership Improves Accident Recording and Safety Education

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Abstract: A strong interest has developed throughout the USA to reduce logging accidents and assist loggers with safety programs. Driven by accident costs, liability issues, a desire to improve public image and the threat of additional environmental regulations, the forest products industry has developed a proactive role in assisting loggers with the education they need to reduce accidents while improving the quality of their work.

The analysis of a logging accident database from the Louisiana Office of Workers' Compensation provided useful information, but the resolution of detail is limited because only the most severe accidents were reported and because the categories are generalized to apply to all industries. In an effort to maximize use of resources, the Occupational Safety & Health Administration (OSHA) extended a "Strategic Partnership Agreement" to the logging companies in the state of Louisiana. One of the components of this agreement is that participating logging companies must submit all of their accident reports to researchers at the Louisiana Forest Products Development Center. The results include a better knowledge of the characteristics of logging accidents, a discovery that fatal accidents tend to be different from non-fatal accidents, and participation by state and federal OSHA personnel in the safety and regulations workshops. The effort resulted in an award from the Assistant Secretary of Labor for OSHA.

Introduction

The forest products industry is plagued with high worker accident rates. The problem is worldwide, and the United States is no exception. Nationwide, about 140 loggers die on the job annually (BLS 1999). Logging is one of the most dangerous of all occupations, with death rates similar to those of policemen and helicopter pilots, and with accident rates similar to miners and construction workers (BLS 1995).

OSHA Partnership

A recent development at the federal Occupational Safety and Health Administration is a program termed AOSHA Partnership.@ In each state, OSHA is targeting an industry that is particularly troublesome from a safety point of view and offering a APartnership Agreement.@ It is hoped that these agreements will result in more efficient use of resources for both industry and OSHA. In Louisiana, this offer was made to the Louisiana Logging Council. The agreement was signed 17 May 2000, and

could easily be the first such agreement made in the country. It was implemented immediately

OSHA plans to randomly select at least 5% of the logging companies in Louisiana and conduct compliance inspections (with or without the partnership agreement). Under the terms of the OSHA Partnership agreements, logging companies can voluntarily sign up with the program. These companies will submit all of their accident reports to the Louisiana Logging Council for summary evaluation by the author and OSHA. Based on the findings of these accident analyses, the Louisiana Logging Council will formulate and conduct training sessions that target the problem areas. When OSHA conducts its random inspections of the logging industry, it will perform only a Atargeted@ inspection if the logging company happens to be a member of this Partnership Agreement. The targeted inspection will focus only on those aspects of the safety program covered in the training. If the logging company did not sign on with the Partnership agreement, it will receive a complete inspection from OSHA, presumably resulting in more violations found.

By August 2000, 185 logging companies had signed up. Approximately 60 of these submitted accident reports for 1998 and 1999 (de Hoop and Lefort 2000). By the end of 2001, 232 companies had signed up.

In January 2001, the Louisiana Logging Council requested the loggers submit their accident reports for 2000. The response was almost zero. As a result, two changes were made to the system. The authors created an accident report form that was as simple as possible and requested only the most critical information. The executive director of the Louisiana Logging Council mailed this form to each Strategic Partnership member and followed up with a telephone call to each member.

Of the 232 Strategic Partnership members, 127 companies actually submitted accident reports in January 2002 (for 2001). They reported 41 accidents. A substantial number of these were reported on the new forms. Others faxed copies of their insurance forms, OSHA 101 forms or OSHA 200 forms. Seventy-one percent of the companies reported having no accidents in 2001. The results were printed in the Louisiana Logging Council's quarterly magazine (de Hoop 2002). The results in January 2003 (for 2002) were very similar.

By January 2004, there were 258 Strategic Partnership members, of which 100 actually sent in their accident reports. Eighty of these reported having had no accidents. Twenty companies submitted 24 accident reports, including two that appeared to be fraud cases.

Since OSHA performs inspections after each work-related fatality, reports on fatal accidents were also made available for summary analyses.

Results

Much good information was extracted from an analysis of an accident database collected by the Louisiana Department of Labor, Office of Workers' Compensation Administration (Lefort et al. 2003). For example, although the overall number (and rate) of logging accidents in Louisiana during the 1990s is about half that during the 1980s, the rates do not appear to have declined significantly during the 1990s when late reporting is

taken into account. The decline in accident rates around 1991 follows a time period when many logging companies changed from manual felling (chainsaws) to mechanized felling.

During this time, there was a change in the most common types of injuries. The most common types of injuries in the 1980s were cuts. In the early 1990s, strains/sprains were the most common (sprains/strains are more expensive than cuts and require longer recovery times). In the late 1990s, fractures were the most common. Thus, the logging industry was following classical safety theory. As the industry became more mechanized, the number of accidents decreased, but the severity of the accidents increased.

While analyses of the government accident database provided much insight about the injuries and their trends, they provided little knowledge about the causes of the accidents. Such information would be crucial to the prevention of accidents. It was hoped that better access to the original accident reports would provide such insight. This was impossible with the Office of Workers' Compensation Administration database, because privacy concerns were strictly enforced.

Access to the accident reports submitted through the Strategic Partnership program provided new benefits. It was possible now to gain knowledge about less serious accidents. It also became possible to know more about the causes of the accidents.

For example, we knew there were many strains of the knees caused by falls. We did not understand why. From the developing Strategic Partnership database, it is readily apparent that 20-25% of the accidents occurred while mounting or dismounting equipment and trucks. Once this was understood, the safety training workshops were modified slightly to emphasize proper mounting and dismounting techniques. An article was written for The Louisiana Logger magazine. Mounting and dismounting were given added emphasis during routine OSHA safety inspections (both the observed actions of employees and records of training). This added emphasis seems to have worked, as mounting/dismounting accidents declined to roughly 10% in 2002 and 2003 (mostly with truck drivers).

Another example is the difference between fatal accidents and non-fatal accidents. Fatal accidents are often omitted from the Office of Workers' Compensation Administration database. While non-fatal accidents tended to be related to performing maintenance, mounting/dismounting equipment and binding/unbinding logs on trucks, most fatal accidents occurred during manual felling activities. All of these were the result of limbs or snags falling on the faller. It is believed that improved employee training is needed on this topic. Set hands (chainsaw operators who trim logs between skidding and loading) are also highly vulnerable to fatal accidents. They get run over by a skidder or its drag when a skidder operator fails to notice their positions. However, some of the fatalities were also related to repairs.

The Strategic Partnership accident database also provides better information about the occupation of the injured worker (and others involved in the accident). Previously, only truck drivers could be separated by occupation (20% in the OWC database). With the Strategic Partnership database, more occupations can be discerned (Table 1). In nearly all cases, equipment operators were injured while they were outside of the cab – most commonly while performing repairs or maintenance.

Summary and Outlook

The forest products companies like to have an Aarm's distance@ relationship with logging contractors to avoid legal and tax problems with the issue of contractor versus employee relationships. However, the expenses associated with logging accidents have become so severe that it has become obvious that a cooperative venture by all interested parties is needed to propagate a solution. At the same time, the companies and landowners are realizing that a greater level of professionalism is needed with all workers performing silvicultural activities.

Most of the safety training to date has been basic. Future training in logging safety is likely to be more in-depth on areas that are particularly troublesome. The industry will need to be monitored more closely to detect whether the training is producing the desired results. This will require even better accident reporting mechanisms than are in place today. The OSHA Strategic Partnership program in Louisiana is a major step in that direction.

The Strategic Partnership program as implemented in Louisiana with the logging industry has received the attention of upper management in OSHA in Washington, DC. As a result, the major players in the Strategic Partnership received an award in September 2002 from the Assistant Secretary of Labor for OSHA (the highest administrator in the organization). This award was not given because of the improvement in accident rates. These people realize that accident rate can be very fickle. This award was given because of the strong cooperation among various unrelated entities – industry, industry associations, federal government, state government and academia. Such cooperation among disparate entities can happen only when each participant has something to gain and is willing to give the agreement its highest priority.

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Table 1. Occupation of injured loggers participating in the Louisiana OSHA Strategic Partnership Program.

OCCUPATION	1998-1999	2001	2002	2003	Total	% of Total
FALLER	6	1	1	1	9	6%
SAW HAND	5	4	8	4	21	15%
CUTTER OPERATOR	2	7	7	3	19	13%
SKIDDER OPERATOR		1	5	6	12	8%
LOADER		5	1	1	7	5%
DE-LIMBER				1	1	1%
CHIPPER				1	1	1%
MECHANIC		3	5	1	9	6%
TRUCK DRIVER	8	11	11	4	34	24%
BOSS	2	3	4	2	11	8%
DOZER		2	0	0	2	1%
MACHINE OPER Unspecified	12	3			15	10%
TRIMMER	3				3	2%
TOTAL	38	40	42	24	144	100%

HOW TO IMPROVE TRANSPORTATION EFFICIENCY AND COST A WSRI PROJECT

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Abstract: This study is the fifth project to be funded by the Wood Supply Research Institute (WSRI). WSRI is a group of forest products companies and loggers organizations that are working together to address wood supply issues to the benefit of both companies and independent loggers. The objective of the study is to describe how trucking operates now and to explore ways to improve the productivity, efficiency, safety and cost of the transportation portion of the wood supply system. Field surveys and truck data will be collected to determine the current condition of the fleet. Simulations will be done to determine the feasibility of a third party, independent trucking contractor.

Objectives:

The objective of this study is to explore ways to improve the productivity, efficiency, safety and cost of the transportation portion of the wood supply system. The study will be organized into three sections: Equipment, Logistics, and Safety. Past studies will be evaluated to determine the state of the art and look for opportunities not examined. Current practices will be observed to evaluate the effectiveness of various methods in use. Site visits and surveys will be used to identify promising techniques and assess logger's attitude. Simulations will be used to determine the cost effectiveness and productivity gains of proposed changes to the transportation system. Coordination of truck flow (including possible staging opportunities) and payload efficiency through weighing systems and equipment improvements will be primary areas of study. Safety measures will also be suggested to improve the public image of logging and as a means to reduce insurance costs.

Proposed Methods:

For each section (Equipment, Logistics, and Safety), an extensive literature review will be performed and the benefits determined from past studies will be highlighted. A survey of loggers will be developed to gather information for all three sections. Computer simulations will be run to evaluate some of the recommendations and test their feasibility in today's business environment. Finally, field visits to various operations with improved transportation ideas will be completed to benchmark the benefits. The following is additional details about the three sections:

Equipment – Through the Fleetsmart program in Canada, FERIC has implemented optimal logging truck configurations to reduce tare weight and improve fuel efficiency. Trucks with optimal configurations achieved a 9% increase in payload and a savings of $0.70 per ton for an average haul when compared to a typical tractor-trailer.

Results of a 2003 limited survey in east central Alabama found that tare weights of the lightest tractor-trailers in use were 6-9% lighter than the median unit. Options implemented by FERIC such as aluminum components in the truck and cab were already implemented on 50% to 80% of the tractor-trailers in east central Alabama. Other components such as GPS and navigation systems, on-board computers, on-board scales, single frames, aluminum wheels, super single tires, smaller horsepower engines, and light weight trailers have been implemented at a lower rate.   Limits to acceptance of some technology are presumably due to questions about durability in harsh logging conditions, return on investment, products hauled, and truck driver and owner preconceptions.

To evaluate truck and trailer technology and components, the research team will network to find truckers implementing specific technologies and document their experience. Data collected will include the tare weight, downtime, maintenance costs and ownership costs for each location to determine the benefit to each operation.

Optimum tractor specifications for given conditions will also be determined from data collected from field visits or output from onboard computers when available. Data will be collected on the range of truck operating conditions, such as round trip distance, road quality, speed and slope distribution. From these data, specifications will be generated on the lightest weight tractors available that will perform in specified conditions. The use of this equipment will be validated by identifying similar tractors currently in service and documenting to the extent possible average payload, downtime, maintenance costs and ownership costs.

Logistics – Efficiency of log transport in the South could be increased greatly through application of modern logistics technology. The current practice of dedicating tractor units to a particular logger maximizes the total number of miles driven to deliver a given quantity of wood and often leads to underutilization of trucking resources. Under some circumstances, having too few trucks assigned can lead to underutilized harvesting equipment if it sits idle waiting on wood already processed to be loaded and delivered. Random arrival times at mills can lead to extended waits at the woodyard. Coordination of pooled trucking resources, if managed properly, would eliminate most of these types of inefficiencies, but the forest products industry, and the logging community in particular, has been reluctant to adopt this strategy. One objective of this study is to document reasons why loggers have not adopted this approach and to propose a business model for a trucking company that satisfies most loggers' transport needs. A survey of loggers will be conducted to assess their willingness to turn over log transport functions to an independent trucking contractor. The survey will include questions on current transport practices, fleet size and equipment, safety and employment records, variations in transport distances and delivery volumes, maintenance practices and schedules, and general expectations for trucking fleet performance. Loggers and trucking firms using automated dispatch and GPS technology will be asked to share information on truck turn time variations as a function of distance, time of day, and road and weather conditions. In addition, we will review practices of other trucking fleets using modern logistics technologies (e.g. Federal Express) and integrated wood transportation systems in other countries, particularly Scandinavia. The review will identify key technologies that could be adapted for use by WSRI members and serve to establish benchmark performance

criteria for log transport in the region. All survey results will be used to develop a report on the present state of the art in log transport.

Given some knowledge of the performance of trucking under current practices, the next objective of the project will be to investigate how best to configure a transport system to serve the needs of participating loggers and deliver wood at lowest cost. It is expected that performance of a pooled transport system, while cheaper than traditional trucking approaches, will be affected by numerous interacting factors making generalizations about efficiency gains achieved through pooled transport difficult to make. We will therefore create a flexible analysis tool to evaluate performance of pooled trucking systems in general, then apply 3-4 scenarios that cover the circumstances of most loggers responding to the survey mentioned above. Scenarios will vary number and location of mills and loggers, as well as product mix, delivery schedules, weather disruptions to wood flow, and capacity, traffic, and delays through mill woodyards. Dispatch and routing of trucks will be controlled using alternate objective functions. In one instance, the dispatch algorithm will route trucks to loggers based on minimization of total unloaded miles. This approach, however, may not satisfy time constraints of individual logging contractors who could be caught waiting for a trailer to load, and also potentially cause non-uniform flow of wood into the mill. We will therefore also look at heuristic dispatch methods that 1) attempt to minimize logger wait times, and 2) perform some sort of combined optimization that considers mileage as well as serving mill and logger needs. Model outputs will, to the extent possible, be verified against existing log truck productivity data. Results will include a report on expected relative gains in trucking efficiency given a range of conditions, plus recommendations on how to structure a trucking business to best serve consuming mills and loggers. The report will also identify existing communication, status tracking, and routing/scheduling technologies available for transportation fleet management. Estimates will also be made of the incremental cost for managing truck scheduling, and savings realized from sharing maintenance facilities and personnel.

The simulation approach taken in this study will provide a low-cost, general method by which we can identify key variables affecting log transport, study their relative importance, and predict expected gains in transport efficiency. We propose to modify existing models for truck allocation to satisfy the needs of this study. We have on hand simulation models that can be updated to include pertinent objectives, as well as extended to include optimization algorithms to perform mileage minimization tasks. Any additional development of objective functions will be done using the expertise of faculty skilled in optimization techniques. The final models will be compiled, documented, and made available for use by interested parties, either in the form of a stand-alone application or a web-based tool for comparing alternative schemes in setting up a pooled transport system.

Safety – Any method implemented to increase efficiency of the log truck fleet is likely to lead to improvements in safety. Decreasing the number of miles driven by log trucks are likely to result in the following: 1) a reduced risk of involvement in incidents or accidents, 2) a reduced number of poor drivers through decreased employment, 3) an improvement in training of the remaining drivers and better compliance with Federal

Motor Carrier Regulations since centralizing trucking should lead to economies of scale in training and record keeping, and 4) a greater investment in modern trucks and trucking technology. Two surveys completed in Alabama in 2000 and 2003 indicated that the median tractor was 8 years old and 20 and 30 year old tractors are not uncommon.

General trucking industry statistics can be obtained from a variety of sources. The Vehicle Inventory and Use Survey for 2002 (Economic Census) may be available during the project term; 1997 and 1992 are currently available. For instance, in 1997 the survey reported that for the United States, 119,000 trucks hauled logs or forest products and traveled 3.7 billion miles. Safety implications of changes in the transportation system may be estimated using Federal Accident Reporting System (FARS), and the Motor Carrier Information Management System (MCMIS). FARS compiles data on fatal crashes and MCMIS compiles information on companies subject to Federal Motor Carrier Safety Regulations. More complete information on log truck accidents maybe compiled on a state by state basis through the states' Department of Transportation or Public Safety.

Auburn University has participated in truck driver training and analysis of the driver risk based on personal characteristics and driving history. Brian Carnahan, Ph.D. (Department of Systems and Industrial Engineering, Auburn University) has previously compiled and analyzed trucking safety information and has agreed to consult or become involved on this project as needed.

Expected results:

The final report will be divided into the three sections: Equipment, Logistics, and Safety. Each section will document the literature in that area, describe the system used as a benchmark and detail the strategy and methodology that has the potential to provide an improvement in productivity, efficiency, safety and cost. An estimation of the cost impact of implementation for each recommendation will also be included along with an analysis of the "road blocks" to implementation. Results will be in a format that will allow easy publication of information.

Lessons Learned from Logging Litigation

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ABSTRACT - From the author's experience with more than twenty-five cases involving logging accidents over thirty years, lessons are distilled for forest engineers, loggers, foresters, machine manufacturers, and others in the public and private sectors. The frequency of accidents and litigation may mean professionals may be involved in legal actions during their careers. Safety lessons, operating procedures, machine design, and human factors issues are all involved in the accident scenarios illustrated in the ten lessons examined.

1. Bizarre does happen
2. Time is of the essence
3. Ignorance is not an excuse
4. Location is everything
5. First cause may not be correct
6. Competence counts
7. Designed to damage
8. Hazards may be known
9. Deep pockets are the cause
10. Attack the expert

Both the negatives and positives of litigation are reviewed from the perspective of cause and effect for accidents as opposed to correctly or incorrectly finding fault during the process.

INTRODUCTION

The following lessons are derived from the author's experience with more than twenty-five cases involving logging accidents. These cases involved various work activities such as felling, yarding, loading, hauling, and machine operation. Various harvesting systems were in litigation including helicopter operations, mechanized harvesting, cable yarding, tractor skidding, and manual or mechanized felling. The geographic area of cases spans the West Coast including Canada, the South, and midsection of the United States. In about half the cases, the author has served the plaintiffs and served the defendants for the remaining half. The author was paid for his time providing services not on the basis of the settlement amount. In addition to the cases that moved forward to filing suit, the author has provided assessments to attorneys that established cause and effect of the accident that resulted in dismissal of the case or acceptance of an offered settlement. Specific case citations are not provided in this treatise as some are protected by confidentiality agreements while others may be still in process.

Without appearing to suggest practicing law without a license, readers might benefit from looking up a few key concepts. Various websites are listed in the sources. The difference between a "preponderance of evidence" (civil cases) versus "beyond a reasonable doubt" (criminal proceedings) is important in the "adversarial" system of law in the U.S. When a case is settled, damages may be "compensatory" (medical, lost wages, pain, etc.) or "punitive" (penalty for outrageous behavior). Product liability along the "chain of manufacture" may be from "negligence, strict liability, or breach of warranty of fitness" due to "design defects, manufacturing defects, or defects in marketing." More importantly, it may be better to avoid litigation with "alternative dispute resolution" procedures such as "arbitration, mediation, or settlement hearings." Finally, the outcome of litigation (or avoidance by settlement) may depend on the "jurisdiction" or even on the judge assigned to try the case. (www.cornell.law.edu, accessed on March 20, 2004)

1. Bizarre does happen

Work in the unpredictable environment of the woods leads to unexplainable events. Three timber fallers show up to work on a windy day and sit drinking coffee in the pickup after deciding it is too windy to work. A tree falls on the pickup lengthwise killing the middle faller and leaving the others shaken but unhurt. Who is to blame? A sawyer cutting firewood on a hillside kicks a short segment out of his way and it travels more than 800 feet down and across the slope striking another sawyer cutting a tree in the back of the neck killing him. Is the helicopter

company that flew logs from the area and left some trees unyarded a party to the litigation? A sawyer topping trees is found unconscious with a broken hardhat and a 4" diameter by 8" long chunk of Sweet Gum nearby with hardhat color paint on it. The nearest "Hot Saw" was working over a football length away, but what happened? The first two events are not explainable to me but investigation of the last one showed, circular saws can throw objects considerable distances. Nonetheless, the strange and bizarre does happen in logging accidents.

2. Time is of the essence.

When someone is hurt in the woods, the first priority should be to get the injured treated and hospitalized. With due consideration to the trauma suffered by others not injured but involved in the incident, it is important that potential evidence be preserved by photos, measurements, and interviews. Litigation may occur from three to five years after the event. Machines are often moved as soon as the victim is taken away, and as time passes, physical objects change, rot, disappear or are burned over. It may be no surprise that memories of the event change over time itself and with the prospect of a multi-million dollar lawsuit affecting a family member or former co-worker.

Prompt and effective accident analysis ("investigation") is needed immediately after the accident to the degree that the author offers courses on the topic (Garland, 2003). State and federal safety standards require reporting fatalities, accident investigation and preservation of evidence (OR-OSHA, 2003). While it is still possible to establish cause and effect relationships for logging accidents five years after the event, it is much harder without good accident analysis at the time.

3. Ignorance is not an excuse!

Not knowing the correct ("legal requirement") action to be taken to avoid accidents is not a defense the courts readily accept. Logging is dangerous and in some jurisdictions, some tasks are considered "inherently dangerous" and require a higher standard of precautions to avoid accidents. Employers with accidents are often found to provide little or no training to new and green employees, yet place them in highly hazardous situations such as a rigging slinger with two weeks woods experience (fatal result). Employer training requirements are well established as necessary for logging.

Organizations that employ loggers cannot transfer all accident responsibilities to contractors through the contract, especially if those contractors could really be considered "employees" (contractor test of independence). Landowners have been held liable for logging injuries when they require unsafe actions or fail in their due diligence to stop a known unsafe act or condition to remain untreated or allow an incompetent to do their logging. For the US Forest Service, conflicting contractual documents and Washington Office directives leave a trail of confusion.

Manufacturers have substantial obligations for the products they manufacture and put into the "chain of manufacture" extending obligations to assemblers, wholesalers, and retailers as well. Claimed ignorance of the product hazards or the loss of design information (e.g., files dumped when one company takes over another manufacturer) are viewed negatively by courts, and settlements may include "punitive" damages.

It is indefensible not to follow the Federal or state safety regulations that govern the logging industry. Further, failure to follow the engineering or product manufacturing processes typical of the industry leaves organizations vulnerable. The standard is to follow the "usual and customary practices" of the industry, as a "prudent" person would do.

4. Location is everything

The physical location of the accident and the relational positions of key people and objects during the accident are fundamental to explaining what happened. Yet I have seen opposing experts armed with photos and GPS coordinates take nice walks in the woods and never actually visit the site of the accident. In another case, the expert made it to the landing but not the 500 feet down the hill where the accident occurred. Other experts in warnings/labels only need to see photos of the decals from the machine to assess liability. In my judgment, an expert who has not been to the scene of the accident cannot render an effective opinion about the cause of the accident. Good location (witnesses and measures, not GPS), physical measures and references along with photo images are needed for accurate accident analysis after the fact.

5. First cause may not be correct

When an accident occurs, it is a natural human process to speculate on what "caused" the accident. People involved in the event (and those not even close) offer their opinion of the cause without prompting. Offerings such as "the downdraft from the helicopter caused the snag to fall on the man" take on a life of their own. They can cloud the true cause which in this case was a windfall entangled in the turn that struck the snag at the base causing it to fall on the man. In another case, a federal safety inspector made a video showing many safety violations and implicated many and all factors as the cause of the accident but the true cause was unrelated and due to a known improper rigging practice for cable yarding.

In the event of a fatality, there will be several records that call for the "cause of death" by those who complete the form. Paramedics, attending physicians, law enforcement personnel, safety investigators, and coroners may make statements that may be confusing later. It is essential that cause and effect be established for logging accidents if at all possible or three bad events happen:

- The wrong party is punished or exonerated
- The source of the accident continues unabated
- When the true cause may be established later, there is little motivation to correct the problems

It is difficult to get an accurate description of what happened during an accident and litigation to establish the truth is hampered by "utterances" of what caused the accident.

6. Competence counts

Parties associated with the litigation may be knowledgeable but considered biased by the courts. Attorneys on both sides need objective analysis and advice during litigation and trial. Experts abound! Litigation is the basis for part of the consulting industry. Attorneys may seek experts willing to provide reports favoring their positions, although I have never worked for one. Some experts are known as "plaintiffs" or "defendants" experts. There is even a secondary industry of firms who seek out and retain/list experts for trial attorneys.

Courts qualify experts during trial but judges are not logging experts and allow much latitude for an "expert." Opposing experts in logging have been:

- A forest products professor with expertise in wood anatomy who once had to teach a harvesting course in the university
- A tree surgeon who said rotten trees can be cut down in pieces (without ever examining the tree in question)
- Retired industry and agency foresters without experience in logging or engineering
- Various self-taught felling experts or engineers who have hardly cut a tree
- "Safety Engineers" unfamiliar with the work environment in the woods

The "preponderance of evidence" required in civil cases does not depend on the number of experts on each side but rather on the credibility and weight of the evidence provided by an expert to the judge or jury.

On rare occasions, the court may retain an expert of its own to provide technical counsel. Good experts spend time educating attorneys on the issues themselves so they can ask the correct questions in depositions (or experts may provide appropriate questions for depositions). Experts may even be called on during settlement procedures for relevant information on accident causes.

7. Designed to damage

At times, accidents result from problems with the design of the machine or the logging operation itself. For ordinary product liability, users have some responsibility to follow instructions on the use of the item. However, strict liability does not depend on the degree of carefulness; such product liability makes a defendant liable when it is shown that the product is defective. Even if the manufacturers or suppliers exercised great care, but there is a defect in the product that causes harm, they will be liable for it. Defects can be in the original design, defects resulting from manufacturing or assembly, or from failures to warn users of hazards or to properly instruct them on how to use the item. I have seen cases where valves in the holding arms of feller bunchers open without the operator's knowledge (they were designed to open at preset pressures to avoid machine damage). Circular saws were known to need guarding from thrown objects but such guards were not part of final designs. Finally, most manufacturers are so cautious in giving operating instructions that they mostly cover machine maintenance functions and not how to use harvesting machines. Warnings and labels are a science unto themselves as to their effectiveness.

Measures to affix responsibility are complicated when many logging machines are the composite result of a base carrier modified for logging and outfitted with attachments by several independent manufacturers. Cabs and controls may be separate added features, and there may be no final assembler other than the shop of the purchaser. Where is the blame when the machine fails to perform?

Harvest units that are poorly designed with un-addressed hazards (e.g., danger trees), or inadequate roads or landings leave landowners/managers with liability. Efforts to transfer safety responsibility to contractors rests in part on the landowner's flexibility to address hazards and their willingness to cooperate on safety measures. Some public agency timber harvesting contracts are rigid when it comes to modification. Court decisions continue to develop precedents in this area for landowners.

8. Hazards may be known

Logging accidents follow certain patterns over time. For example, the following statements are born out by statistics (Sygnatur, 1998) and my experience:

- It is the new and untrained workers that are involved in accidents (although not always their fault)
- Transportation of products (loading & hauling), workers and driving are hazardous
- Manual felling is the most dangerous task
- Workers are injured when they are not "in the clear" or too close to the hazardous operations of machines
- Danger trees and snags are hazardous for workers
- Workers injure other workers when one or the other does something unexpected

Novice workers are at risk in such occupations as cable yarding, felling, using a chainsaw and working around equipment. Courts recognize the need to train someone before turning them loose to do dangerous activities. Logs can fall from a log truck at any time, loads shift during transport, and woods roads are not designed for highway speeds. Specific procedures are required to successfully cut a tree in the proper direction with either a machine or a chainsaw. I had the first five trees I cut with a feller buncher fall on the machine because I could not catch them after I sawed through them.

Many accident investigations show workers would not have been injured if they had moved further from the hazard by ten feet or ten inches. Staying within reach of falling trees, up-ending logs, machine movement, or flying objects is the result of poor decision-making or risk taking by many workers (also poor supervision). They may be affected by fatigue or false notions of time savings.

Danger trees and snags are part of the woods environment, and working around them safely is necessary at times by reducing the time workers are exposed to these hazards. It is simply not possible to remove all snags from the worksite in the forest.

Teamwork allows workers to expect what other team members will do in specific circumstances, where they will be located, and what to watch for to keep them safe. Breakdowns in expectations or failures to communicate can cause workers to injure or kill their own work mates and suffer the deep guilt associated with such accidents.

9. Deep pockets are the cause

It seems a prevalent notion that big corporations are just in it for the profits and they can pay when they cause accidents! Forest landowners are portrayed as "Timber Barons." And only the rich can afford expensive logging equipment; therefore, they must have "deep pockets" to pay for logging accidents. The litigious society we live in is fueled by such ideas including television news and commercials depicting successful lawsuit victories. Cause and effect for accidents get lost when an individual injured worker is in a jury trial pitted against the US Forest Service, a corporate timber purchaser, and a logging company that owns lots of trucks and equipment. Insurance policies (or the taxpayers) are seen by plaintiffs to be the minimum settlement awards because some defendants are often reluctant to go to trial for fear of "runaway jury" awards.

There is also a "divide and conquer" strategy in multiparty suits where plaintiffs will settle at the insurance level of one of the parties and use the funds to support litigation against those with deep pockets. The linkages of liability can be tenuous such as when claims are that the corporate timber purchaser put so much pressure on the individual timber faller for production that he did not have time to look up and see the tree lodged in the tree he was cutting (thus, he was not responsible for his injuries). Alternatively, there are claims that the successor holding company to a skidder manufacturer (no longer in the logging equipment manufacturing business) is alleged to be liable for defects in a seventeen-year-old skidder that had been wrecked twice and rebuilt. Only vigorous defense of unfounded claims will help reverse the social trend for successful suits against "deep pockets."

10. Attack the expert

If suits come to trial or when depositions are taken, those who offer expert opinions can expect to come under intense scrutiny. If the stakes are high, experts will be personally investigated, all prior writings will be reviewed for inconsistencies, and qualifications will be questioned. Forest Engineering as a discipline is not understood by attorneys and its validity comes into question routinely. I have spent considerable time in depositions explaining Forest Engineering as well as demonstrating that logging is based on physical principles and not uncontrolled forest exploitation by low-level operatives.

At trials in front of a jury, it is a tricky situation when attorneys are hesitant to attack experts in cross-examination because juries might end up disliking the attorneys themselves. But sometimes attorneys can't help themselves, and they attack experts in court by trying to make them look incompetent, misleading, or just in it for the money. In a trial where I once spent the entire day on the witness stand, responding to such attacks to my compe-

tence, my character, my profession, and my unwillingness to give the answer desired, the old Bailiff (who spent his life in court) told me, "You were the best witness I've ever heard." I count that as high praise, but don't relish the next deposition or trial. Beware! A subpoena can bring any professional to court for the same treatment!

SUMMARY

Litigation can be costly to U.S. society and may result in "incorrect" decisions based on later findings. However, the law levels the playing field between the powerful and the injured and seeks to establish the truth or accident cause. For the cost of lawsuits added to product prices, there is some balance in that suits may deter defective products from coming into the market. Case law evolves for logging litigation and may help future courts achieve some measure of justice if the process is effective at establishing cause and effect in accidents and the associated liability.

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Using Synthetic Rope in Forest Operations:
End Connector Concepts

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ABSTRACT – This paper examines the end connections and terminations used for the application of ultra-high molecular weight polyethylene synthetic rope in timber harvesting. Because of material properties, end connections typical for steel wire rope are not readily suitable for synthetic rope. New end connection concepts and techniques were developed to withstand the rigors of forest operations. Results of end connector break tests and the common failure modes for selected end connections are discussed from current research of the Synthetic Rope Project at Oregon State University.

INTRODUCTION - Currently, wire rope is used universally in timber harvesting for skylines, guylines, winchlines, support lines, truck wrappers, chokers, and running lines. It has advanced cable logging and it is employed around the world in millions of miles annually. However, wire rope is heavy, corrodes, and is difficult and time-consuming to splice. Additionally, used wire ropes develop jaggers that puncture the hands of woodsworkers.

The opportunity exists to replace steel wire rope with ultra-high molecular weight polyethylene (UHMW-PE). The braided rope has the strength of steel, lower weight, low stretch, and high flexibility. UHMW-PE rope has a higher breaking strength to weight ratio than steel wire rope by a factor of ten for breaking strengths when compared diameter by diameter for steel wire rope. Synthetic rope does not kink, corrode, or absorb chemicals and water. UHMW-PE braided rope has proven itself in the offshore drilling, mooring, tugline, and powerline industries. The US Navy (Flory et al., 1992) and Canadian Coastguard (Fisheries and Oceans Canada and the Canadian Coast Guard Search and Rescue, 2000) have approved it for use within their maritime operations and deep-sea salvage.

One of the major difficulties with synthetic rope is using it with existing harvesting systems and adapting it to current end connections. Because of the low coefficient of friction, standard wire rope clamps, fist grips, etc. that would yield 90%+ breaking strength with steel wire rope, only yield 50-60% breaking strength with synthetic rope (Garland, et al., 2002). Synthetic rope has a much lower critical temperature compared to steel rope and is thus intolerant of heated connections. Finally, the low coefficient of friction makes pressed connections difficult. Essentially, the rope's physical, chemical, and mechanical properties make it an excellent substitute for wire rope in timber harvesting, but these same characteristics make it difficult to couple with existing cable systems.

Although some steel wire rope end connections are not suitable in their traditional form, the concepts may be modified for synthetic rope. Wire rope clamps and pressed nubbins are two examples of adapted technology. Splicing an eye is one of the most common end connectors for wire rope. However, splicing steel wire rope is tiring, cumbersome work. Synthetic rope manufacturers have developed quick splicing techniques that yield nearly 100% of the rope's ultimate breaking strength. For this project, new end connections were developed to meet requirements unfulfilled by splices or modified wire rope hardware.

The OSU research was the first extensive study on end connections specifically designed for synthetic rope. The objective was to determine suitable end connections and terminations for use with synthetic rope in logging. This study assesses the strength of the synthetic rope end connections under cycled loading at ambient temperature. Without proper end connections and terminations, synthetic rope's advantages over steel wire rope cannot be fully appreciated in the woods.

METHODS - The pilot study determined which concepts are suitable for use in timber harvesting. The study design required rope samples of the diameter classes common to many logging applications: 3/8", 9/16", and 5/8" diameters were tested. However, only the 9/16" and 5/8" Amsteel®-Blue[1] diameter classes will be discussed in this paper.

The rope manufacturer identifies the buried eye splice as retaining the highest breaking strength when the rope is modified. It is a simple splice to construct and is used in all diameter classes, but specifically for the 9/16", and 5/8" nominal diameters. Figure 1A shows the eye of a completed buried eye splice. In this project, the buried eye splice was the control treatment, or benchmark to compare all end connector concepts and represents the ultimate breaking strength of the rope.
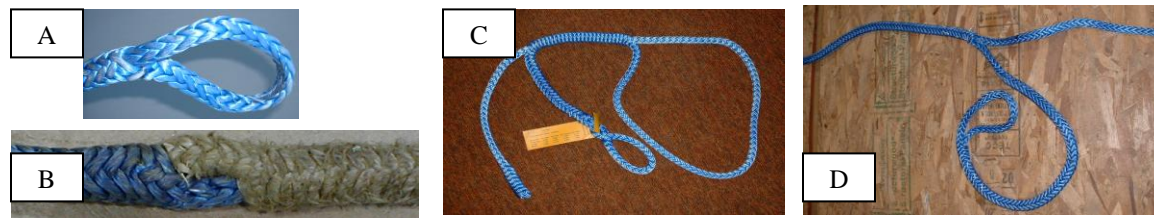

Figure 1. Spiced end connections: A) Buried eye splice B) Long splice C) Whoopie Sling D) Y-splice
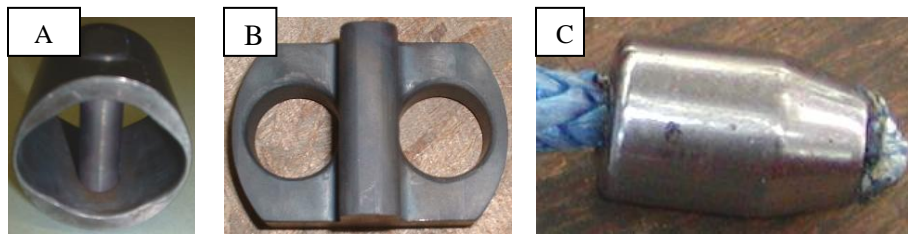

Figure 2. End connections with hardware: A) Pinned nubbin B) Knuckle link C) Pressed nubbin

All test specimens were prepared in accordance with Cordage Institute Standards CI 1500-99 §6 (Cordage Institute, 1999) and tested with the synthetic rope manufacturer's Test Methods for Fiber Rope (SRT Test Method-001-02) in the Knudsen Structural Laboratory in Richardson Hall at Oregon State University. The procedure was standardized for all end connector tests to reduce variability.

The following end connections were evaluated: buried eye splice, long splice, Whoopie Sling, Y-splice, pinned nubbin, knuckle link, and pressed nubbin. Figures 1 and 2 show these end connections. The buried eye splice, long splice, Whoopie Sling, and Y-splice were existing splicing techniques developed by the rope manufacturer. The knuckle link and pinned nubbin were designed by the researcher and fabricated specifically for this pilot study. The pressed nubbin was a straightforward adaptation of steel end termination techniques.

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[1] Amsteel®-Blue is a product of Samson Rope Technologies, Ferndale, WA. Mention of trade names does not constitute an endorsement by Oregon State University.

RESULTS TO DATE - As expected, the buried eye splice had the highest breaking strength of the rope splices. The buried eye splice averaged 50,187 pounds and 94% of the catalogue minimum value (CMV) in the 5/8" diameter and 39,377 pounds and 96% of the CMV in the 9/16" diameter (see Figures 3 and 4). The long splice is used to join two pieces of new or used synthetic rope together by burying tapered sections in each segment. The long splice was the next strongest splice connection at 47,354 pounds and 89% of the CMV for the 9/16" diameter and 38,314 pounds and 95% of the CMV for the 5/8" diameter.

The Whoopie Sling is an adjustable strap with an eye at both ends designed for static line applications such as guylines and intermediate support lines. It had mean breaking strengths of 85-86% of the CMV for the 9/16" and 5/8" diameters. Test samples were consistent for breaking strengths and exhibited a single failure mode. The Whoopie Sling broke at the exit point of the adjustable tail with the butt splice.

The Y-splice was developed as another solution to adjusting rope lengths to meet various job conditions. A Y-splice is a separate section of rope with an eye splice that can be inserted at any point on the main rope segment to change the length to fit particular requirements. For the 5/8" diameter, the Y-splice had a mean breaking strength of 36,438 pounds and 69% of the CMV. The 9/16" Y-splice performed more consistently than the 5/8" rope samples with and average breaking strength of 35,956 pounds, 89% of CMV. The issue with the Y-splice is its performance and consistency. The rope must be slowly and carefully loaded, so the main section of the rope can constrict and hold the Y-splice section. Without this practice, the Y-splice segment can simply pull out of the main section.
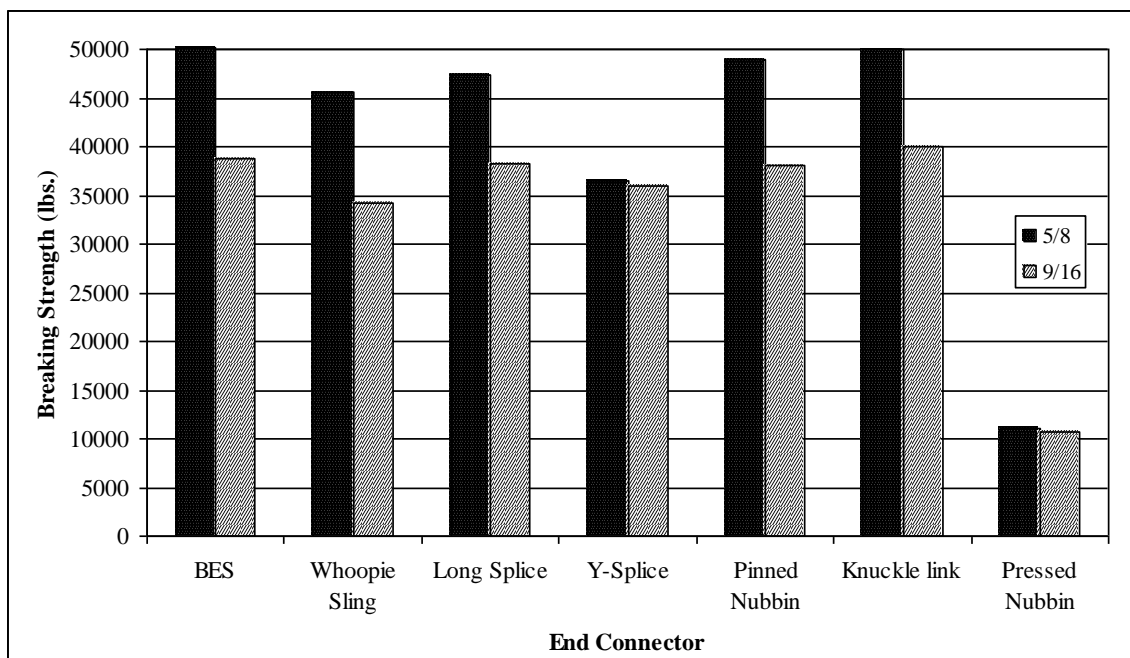

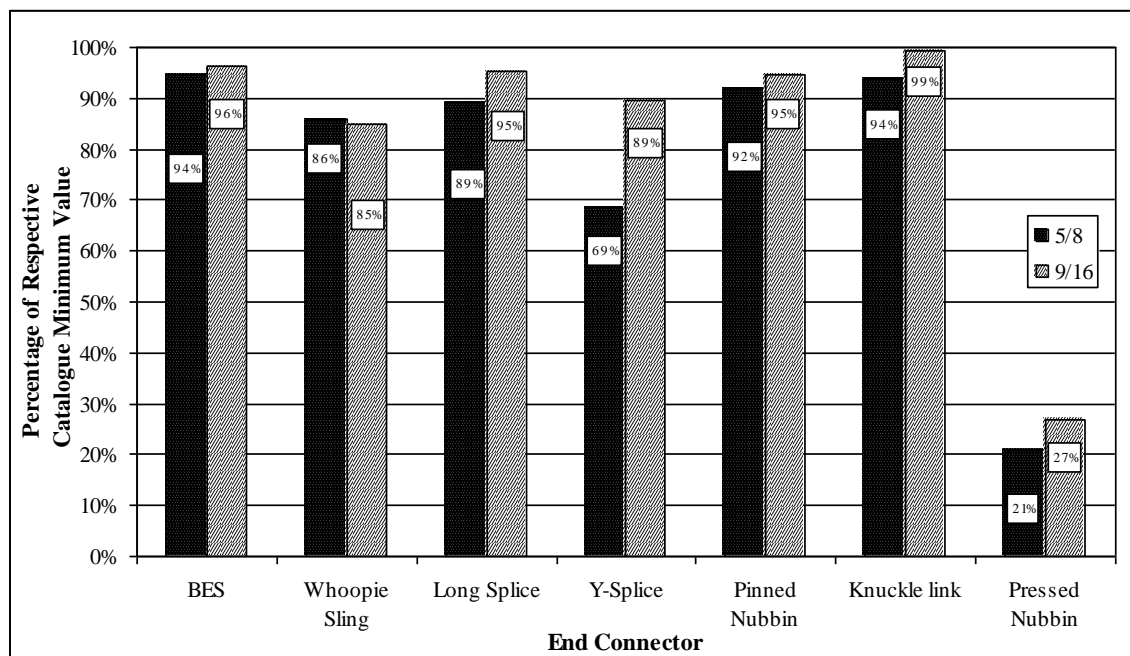*Figure 2. Mean end connection breaking strength*

Figure 3. Mean breaking strength as a percent of catalogue minimum value (CMV).

In addition to the four spliced end connections, three end connections with hardware were tested. The knuckle link had the highest breaking strength in the 9/16" diameter class at 39,944 pounds and 99% of the CMV. The pinned nubbin had a mean breaking strength of 48,868 pounds for the 5/8" diameter and 38,067 pounds for the 9/16" diameter, representing 92% and 95% of the CMV respectively. Both the pinned nubbin and knuckle link concepts performed consistently with low variability among the samples.

The knuckle link and pinned nubbin were designed to attach to the synthetic rope using an eye splice and for use with static and running line applications. For the knuckle link, as the rope is spliced, it is first passed up through one hole, over the bar, and passed back down through the other hole. When the rope is pulled, the strands of the rope are highly stressed, and the top of the eye becomes one of the common failure modes. The second failure mode common to the knuckle link and pinned nubbin is at the end of the splice taper.

Finally, the pressed nubbin concept was derived directly from steel wire rope applications where a hydraulic press compresses the steel nubbin onto the wire rope. A similar procedure was used to compress the steel nubbin on to the synthetic rope. The pressed nubbin for both diameter classes performed consistently to within a 5% standard deviation. Although consistent and a potentially useful end connection for use with breakaway drum connections, it only achieved 21% (11,066 pounds) and 27% (10,724 pounds) of the CMV for the 5/8" and 9/16" diameters respectively.

DISCUSSION - Six of the seven end connections show promise for use with timber harvesting systems. Other end connection concepts were developed and tested, but none consistently achieved more than 60% for both diameter classes. Other concepts tested were wire rope clamps and nubbins with adhesives. The adhesives were weak and inconsistent in breaking strengths. The wire rope clamps provided 57% of the CMV for the 9/16" and 65% of the CMV for the 5/8" diameters.

This study developed and tested different end connection and termination concepts suitable for timber harvesting. Not all end connection concepts tested achieved acceptable breaking strengths. Instead, the variability among end connections was substantial. Sometimes, the end connection that has the highest breaking strength may not be the most suitable for an operation. The pressed nubbin may be an option to attach the synthetic rope to tractor winch

drums. For example, if a load suddenly began to roll down over a cliff, the end connection on the drum should break before the skidder is upset.

Further research and development needs to be conducted on end connector concepts. This research has identified some suitable end connections for synthetic rope. Not all forest operations require maximum breaking strength for certain rope applications. End connections have been tested that break at lower strengths, but can be used in such systems. Some end connectors attain nearly 100% breaking strength of synthetic rope.

End connections and termination concepts from this pilot study have been developed through controlled laboratory testing and engineering analysis. Materials selected and fabricated for the hardware are not only essential to the strength of the end connection, but also to the safety of the workers. Furthermore, when fabricating hardware, one should know the material properties and the effects of welding and heat-treating. It is not advisable to simply use any material available, weld a bolt on, and put it into use in the field. Such actions jeopardize the safety of the entire crew. The rope manufacturer's splicing directions should be carefully implemented. In all cases, the appropriate safety rules should be followed.

CONCLUSION - Synthetic rope has many advantages that make it attractive to logging, specifically in static line and running line applications. Each application is governed by operating regulations, material and strength requirements. For current logging uses, it may be important that synthetic rope performance be held to similar standards as for steel wire rope. As with steel wire rope, the synthetic rope is only as strong as its end connection. It is therefore essential that suitable end connections be developed and tested.

This project was one of the first studies on end connections specifically designed for synthetic rope. New end connections were developed and steel wire rope connections were modified to meet the strength and usability criteria for timber harvesting operations. Future research should modify or refine the designs and test larger sample sizes.

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Comparison of Streamside Management Zone Requirements in the Southeast

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ABSTRACT

Streamside management zones (SMZs) are used in forestry to help improve water quality and to protect the integrity of streams. Other benefits include high quality timber, an increase in wildlife habitat and the potential for additional income to the landowner. Several studies have researched the benefits of SMZs, but few studies have addressed the most suitable amount of harvesting and silviculture treatment types within the SMZ. Using Best Management Practice (BMP) manuals, comparisons of the type of requirements, the amount of harvesting allowed, and recommended harvesting equipment used within these SMZs were conducted for the Southeast region of the USA. Requirements vary for each state depending on slope gradient, stream type, and special concern areas. SMZ widths range from 25-200ft. All southeastern states allow timber harvesting in SMZs and the majority of these states must meet residual density guidelines measured in basal area or canopy cover and specific harvesting treatments. Disturbance measurements vary from no requirements in a SMZ to allowing less than 20% bare ground. Harvesting equipment allowed with the SMZ range from prohibiting equipment within the SMZ to allowing all types of equipment in the area.

INTRODUCTION

"Streamside management zones (SMZ) are buffer strips adjacent to perennial or intermittent streams or other bodies of water (lakes, ponds, reservoirs, etc.) that should be managed with special considerations to protect water quality" (GFC 1999). A cross-sectional diagram of a SMZ is shown in Figure 1.
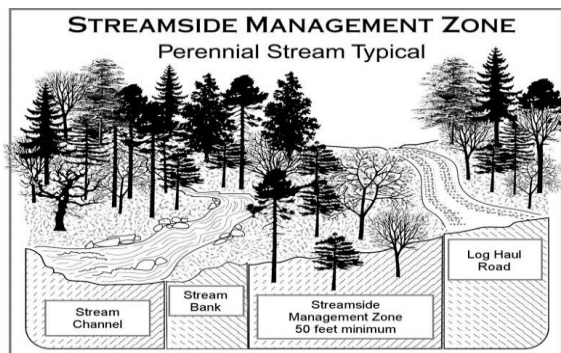

Figure 1. Diagram of a streamside management zone, Virginia BMP manual.

SMZ specifications are found in forestry BMP manuals of each state. Best management practices

(BMPs), which are methods, measures, or practices that are designed to maintain water quality were developed under Section 208 of the Clean Water Act. It states that each state shall develop plans that would assess nonpoint source pollution and then develop and implement BMPs to manage water quality (AFPA 1993). SMZs are primarily designed to focus on the main issue of water quality, but they also contain several benefits such as high value timber, an increase in aquatic and wildlife habitat, and they also may provide income to the owner of the property.

The Department of Forestry of each state or related state agency may design SMZ requirements and over the years there have been revisions. This study compares the SMZ width requirements and the amount of harvesting allowed within each state throughout the southeast. Specifically, how Virginia's plan relates to states with similar geographic regions, vegetative species, and non-regulatory laws for water quality.

METHODS

There is not a universal delineation of which states are included in the Southeast region. However, the United States Forest Service defines the southern region to include TX, OK, AR, LA, MS, AL, SC, NC, VA, TN, and KY. The Environmental Protection Agency delineates the southeastern region to include FL, GA, SC, NC, AL, MS, TN, and KY. The Forest Resource Association considers its southeastern region to be VA, NC, SC, GA, and FL. Based on these organizations and other sources, the southeast region for this study was delineated to contain these states with similar physiography regions and vegetative species (Table 1). BMP manuals were located and attained for each state by means of the internet, mail, and personal communication with professors, experts and students. BMPs for streamside management areas were then compared and analyzed for all southeastern states.

RESULTS

Each state has designed their own specifications for SMZ requirements and some states share certain similarities. Results from this study are given in Table 1. KY, SC, GA, MS, TN, AR, and FL have SMZ requirements for perennial and intermittent streams that are slope dependant. Their widths range from 25ft to 300ft. LA, VA, NC, and AL, are the remaining states that have SMZ widths for perennial and intermittent streams that are not slope dependant. AR, VA, NC, and AL have the same SMZ widths for perennial and intermittent streams, whereas the other states have separate specifications. FL and LA are the only states that have different widths depending on the width of the perennial stream. KY, SC, NC, VA, and GA have set guidelines for special concern areas such as cold water fisheries. GA, VA, and FL are the only states that have determined SMZ widths for municipal water supplies. KY, VA, and FL have also set specifications for sensitive areas such as wetlands.

Table 1. Comparison of SMZ requirements in the southeast region.

State	Perennial			Intermittent	CWF*	Wetlands	Municipal Water Supplies
	(All widths ft)	*(0-20 ft)*	*(20-40 ft)*	(ft)	(ft)	(ft)	(ft)
Alabama	35			35			
Arkansas	35-80sc			35-80sc			
Florida		35	75-200sc	35-300sc		50	200
Georgia	40-100sc			25-50sc	100		50-150
Kentucky	25-55sc			N/A	60	50	
Louisiana		50	100	35			
Mississippi	30-60sc			30			
North Carolina	50			50	50-125sc		
South Carolina	40-160sc			40-160sc	40-200sc		
Tennessee	25-145sc			25-145sc			
Virginia	50			50	60-120sc	50	100-200sc

* Cold water fisheries   sc: slope class dependant

The BMPs of all southeastern states allow timber harvesting in SMZs that must meet residual density guidelines and specific harvesting treatments. Results of these requirements are given in Table 2. KY, SC, and LA haven't set any requirements within SMZs of intermittent streams. SC, GA, MS, and AR require residual stand density of $50ft^2/ac$ that is evenly distributed throughout the area. KY, GA, TN, VA, and AL specify that 50% of canopy cover must be left in the stand. KY and GA set separate specifications for cold water fisheries. KY, GA, and VA mention harvesting in wetlands and set the same specifications as allowed in perennial zones. North Carolina specifies that no more than 20% bare grounds, evenly distributed; result from harvesting operations in perennial zones. Florida doesn't allow any harvesting within 35ft of a perennial stream, however, they are allowed to clearcut 25% of the SMZ, excluding the first 35ft. They also require a residual stand density of $50ft^2/ac$ in perennial zones if exceptions do not apply.

Table 2. Comparison of the harvesting SMZ requirements in the southeast region.

State	Perennial	Intermittent	CWF	Wetlands
Alabama	50% canopy cover	partial or regeneration cut		
Arkansas	$50ft^2/ac$	50% canopy cover		
Florida	$50ft^2/ac$	leave stringer *		
Georgia	$50ft^2/ac$ or 50% canopy cover	$25ft^2/ac$ or 25% canopy cover	$25ft^2/ac$	
Kentucky	50% overstory	N/A	25% canopy cover	50% canopy cover
Louisiana	N/A	N/A		
Mississippi	$50ft^2/ac$ selective harvest	regeneration harvest		
North Carolina	<20% bare ground	40% canopy cover		
South Carolina	50ft2/ac	N/A		
Tennessee	50% canopy cover	50% canopy cover		
Virginia	50%BA or 50% canopy cover	50% canopy cover		50% canopy cover

∗stringer – Narrow strip of trees left on and/or near the banks of intermittent streams.

Since harvesting is allowed in SMZs, there are guidelines set by each state denoting what type of harvesting equipment or system should be used within the streamside management area. Results of this comparison are given in Table 3. KY, NC, and TN recommend that harvesting equipment operate outside of the SMZ and logs are cabled and skidded out. AL, FL, MS, and VA allow harvesting equipment inside the SMZ without any stipulations. GA, LA, and SC allow equipment in the SMZ, but prefer the machines to have wide tires, tracked wheels, or have minimal impact.

Table 3. Comparison of the harvesting equipment allowed in the southeast region.

State	BMP Harvesting Guidelines in SMZs
Alabama	Harvesting equipment is allowed in SMZs
Arkansas	Not mentioned
Florida	Harvesting equipment is allowed in SMZs
Georgia	Harvesting equipment is allowed in SMZs as long as there is no significant impact
Kentucky	No harvesting equipment or vehicles are allowed within SMZ, the preferred method is winching. No equipment operation within 25' of perennial stream.
Louisiana	Harvesting equipment is allowed in SMZs, suggested equipment includes wide-tire and cable skidders, forwarders, and tracked equipment.
Mississippi	Harvesting equipment is allowed in SMZs
North Carolina	No harvesting equipment or vehicles are allowed within SMZ, the preferred method is winching (currently revising this section)
South Carolina	Harvesting equipment is allowed in SMZs, secondary zone suggests using wheel or tracked vehicles
Tennessee	No harvesting equipment or vehicles are allowed within SMZ, the preferred method is winching
Virginia	Harvesting equipment is allowed in SMZs

DISCUSSION

Each state from the southeastern region has developed their own BMP manual with a section denoted to SMZs. In general the manuals discuss their requirements, definitions related to SMZs, and their purpose. It is important to educate the reader of the manual that SMZs have economic value, benefits to wildlife, and improves water quality and aquatic habitat. After reviewing all BMP manuals, Florida seems to have the most detailed SMZ requirements.

When determining widths for the specified water body, there are five parameters that must be measured. These include the stream type, the width of the stream, the level of soil erodability, the K-factor that's dependant on soil type, and slope gradient. This may be a disadvantage because it will require more time and knowledge to determine the effective width. The plan requires the operator to refer to several appendices and tables to attain the desired result. However, Florida loggers do have a BMP implementation compliance rate of 97% in 2003 (Silviculture BMP Implementation Report 2003). The majority of the states have plans that seem feasible and practical to apply in the field.

Virginia's SMZ requirements are both feasible and practical, but there are still some factors that need to be addressed. In the BMP manual it states that "steep slopes, cold water fisheries, and municipal water supplies all need wide SMZs to protect water quality" (DOF 2002) yet the widths for warm water fisheries are not dependant on slope. It is proven that in most cases the steeper the slope the faster the runoff and therefore the more potential for soil erosion (Dissemeyer 1984).

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Most states have identified this relationship and developed their requirements according to slope gradients. However, there is an issue pertaining to the difficulty in attaining an accurate slope percentage due to the variation of slope over the length of a SMZ.

The majority of states have set similar harvesting guidelines, however there have been limited studies that actually quantify the impacts of harvesting on water quality (Liechty 2000). There are also very few states that specify what type of harvest (selective, partial or regeneration) is allowed in the SMZ, even though most states suggest that the residual stand will remain evenly distributed.

North Carolina is the only state that measures bare ground percentages instead of basal area or canopy cover. Virginia is one of those states that allow 50% of the basal area or 50% of the canopy cover in the perennial and intermittent zones. Other states that use this measurement include TN, KY, AL, and GA. More research is needed to determine if this limit is based on science. It is also important to note that basal area is more feasible to measure than canopy cover when pertaining to the operator. Canopy cover requires the use of instruments or the operator leaving the machine to get an accurate estimate.

Harvesting equipment becomes an issue when dealing with sensitive areas, such as SMZs. Heavy machinery have several impacts on the landscape, a few include soil compaction, increased erosion rates, and a decrease in soil productivity and infiltration rates (). States have tried to minimize these impacts by recommending where to perform the operation and what types of equipment should be used. Several states allow equipment within the SMZ, but acknowledge that the proper measures should be taken to minimize impacts. Other states suggest that equipment should be located outside of the SMZ and timber should be skidded out with a cable-winching system.

While keeping machinery out of the SMZ might seem to have the least amount of impact on the soil, skidding logs across the forest floor can also have negative effects (Patric, 1978). Generally, most equipment is chosen depending on site specifications.

Further research studies should be designed to attain the scientific data needed to measure the impacts of different harvesting levels, and different types of harvesting systems used within SMZs.

CONCLUSION

Southeastern states have specified requirements for SMZ widths in their BMP manuals based on a variety of factors. Some states set recommendations that are based on stream type, and others use slope class to set guidelines. Some manuals mention water municipalities, cold water fisheries, lakes, ponds, and wetlands, while others only mention perennial and intermittent streams.

Overall, the majority of states have set similar SMZ guidelines. This also applies for the amount of harvesting allowed within a SMZ. Parameters used to measure the amount of harvesting include basal area, canopy cover, bare ground percentage, and treatment types. The type of harvesting equipment that is recommended is based on the decision of whether or not equipment is allowed within the SMZ. Cable skidders are the preferred method for timber removal for states that prohibit equipment in the SMZ. Other states allow all equipment or suggest wide tires or tracked tires.

This study has shown that states are concerned about water quality and the integrity of the stream by setting SMZ widths and harvesting limits. In the future, studies should be designed to address the most suitable amount of harvesting and equipment used within the SMZ.

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Unmanned Aerial Vehicles: Applications for Natural Resource Management and Monitoring

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ABSTRACT

Unmanned aerial vehicles (UAV) are commonly used in the defense and espionage industry. As the technology advances and costs decrease, the deployment of UAVs for natural resource applications becomes more obtainable. The USDA Forest Service, San Dimas Technology and Development Center, tested a UAV for mapping and monitoring capabilities on research sites near Volcano National Park. The tests proved that 8 cm per pixel resolution mapping is possible with UAVs. However, improvement is needed in areas such as aircraft state data and automated image processing. With improvements the system will have full high-resolution, forest mapping abilities. Currently the unit is fully capable of mapping forest edge and stream images, which could be used for SMZ monitoring. This may be particularly useful in the southern states where trespass rights by state inspection officials are limited.

Introduction

Many successfully adapted new technologies in the field of forest engineering have had military development as their point of 'birth'. Examples of such technologies include Geographic Positioning Systems (GPS) and mapping with Geographic Information Systems (GIS), lasers for range finding, radio frequency tagging for supply chain management, and self-leveling vehicles for working on steep terrain (Rumsfeld, 2003).

A new technology, using unmanned aerial vehicles (UAV) combined with digital imaging for use in the espionage and defense industry, is currently being developed by the military. The technology is reaching maturity and becoming available for non-military use. Considerable advances have been made in the technologies commonly incorporated in UAV use including guidance systems, aircraft reliability and durability, digital photography, hardware and software applications, and battery options. These technological improvements combined with an overall decrease in ownership costs present a fantastic opportunity for UAV applications in forest engineering and forest resource management.

This paper reports on the initial testing of a currently available UAV technology for forest management purposes. The paper also explores potential field applications of forest engineering as well as noting some possible limitations that need to be addressed before this technology will play a critical role.

UAVs and their Capabilities

UAVs, also known as 'drones', come in a wide variety of sizes, ranging from palm size units up to standard sized aircraft exceeding 12.5 tons. The UAV industry has not fully agreed upon exact classifications, but generally consist of micro UAVs, mini UAVs (5 to 20 pound gross take off weight), small UAVs (20 to 80 pound gross take off weight), tactical

UAVs, and High Altitude Long Endurance (HALE) UAVs.

Configuration varies with the intended use of the vehicle and the funds available. Rotor-wing units have hovering capabilities, while fixed-wing units tend to have longer flight durations and are inherently more stable in flight. Flight times range from several minutes to a few days.

Generally, there is a trade off of system accuracy and UAV size. Smaller UAVs tend to have less accurate aircraft state data. This type of information includes pitch and yaw of the aircraft, as well as location information, which tends to use a form of GPS. This aircraft state data can directly impact the accuracy of the data collected by the UAV.
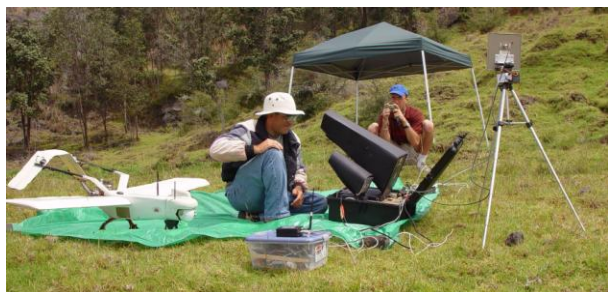

Figure 1: UAV components

UAV Testing

The USDA Forest Service, San Dimas Technology and Development Center, tested a UAV for mapping and monitoring capabilities on research sites near Volcano National Park. The goal of the test was to provide high-resolution, on-demand imagery for invasive species monitoring, since current imagery was unsuitable. The tests proved that 8 cm per pixel resolution mapping is possible with UAVs.

After a thorough market search, it was determined that the Bat III, produced by the MLB Company, was the most appropriate unit to use, due to its availability as an off-the-

shelf-unit. Additionally, the US Fish and Wildlife Service used previous versions of the Bat for similar applications. MLB technicians performed all the functions necessary for the flight, including flight planning and operation of the unit.

The Bat III has a 15 lbs gross weight and is capable of a 4 lb payload, depending upon sensor configuration. Despite the 72 inch wing span and 56 inch length, the modular design of the unit makes it relatively easy to transport. This unit is capable of autonomous take-off and landings as well as autonomous flight. Maximum flight duration is six hours with a seven mile telemetry limit and a 200 mile fuel limit. A 23 cc two-stroke engine propels the Bat III to speeds ranging between 25 and 50 mph.

Due to the constraints placed on the test and the limited size of the available landing areas, both takeoffs and landings were performed manually. The data collection portion of the study used preprogrammed flight plans which utilized the autonomous flight capability.

The Bat III collected both still imagery and video imagery in flight. A live video feed was successfully transferred to the base station during flight, provided that the base station remained within line-of-sight to the Bat.

Using Photo Stitch software by Canon Inc. imagery sets of 10 or less, gathered along a road, forest edge, or stream course, could be rapidly mosaicked. However, within a forest stand mosaicking images became more difficult due to the lack of obvious control points within the images. These images required orthorectification using the state data available on the aircraft. As a result, forest stand maps required higher power image processing capabilities.

The UAV images were used to create second-generation orthophotos for some of the areas flown. Some difficulties encountered in this mapping process included a lack of suitable image overlap, unsuitable precision of aircraft state data, and a lack of control point flexibility within the processing packages. The cost of mapping through US processing companies ranged between $50 to $200 per image, on a 71 image set. These costs can be expected to decrease as contractors become more familiar with UAV image processing and processing volume increases.

Image 2: UAV launch

Potential FE Applications

Currently there are a number of potential applications of UAVs to resolve forest engineering related problems.

BMP Inspections
Whether a state has a forestry practices act, or they have voluntary BMPs, the EPA requires the state forestry agency to help protect water quality. Locating harvest sites and inspecting forestry operations is a cumbersome and time-consuming activity. This is especially true in remote locations that are harvested over unspecified time frames. In some cases, driving to a single harvested tract can take a state official an entire day. Additionally, in most southeastern states the State Forestry agency does not have the right to trespass onto forested land to inspect for potential water quality violations (Yonce and Visser, 2003).

For this purpose the use of a UAV presents many opportunities. For those states that do not have a notification requirement, a high altitude flight would replace the current manned flight to locate recently completed or active harvest sites for reporting purposes to the EPA. Once located, a low altitude flight could capture high resolution images that would allow a state official to inspect environmental 'performance', such as the adequate use of SMZs, the quality of the stream crossing, the use of water-bars or turn-out structures on the skid-trails, and most importantly locating any active erosion sites that may be impacting water quality.

The ability of UAVs to fly in low cloud cover and moderate precipitation provides an additional advantage in SMZ monitoring. Given their ability to be deployed quickly, a specific area of concern could be checked during or immediately after a rain event. This type of low elevation, low visibility flight would not be permitted for manned aircraft due to Federal Aviation Administration (FAA) regulations.

Figure 3: Mosaicked Images of Forested SMZ

Timber Theft
Timber theft continues to be a large financial concern to forestry companies, and a recent study in just 12 counties in South West Virginia indicated up to 12 million dollars

were being stolen every year (Baker 2003). Issues include the extensive forest boundaries, difficulty in finding boundaries on the ground, and a lack of manpower to actually monitor for illegal logging practices. UAVs could be programmed to fly boundaries of large forested landholdings; the images collected could then be analyzed manually or with automated comparison software to detect changes in the landscape. Any harvesting activities located can be verified with legal harvesting operations.

Figure 4: Image of active harvest operations

Road Maintenance
Forest roads and skid trails are typically the main source of erosion in forest operations. Even closed roads and trails are a concern. Using the corridor mapping capability UAVs can be programmed to fly over the complete forest road network and inspect for bank blow-outs or compromised drainage structures. If trouble spots were detected, an observer could retask the UAV during the same flight to take a closer look at those areas. Again, there is the benefit of using the UAV during or immediately after a rain event.

Trespass
Trespass is another issue where UAVs can aid forestry companies. Typical trespass issues for forestry include:

- ATV traffic compromising BMP structures (such as waterbars)
- ATV users constructing new trails through the forest
- poaching of managed game species
- dumping of refuse along roads
- arson

A UAV could be deployed at times when these behaviors are suspected to occur. The small size and relatively quiet operation of many UAVs would permit rapid surveillance of an area with minimal likelihood of detection.

Research
Forest operations research commonly compares the production rates of equipment on a particular site. With the relative ease of UAV deployment, high-resolution images could be collected as needed. For example collecting images twice a day would provide an effective means of mapping progress and provide production rates on a per acre basis. Higher intensity collection would provide data on machine interaction and bottlenecks. Combining these maps with site data would allow for further analysis, including the effect of slope on an operation.

UAV issues

Although the opportunities for using UAVs are great, there are still some potential problems to overcome. The current cost of purchasing the UAV system which was tested by the San Dimas Technology and Development Center is approximately $42,000, which includes the base station, UAV, guidance software, and training. Replacement cost of the drone in case of a crash and complete loss is estimated at $20,000.

Digital flight path coordinates that provide a wide margin of safety around objects the UAV might impact in flight are critical as the drones typically do not have warning or evasion

systems. Therefore inaccurate input of desired flight coordinates, especially altitude, could result in a crash. Along with collisions with hillsides, other objects will also pose problems, including water and cellular towers, trees, and other aircraft.

Although significant advances have been made in automated high-resolution digital mapping (e.g. merging digital images, automated identification of land-use change, identification of potential trespass), significant software development still needs to take place for this technology to be a turn-key solution for many small forest managers. The relative inaccuracy of aircraft state data currently collected by small UAVs also presents challenges to image analysis software.

Additionally, the UAV community has been funded by, and as a result, is focused on defense related work. This work has funded the efforts required to develop the current capabilities of UAVs, but the needs and concerns of the defense industry are not entirely identical to those in the natural resource profession. This means that the UAV industry will need to modify their product and approach to consistently deliver usable goods to those working with natural resources.

However, the products will not be derived from the UAV community without support from those in the forest industry. Currently the FAA has chosen not to differentiate among different sized UAVs or to provide a gradient of flight requirements for UAVs. As a result, "see and avoid" procedures are required for UAVs as well as other aircraft, and UAVs are not allowed to exceed one thousand feet above terrain in US civil airspace. This requirement does limit the opportunities for many small UAVs. While the FAA and industry are discussing the matter, the applications of these units within the natural resource field will not be considered in the possible creation of these requirements, unless the UAV community

learns the needs and intentions of users in the field.

Conclusions

Although there are still many limitations to the use of UAVs in forest engineering, broad utility has already been demonstrated in situations where manned flights would pose an unreasonable risk to the aircraft's pilots and passengers. UAVs and data provided from UAV flights have just recently become available to the general public, and while image manipulation is currently time-consuming and imprecise, relatively minor upgrades to the flight platform and software used for mosaicking will soon allow more accurate, efficient automated image processing. Such imagery makes evaluation much simpler and makes UAV applications more cost effective.

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Low Impact Forest Harvesting at the Urban Interface

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ABSTRACT

Active forest management at the urban interface is becoming more important to address issues such as poor stand health, fire risk and wildlife habitat. Residential forested housing is increasing in popularity and fragmentation of large tracts into smaller holdings of individual landowners continues. With the support of the Virginia Department of Forestry, this study examined the productivity, soil impact, and residual stand damage of an agricultural tractor based "low impact" harvesting system. The study site was typical of a small Appalachian mixed-hardwood woodlot that had been high graded in the past. Two silvicultural treatments were applied; a crop tree release and a even-spaced thinning. Prior to and immediately following the harvesting operation, visual soil disturbance categories were recorded every meter and soil cores were taken every ten meters along line transects at 20 m spacing. The soil cores were used to determine micro porosity, macro porosity, K saturated, and bulk density. Average production for this system was 3.2 m^3/PMH, and residual stand damage, visual disturbance, and soil impact were minimal.

Introduction

Urban and rural areas merge together to form a region that is characterized by lower population densities than urban areas and higher amounts of development than rural areas (Shelby et al. 2004). This transitional area is referred to as the urban interface. The rapid expansion of urban and suburban populations has resulted in the urban interface expanding into areas that used to be entirely rural (Shelby et. al 2004). In 1996, the number of non-industrial private landowners in the United States reached 10 million, a 20% increase over the previous 15 years (Erickson et al. 2002). According to Birch et al. (1998), approximately 86% of the 15.1 million acres of forest in Virginia belongs to non-industrial private landowners.

Forest harvesting has traditionally occurred in remote locations and on large tracts of lands, but the influx of people and development into these areas has created a need for forestry to operate on the urban interface (Shelby et al. 2004). As more people move into rural areas, forestland is being divided from large contiguous forests into smaller blocks of land with different owners (Birch et al. 1998).

The expanding urban interface will change the way forest harvesting is conducted (Hull et al. 2004, and Shelby et al. 2004). In Virginia, 75% of all forestry operations occur on non-industrial private land (Birch et al. 1998). This dependence on non-industrial private land allows forest landowners to have a great deal of influence over the way forestry is practiced. Increasing urban interface populations and forest fragmentation may have negative effects on the timber supply network by limiting the amount of land available for harvest and reducing the cost effectiveness of harvesting small tracts (Hull et al. 2004, Shelby et al. 2004, and LeDoux and Huyler 2000).

Many non-industrial private landowners distrust the ethics, motivation, and level of environmental concern displayed by foresters and loggers and as a result traditional forestry risks loosing access to these forest lands (Hull et al. 2004). Multiple surveys of landowners have determined that the primary goal of most small forestland owners is not generating revenue (Erickson et al. 2002, Hull et al. 2004. Shelby et al. (2004) reports that 98% of respondents in their Oregon survey listed ecological impacts as important considerations, followed by aesthetic concerns at 90%, and wildlife at 88%. A survey of Virginia landowners ranked generating income between not important and neutral, but ranked amenities like preserving nature and seeing wildlife very important (Hull et al. 2004).

These diverse and complex goals are not easily met with traditional harvesting equipment. Large skidders or forwarders may cause residual stand damage or high levels of soil disturbance when they are used to conduct partial harvests (Shaffer 1992). Because public scrutiny is focused on every aspect of the harvesting operation and public pressure demands that recreation and aesthetics be considered, forest harvesting costs may increase when operating on the urban interface (Shelby et al. 2004).

High capital investment, transportation costs, and operating expenses may prevent traditional harvesting systems from being able to operate in small woodlots (Shaffer 1992). Profit in forest harvesting is a function of timber value and volume (Hull et al. 2004). Traditional forest harvesting systems operate on small profit margins, face stiff competition, and are focused on productivity (LeDoux and Huyler 2000). The reduction in harvest volume on small woodlots and the diverse goals of landowners is a compelling argument for using less expensive, small scale harvesting systems (LeDoux and Huyler 2000).

While harvesting timber is not the top priority for small forest landowners, 49% of landowners would consider harvesting timber if other forest amenities could be protected, and the majority of landowners surveyed are interested in using "small" equipment and technologies to harvest and process timber (Hull et al. 2004).

Harvesting systems that are appropriate for operating on the urban interface have been developed by modifying existing equipment and converting agricultural equipment to forestry applications. Specially equipped agricultural tractors are lighter and smaller than traditional equipment and can be used effectively on partial harvests of small woodlots (Shaffer 1992). These systems are widely used in Central Europe, but are rare in the United States. Tractor based systems are well suited for operating in small woodlots due to their maneuverability and low initial investment, but their low productivity may limit there use in commercial systems (LeDoux and Huyler 2000).

Figure 1. 4wd John Deere Tractor used for extraction

Most landowners form their opinions about the quality of a harvesting operation based on visual information. Activities such as chipping slash, removing trash, minimizing mud on the roads, and maintaining clean vehicles and equipment can greatly improve a landowner's opinion of the harvesting operation (Hull et al. 2004). These types of activities in addition to reduced harvest volumes can make harvesting on small woodlots unprofitable (Hull et al. 2004).

To make harvesting small woodlots economically feasible, it may be necessary to vary the payment percentage of the timber sale according to tract size and timber value. Another possibility is to remove the timber sale from the payment equation by adopting a service industry mentality and selling services such as improving wildlife habitat, stand health improvement, and aesthetic modifications (Hull et al. 2004).

An estimated $15 billion dollars is spent annually in the United States on professional garden and tree care, but forestry accounts for very little of these expenditures (Hull et al. 2004). Forest harvesting on the urban interface has the potential to become a major part of the forest industry if foresters can demonstrate to landowners that harvesting can be done in an environmentally sensitive way that promotes the diverse amenities of the forest (Hull et al. 2004).

This study investigated a small scale harvesting system in a typical Appalachian hardwood stand. The objective of this study was to establish if a harvesting system based on a modified agricultural tractor is in fact low impact. The level of impact was determined by visually classifying soil disturbance, measuring soil bulk density and hydrological properties, and determining residual stand damage,

Site description

The study site was located at the Shenandoah Valley Agricultural Research and Extension Center located at McCormick Farm in Steeles Tavern, VA. The site was typical of small woodlots in VA. It was an uneven aged, mixed hardwood stand that had been high graded and grazed by cattle in the past. A crop tree release was conducted on 3.5 acres and an even spaced thinning was conducted on 1 acre of the study site.

Methods

The harvesting operation was conducted using motor manual felling and a model 950 John Deere agriculturual tractor for extraction (Figure 1). The tractor was 4 wheel drive and equiped with a skidder plate and PTO driven pulling winch. Directional felling was used to increase skidding efficiency and reduce residual stand damage.

System Productivity

Productivity of the system was determined by conducting a time study during the harvesting operation. The time study was based on the methods used by Kluender and Stokes (1994). For each extraction cycle, times were recorded for travel from the deck to woods (travel out), bunching and choking logs (acquire), travel from the woods back to the deck (travel in), and unhooking (decking). Extraction productivity was determined using times recorded during 33 extraction cycles. Distances were measured along the skid trails, and estimated from the individual accumulating locations to the skid trails. For pulpwood turns, the number of stems per turn was recorded, and for saw log turns, the diameter and length of each log was measured using a logger's tape. Field data and volume tables were used to determine the volume for each turn (Kluender and Stokes 1994).

Soil Disturbance

The soil disturbance data were collected using line transects spaced 20m apart throughout the harvest areas. Transects were placed perpendicular to the expected path of the skid trails. The same transects were used to collect the pre-harvest and post-harvest data.

Visual estimates of soil disturbance are widely used to quickly determine the level of impact that occurred during a harvesting operation (Aust et al. 1998). A visual soil disturbance class was determined and assigned at 1m intervals along each transect. The visual disturbance classes are the same as the system used by Aust et al. (1993).

The disturbance classes are:
- Class 1 – Undisturbed
- Class 2 – Slightly disturbed
    a. litter still in place
    b. litter removed and mineral soil exposed
    c. mineral soil and litter mixed
    d. mineral soil deposited on top of litter
- Class 3 – Deeply disturbed, surface soil removed and subsoil exposed
- Class 4 – Rutted, compacted
    e. 0-15.2 cm
    f. 15.2-30.5
    g. >30.5
- Class 5 – Depression deposit, soil deposited in low spot
- Class 6 – Covered by slash to depth that will hamper regeneration
- Class 7 – Nonsoil, streambed, stump, etc.

Residual Stand Damage

Residual stand damage was determined by counting damaged trees that were within 2m (1m on each side) of each transect during the post-harvest sampling. This number was used to estimate the number of damaged trees per acre. A damage class was assigned to each damaged residual tree to help explain which part of the harvesting operation caused the damage. It was assumed that stem damage resulted from extraction and crown damage resulted from felling.

The residual stand damage classes are:
- Class 1: undamaged
- Class 2: minor stem damage ($<10cm^2$)
- Class 3: major stem damage ($>10cm^2$)
- Class 4: minor crown damage (<1/3 crown)
- Class 5: major crown damage (>1/3 crown)

Soil Impact

Soil core samples were taken at 10m intervals along each transect using a bulk density hammer and 5.1cm x 5.1cm aluminum cylinders. The bulk density core samples were analyzed in the forest soils lab to determine total porosity, macro porosity, micro porosity, saturated hydraulic conductivity, and bulk density. Comparisons between pre harvest and post soil data were made using a paired t-test.

Porosity

Macro, micro, and total porosity were determined using the water desorption method described by Danielson and Sutherland (1986). Using this method, porosity is determined by draining a saturated soil sample by steps. Macro porosity was calculated using the formula (saturated weight – drained weight)/volume. Micro porosity was calculated using the formula (drained weight – dry weight) /volume. Total porosity was calculated by adding macro and micro porosity.

Saturated Hydraulic conductivity

Saturated hydraulic conductivity was determined using the constant head method described by Klute and Durksen (1986). Using this method, a column of water is placed

over a known volume of saturated soil, and the volume of water that travels through the sample and the length of time are recorded. Each soil core was left in the apparatus for a minimum of 1 hour or 3 full 500ml flasks. Saturated hydraulic conductivity (K_S) was calculated using the formula $K_s = VL / (AtH)$. Where V is the volume of water, L is the length of the soil core, A is the cross-sectional area of the soil core, t is the amount of time elapsed and H is the head.

Bulk Density

Bulk densities were calculated using the core method described by Blake and Hartge (1986). The soil cores of known volume were placed in a 105° C oven and dried for a minimum of 48 hours. Bulk density was calculated by dividing dry weight by the sample volume

Results

The results from the productivity study showed that an agricultural tractor is not a high production machine for timber extraction. 33 skidding cycles were measured in the field, and the average skid distance was 119 m. Total production for this system was 3.2 m^3/PMH (108.4 ft^3/PMH). Acquiring each turn, which consisted of bunching, choking, and winching logs up to the tractor, took the most time and accounted for 54% of the total cycle time (Table 1).

Table 1: Mean times for each skidding cycle component (n =33)

	Mean time (min)
Travel out	2.59
Acquire	9.21
Travel in	1.87
Deck	3.47
Total cycle	17.14

Residual stand damage was minimal. The harvesting operation resulted in 14 trees/acre with minor stem damage and 4 trees/acre with minor crown damage. No trees with major damage were found.

Visual disturbance was recorded a total 881 times along the transects. The visual survey prior to the harvest classified the entire harvest area was classified as undisturbed. Immediately following the harvest operation, the visual survey showed that 11% of the harvest area had been disturbed. All 97 of the disturbed points were classified as a category 2 (slightly disturbed). Table 2 shows the individual frequencies of the disturbed points.

Table 2: Post harvest frequencies of visual disturbance class categories

Disturbance Category	# of points	% of harvest area
1 (undisturbed)	784	89%
2a (litter still in place)	57	6%
2b (litter removed)	33	4%
2c (litter & soil mixed)	6	0.7%
2d (soil on top of litter)	1	0.1%

Bulk density is the dry weight divided by the volume of the sample, and can be used to measure soil compaction. Laboratory analysis of the soil cores showed that 95% of pre-harvest bulk densities were between 0.61 Mg/m^3 and 1.29 Mg/m^3 with a mean density of 0.93 Mg/M^3, and 95% of post-harvest bulk density were between 0.53 Mg/m^3 and 1.25 Mg/m^3 with a mean density of 0.88 Mg/m^3. Most forest soils range from 0.13 Mg/m^3 to 1.0 Mg/m^3, and densities greater than 1.2 Mg/m^3 hinder root growth (Wenger 1984).

The high mean density of both the pre- and post- harvest samples may have been caused by the previous practice of grazing cattle in the

harvest area. Equipment traffic during harvesting operations can increase bulk density. However, in this study, mean bulk density decreased by 0.05 Mg/m^3. We are not implying that the harvesting operation caused the decrease in bulk density, only that it did not cause further compaction.

Porosity is a measurement of the amount of space in the soil that can be occupied by air or water (Danielson and Sutherland 1986). Macro porosity refers to the ratio of non-capillary pores to the volume of soil. Micro porosity is ratio of capillary pores to the volume of soil. Total porosity is simply the sum of macro and micro porosity (Fisher and Binkley 2000). Laboratory analysis showed that porosity increased after the harvesting operation (Table 3). Porosity is inversely related to bulk density, and the increase in mean porosity is probably a result of the decrease in mean bulk density after the harvest.

Table 3: Pre- and post- harvest porosity (%)		
	Pre harvest	Post harvest
Macro avg.	13.5	14.8
95% range	5.8 to 23.2	7.3 to 27.0
Micro avg.	41.4	46.7
95% range	28.2 to 48.3	35.4 to 57.7
Total avg.	54.9	61.5
95% range	45.9 to 64.6	47.9 to 71.8

Hydraulic conductivity is a measurement of the soil's ability to transport water (Klute and Durksen 1986). Laboratory analysis showed that saturated hydraulic conductivity decreased after the harvesting operation. The 95% range of pre-harvest saturated hydraulic conductivity was 0.0031 cm/min to 1.45 cm/min with a mean of 0.26 cm/min, and post-harvest ranged from 0.0008 cm/min to 1.42 cm/min with a mean of 0.19 cm/min. This was not a significant change at the alpha = 0.05 level (p = 0.0746).

The reduction in saturated hydraulic conductivity was the only soil property that changed in the expected direction. However, hydraulic conductivity is directly related to porosity, and it is difficult to explain why porosity increased and hydraulic conductivity decreased after the harvest. The most likely explanation is the presence or absence of pipe flow. Pipe flow is when a root channel or other soil macro pore allows water to drain directly through the soil sample. Paired samples could have similar bulk densities and porosities, but the presence of a direct passage for water will result in drastically different hydraulic conductivities for the samples.

Discussion

As with similar studies, this study showed that agricultural tractors are not highly productive when compared to conventional timber harvesting systems. Productivity is important to equipment owners and operators, and conducting low volume and/or value timber harvests on small woodlots magnifies the need to operate quickly and efficiently. Pre-harvest planning is critical for an efficient harvesting operation. During pre-harvest planning, the skid trails should be laid out to increase efficiency and reduce overall skid distances, and property boundaries, fences, SMZs or any other control points should be located so they can be avoided with out slowing the operation down.

Directional felling is important not only because it increases production, but it also reduces residual stand damage, and it further illustrates the need for pre-harvest planning. An experienced choker setter using a second set of chokers could increase productivity by bunching and chokering the next turn of logs while the skidder is traveling to the deck and back into the woods. Harvesting systems using agricultural tractors can increase production by becoming as efficient as

possible, but even the most efficient tractor based system will still be much less productive than conventional harvesting systems.

Most owners of small woodlots value aesthetics, wildlife, and low ecological impacts much higher than timber production. Focusing on meeting the landowner's objectives and adjusting the fee structure accordingly, helps to take some of the pressure for high production off of the harvesting system. With the incentive to increase production removed, the operator can focus reducing residual stand damage and the overall impact of the harvesting operation.

Conclusion

This study showed that harvesting systems that use agricultural tractors for extraction are not high production systems. However, agricultural tractors are lightweight and maneuverable which allows them to be used to conduct thinnings or partial harvests with a minimum of residual stand damage and soil impact. Situations where the landowner is more concerned about aesthetics and impact than production are ideal for harvesting with an agricultural tractor.

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Production and Cost of a Conventional System Harvesting Small-Diameter Lodgepole Pine in Wyoming

by

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Abstract - During August 2001 a highly mechanized harvest system was evaluated while working in a clearcut harvest of small-diameter material on the Medicine Bow-Routt National Forest in Wyoming. The operation consisted of a Timbco[1] T425-D tracked feller-buncher, a ProPac stroke delimber, a John Deere 648 E grapple skidder, and a Barko 160 knuckleboom loader. Species composition consisted mainly of lodgepole pine (*Pinus contorta* Dougl. Ex Loud.) with a small component of white fir (*Abies concolor*). Total system cost was $237/SMH from stump-to-truck. The feller-buncher was the limiting factor in the system with a production rate of 690 ft^3/PMH. Production rates for the stroke delimber, skidder, and loader were 958, 813, and 3840 ft^3/PMH, respectively.

INTRODUCTION

Forests in the western US have a profusion of small-diameter material, which adversely affects forest health. The reduction of fire as a tool to effectively manage fuel loading, coupled with restrictions on logging, have been major factors contributing to this problem. The Cohesive Strategy of the National Fire Plan proposes to treat approximately 1.8 million acres of Federal land per year for hazardous fuels reduction over a 15-year period, especially along the urban interface (Laverty and Williams, 2000).

Harvesting small-diameter material is generally a low-production, high-cost process, especially for loggers with conventional equipment such as feller-bunchers and rubber-tired skidders. Conventional forest machines are designed to be most productive and efficient in merchantable stands. As volume per tree increases, cost per unit decreases. Hartsough (2001) reports that harvesting costs make up a large percentage of the total life cycle cost of managing a stand, and the relationship between logging costs and stand parameters has a large impact on which silvicultural regimes are feasible. Finding suitable markets that will increase the value of this material and help offset harvest costs is a challenge.

The objective of this study was to evaluate cost and production of a conventional harvest system used in the West operating in a stand of small-diameter material (5 to 13 inches).

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STUDY METHODS

Study Area And System Overview

The study area was located on the Medicine Bow-Routt National Forest in Wyoming. Species composition consisted mainly of lodgepole pine (*Pinus contorta* Dougl. Ex Loud.) with a very small component of white fir (*Abies concolor*). The prescription was a clearcut harvest where all material over 5 in Diameter at Breast Height (DBH) was merchandized. The prescription also required that all trees less than 5 in DBH be felled. There were 396 trees/acre with a Quadratic Mean Diameter (QMD) of 6.9 inches for all merchantable material. Of these, 97% were lodgepole pine with the remainder being white fir.

Trees were felled with a Timbco T425-D feller-buncher equipped with a chainsaw felling head with a 28-inch bar. Delimbing and topping were performed in-woods by a Pro Pac stroke delimber equipped with a 40-ft boom. The delimber was mounted on a John Deere Model 200LC carrier. This was an unconventional use of the stroke delimber, since most normally work at the landing. A John Deere 648E grapple skidder utilizing a 115-inch Esco grapple and mounted on 28L-26 tires transported merchantable stems from woods to landing. The delimber and skidder were both powered by John Deere 6068T 140 hp engines. Products were loaded onto haul trucks by a Barko 160 knuckleboom loader.

Products extracted included sawtimber and products other than logs (POL). These poles from small-diameter timber were used for fence construction, which is done extensively throughout the area. POL material was manually bucked at roadside and loaded by hand.

Felling

To assess feller-buncher performance, three fixed area plots were installed. Within each plot all trees greater than 5 in DBH were recorded. Tree diameters were measured to the nearest 0.1-inch using calipers. Total heights were measured to the nearest 0.5-ft using an electronic hypsometer. A unique number was painted on each merchantable tree for identification during the study. The feller-buncher was recorded on videotape as it harvested each study plot. Tree identification numbers were verbally recorded as trees were felled and bunched. In addition, trees were tracked into bundles to aid in studying productivity of the stroke delimber.

A cycle was defined as the time between moves, or move-to-move. Time study elements evaluated included move-to-tree, reach-to-tree, cut, move-to-dump, dump, and brush. The brushing elements occurred due to the feller-buncher being required to cut unmerchantable material as specified in the contract. Gross productivity of the feller-buncher was also estimated using total area of all study plots. Stem volumes were estimated using appropriate equations (Myers, 1964).

Delimbing

The stroke delimber was recorded on videotape as it worked thru the study area and processed bundles that were made by the feller-buncher. Since it was known which trees were in each bundle, volume processed per bundle was estimated for the delimber. Move distances were estimated using the track length of the carrier.

A cycle was defined as the time to move to and process a bundle. Dependent variables evaluated included move-to-bundle, reach, process, pile, arrange, and clear. The arrange element consisted

of pulling stems from a bundle closer to the machine for processing. The clearing element included knocking down unmerchantable material that the feller-buncher missed. Independent variables included bundle volume, number of stems processed, and move distance.

Skidding

To estimate skidder productivity, bundles processed by the stroke delimber were selected and numbered. Trees within each bundle were sampled for DBH, merchantable length, and top diameter. Total number of stems within a bundle was also recorded. The skidder was then timed using stopwatches as it transported stems from woods to landing. Travel empty and loaded distances were measured for each cycle using an electronic hypsometer.

Dependent variables evaluated for the skidder included travel empty, position and grapple, intermediate travel, travel loaded, and piling. Independent variables included load volume, travel distance, and number of stems per load.

RESULTS

Felling

A total of 43 observations were collected on the feller-buncher. Gross time study data indicated a production rate of 0.31 acres per hour. Table 1 summarizes the elementary statistics for the variables studied. Mean distance per move for the feller-buncher was 14.8 ft. This resulted in a mean cycle time of 1.83 min and a mean productivity of 689.6 ft^3/Productive Machine Hour (PMH). One factor that had an adverse effect on productivity was brushing. Without brushing mean cycle time could be reduced by 11%, increasing productivity to 759 ft^3/PMH.

Table 1. Summary of descriptive statistics for the Timbco T425-D feller-buncher.

Variable	N	Mean	Std. Dev.	Min.	Max.
Move (min)	43	0.24	0.210	0.047	0.90
Reach (min)	43	0.67	0.510	0.052	2.28
Cut (min)	43	0.16	0.123	0.018	0.61
Move-to-dump (min)	23	0.18	0.079	0.078	0.33
Dump (min)	43	0.47	0.342	0.072	1.70
Brush (min)	25	0.35	0.240	0.038	0.89
Total time (min)	43	1.83	1.184	0.37	6.33
Move distance (ft)	43	14.8	16.34	3	91
No. of stems/move	43	3.8	2.58	1	12
Cycle volume (ft^3)	43	21.0	16.17	1.9	66.7
Productivity (ft^3/PMH)	43	689.6	328.58	156.7	1614.6
DBH (in)	171	6.7	1.55	5.0	13.2
Total height (ft)	171	41.0	7.01	5.0	68.0
Volume per tree (ft^3)	171	5.5	3.56	1.9	24.2

Of the total cycle time the feller-buncher spent 36% of the time reaching to cut trees. Moving to dump trees into bundles required the least amount of time, accounting for only 5% of the total cycle time. The feller-buncher spent 26% of the time dumping trees into bundles. Moving, cutting, and clearing accounted for 13%, 9%, and 11% of the total cycle time, respectively.

General Linear Models procedure revealed that total cycle time was most significantly influenced by move distance and the number of stems cut. Figure 1 shows the regression line predicting total cycle time with the number of stems as the dependent variable for a move distance of 15 feet.

Total cycle time (min) = 0.010862 + 0.42552*Stems + 0.013458*Mdist
$R^2 = 0.91$; C.V. = 20.1%; n = 43

where: Stems = number of stems cut
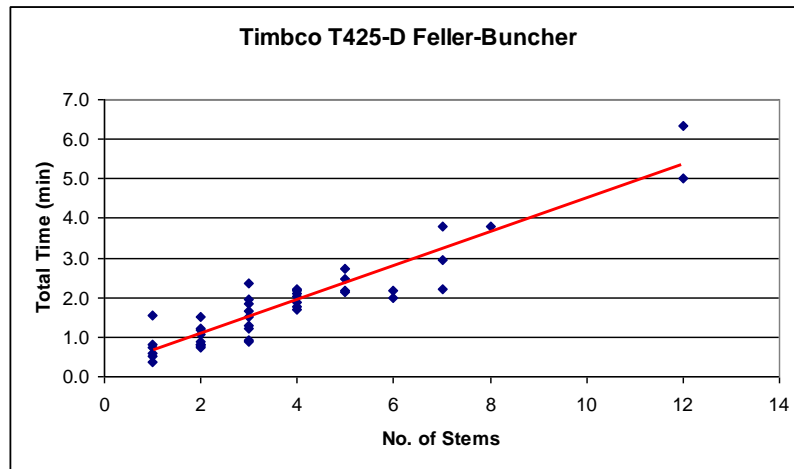   Mdist = move distance (feet)

Figure 1. Plot of regression predicting total cycle time for the feller-buncher.

Delimbing

The delimber moved 13 times, which resulted in a mean of 12.3 stems/move processed (Table 3). On a per tree basis, reach, process, and pile times averaged 0.17, 0.12, and 0.12 min, respectively. For a mean bundle size of 5.2 stems productivity averaged 958 ft^3/PMH.

Table 3. Summary of descriptive statistics for Pro Pac stroke delimber.

Variable	N	Mean	Std. Dev.	Min.	Max.
Move (min)	13	0.24	0.287	0.12	1.24
Reach (min)	31	0.69	0.491	0.19	2.19
Process (min)	31	0.47	0.402	0.15	2.22
Pile (min)	31	0.48	0.189	0.092	0.96
Arrange (min)	8	0.31	0.174	0.14	0.66
Brush (min)	5	0.20	0.041	0.15	0.26
Total time (min)	31	1.9	1.05	0.59	5.56
No. of stems	31	5.2	2.18	2	12
Volume per bundle (ft^3)	31	28.8	15.93	6.9	65.5
Productivity (ft^3/PMH)	31	958.2	508.12	245.3	2927.1
Bundle diameter (in)	31	6.7	0.983	5.4	9.7
Bundle height (ft)	31	41.5	3.32	33.3	46.3

While processing bundles the largest portion of cycle time was spent reaching for trees to process, which accounted for 36% of the total cycle time. Processing and piling stems accounted for 25% of the total cycle time each. Moving between bundles occupied 9% of the total time, while arranging stems and clearing unmerchantable standing trees occupied the remaining 5%.

Using General Linear Models procedure total cycle time was found to be most significantly influenced by the number of stems and the square of the mean bundle diameter. Using a mean bundle diameter of 6.7 inches, the regression line predicting total time as a function of number of stems is displayed in Figure 2.

Total cycle time (min) = 3.2088 - 0.47366*Stems - 0.065014*MDbh^2 + 0.017267*Stems*MDbh^2
$R^2 = 0.73$; C.V. = 30.0%; n = 31
where: Stems = number of stems processed
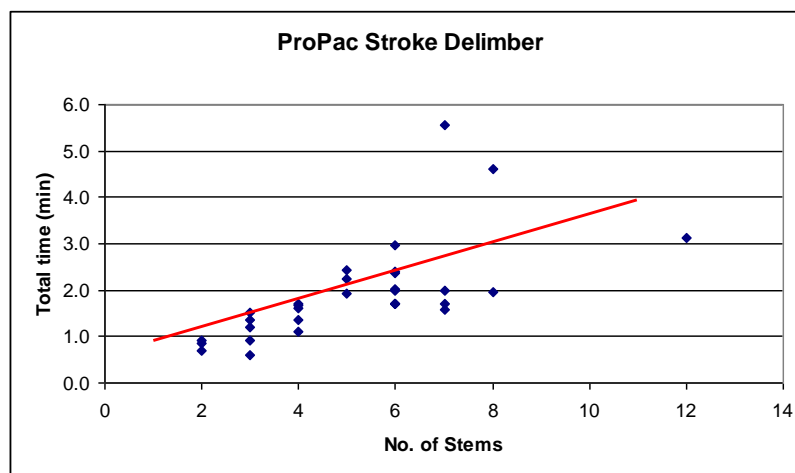MDbh^2 = mean bundle diameter (inches)

Figure 2. Plot of regression predicting total cycle time for the stroke delimber for a mean stem diameter of 6.7 in.

Skidding

A total of 20 observations were collected for a range of one-way skid distances of 241 to 423 feet (Table 4). Of the variables tested for predicting total cycle time (distance, no. of stems, mean DBH, and cycle volume), none were found to be significant. Therefore, no regression line is reported for the skidder.

The operator focused on skidding stems by products, either sawlogs or products other than logs (POL's) to the landing. This required a significant amount of time sorting in the woods by the skidder. The skidder spent 29% of total cycle time positioning and grappling, which included sorting of products to skid. Percentage of time spent traveling empty and loaded was about the same at 21% and 22%, respectively. Intermediate travel consumed 13% of the total cycle time, which consisted skidder travel while transporting stems to a staging area, or collection point, for the payload. Piling stems at the landing accounted for 15% of the total time.

Table 4. Summary of descriptive statistics for the John Deere 648E skidder.

Variable	N	Mean	Std. Dev.	Min.	Max.
Travel empty (min)	20	1.07	0.251	0.77	1.81
Position and grapple (min)	20	1.48	1.096	0.16	4.63
Intermediate travel (min)	17	0.76	0.764	0.14	3.08
Travel loaded (min)	20	1.13	0.329	0.37	1.73
Pile (min)	16	0.93	0.434	0.45	2.33
Total time (min)	20	5.07	1.797	2.8	10.4
No. of stems	20	13.2	4.76	8	26
Volume per bundle (ft^3)	20	62.5	27.00	14.6	118.2
Productivity (ft^3/PMH)	20	812.8	399.11	146	1583
Travel empty distance (ft)	20	329.5	49.88	239	422
Travel loaded distance (ft)	20	309.1	58.56	238	423
Oneway distance (ft)	20	319.3	47.03	241	423

Loading

Production data were not collected for the loader. Cost per unit for the loader to load sawlogs was estimated by assuming it could load a 10-cord trailer in 30 minutes (Lanford, 1990), which resulted in a total cost of $29.07/SMH. Using $10.50 plus $0.53 fringes for a Group 1 laborer (Davis-Bacon Wage Rates) resulted in $11.03/Scheduled Machine Hour (SMH) labor cost for handling POL. Assuming two workers resulted in a total cost of $22.06/SMH to process and load POL material.

Costs

Individual machine costs were calculated using standard machine rate analysis (Miyata, 1980). This reflects the average owning and operating costs over the life of the machine. Depreciation costs were determined using the straight-line method. Interest costs were based on 9% of the Average Yearly Invesment (AYI). Salvage values, insurance, fuel and lube, and repair and maintenance costs, were calculated using appropriate estimators (Brinker and others, 2002). A 5-year life was assumed for all machines with a fuel cost of $1.45/gal. A labor rate for machine operators of $11.73 for Carbon County, Wyoming was used (Davis-Bacon Wage Rates), plus 18% for benefits. A utilization rate of 75% was used for all machines except the loader, where a 50% rate was assumed. The feller-buncher had a total cost of $70.68/SMH, followed by the delimber at $64.79/SMH. The skidder had a total cost of $52.56/SMH.

CONCLUSIONS

Variables that most significantly affected total cycle time of the feller-buncher were number of stems cut per cycle and move distance. Cycle time averaged 1.83 min while mean productivity was 6.9 cunits/PMH. The stroke delimber was capable of processing 5.2 stems in 1.9 min, which resulted in a mean productivity of 9.58 cunits/PMH. Variables that most significantly affected total cycle time of the delimber were number of stems processed and mean bundle diameter squared. The skidder was able to transport 0.63 cunits of wood in 5.1 min at a mean one-way distance of 319 feet. This resulted in a mean productivity of 8.13 cunits/PMH.

Using the production rate of the feller-buncher of 5.17 cunits/SMH as the limiting factor in the system and calculating new utilization rates for the other machines, this system was capable of

moving wood from stump-to-deck for $188/SMH, or $42/cunit. Adding the cost to load sawlogs and process and load POL material resulted in a total system cost from stump-to-truck of $239/SMH.

Assuming the feller-buncher was not required to fell material less than 5 inches, system rate would increase to 5.69 cunits/SMH, reducing stump-to-deck cost to $39/cunit.

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Productivity and Cost Evaluation for Non-guyline Yarders in Northern Idaho

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INTRODUCTION

Harvesting areas often include a riparian zone that requires protection from logging activities (Lawson 2002). Felling and wood extraction activities in these zones can be prohibitive due to strict environmental requirements and higher logging costs. Greater difficulties occur on small parcels of steep slopes (> 35%) along streams and lakes, where ground-based wood extraction may not be applied. In such environmentally sensitive areas, it is hard to justify use of large or expensive cable or helicopter logging equipment to harvest timber. Therefore, there are not only environmental requirements (Idaho's Forest Practices Act), but also economic objectives to be achieved in these sensitive areas from commercial thinning operations.

A new approach for skyline operations that is suited to harvesting timber on steep slopes and environmentally sensitive zones is the use of non-guyline yarders with a gravity skyline system. Non-guyline yarders have been developed by adding a winch and a tower to conventional logging equipment (feller-bunchers and excavators). Without guylines to rig, the machine can be moved more quickly between landing positions along the hauling roads, or within stands. The elimination of guylines on the rear of the main spar, also allows forest traffic to pass without disruption of the yarding operation.

The objectives of the study were to: 1) determine yarding production rates and costs for two non-guyline yarders, and 2) evaluate their operational capabilities and limitations in commercial thinning operations in Northern Idaho.

STUDY METHODS

Non-guyline yarding equipment

Two modified yarders without guylines were recently introduced in northern Idaho by independent logging contractors for use in commercial thinning: the TIMBCO T-425 yarder (a feller/buncher-based machine), and the CAT 315-L yarder (an excavator-based machine). Both were re-built as yarders with the addition of a two-drum winch (Allied Winch W400™ model) and a small tower for use as a gravity skyline system without guylines. (Table 1). A live skyline with a gravity carriage return (Christy™) and with lateral yarding capacity was used for both TIMBCO and CAT yarders to transport logs and tree-lengths uphill to the landings respectively (Fry 1983). Both yarders allowed for

minimization of the initial investment because they use re-built equipment. The non-guyline yarders can operate with crew size of two-persons, which also means a reduced labor cost, compared with conventional yarders such as the Christy and the Ecologger (Sturos et al. 1996; and Fisher et al. 1980).

Table 1. Technical specifications of non-guyline yarders

Technical Specifications	TIMBCO T-425 yarder	CAT 315-L yarder
Machine base	Feller-buncher	Excavator
Diesel engine	169 Hp Cummins B	102 Hp Caterpillar 3046T
Operating weight (lb)	58,422	38,360
Ground pressure (lb/inch^2)	6.46	5.65
Under-carriage type	CAT D6H	CAT D5H
Upper-carriage type	Self-leveling capability	Non self-leveling capability
Tower height (ft)	28	25
Tower-end	Lattice boom-end	Excavator bucket

Study sites

Two sites were selected near the town of Saint Maries in northern Idaho. Both sites had similar species composition of western white pine (*Pinus monticola*) and Douglas-fir (*Pseudotsuga menziesii*) (Benson et al. 1987). Characteristics of the stands and site conditions are listed in Table 2: Syringa South (TIMBCO site) and Heinaman Creek (CAT site). The prescription for both sites included a commercial thinning leaving a residual stand of 60 to 65 trees per acre. The site conditions and thinning treatments were similar in both working units, but the initial number of trees per hectare was lower on the Heinaman Creek site and average tree size was larger.

Table 2. Study sites and stand characteristics

Characteristics	Syringa South	Heinaman Creek
Area (acres)	16.80	25.45
Age (years)	60	80
Trees per acre	324	252
Stand DBH (inch)	11	13
Stand height (ft)	75	82
Avg. ground slope (%)	41	45

Yarding operations

In both working sites, the skyline corridors were arranged in a fan-shape pattern from landings. Tail trees were used to create required deflection in all skyline corridors. Yarding distances ranged from 15 to 540 ft. Single-span skyline configurations were used at both sites without intermediate supports.

Although it could have operated with a two person crew, the TIMBCO yarder operation had two choker-setters, and one yarder operator and was observed only at roadside yarding. A log-length harvesting method was used, in which felling, delimbing and bucking were done with a mechanized Volvo ™ harvester and logs were extracted to roadside. Logs averaged 29 ft in length with an average diameter of 10 inch. Average yarding distance was 261.34 ft with an average lateral distance of 15.17 ft.

The CAT yarder operation was organized with one choker-setter and one yarder operator. The Cat operation alternated work duties of the two workers each half-day to reduce job fatigue, as well as allow both of the crew to gain experience in operating the yarder. In this operation a tree-length method was implemented. Trees were felled, delimbed and topped with chainsaws before yarding. The tree-lengths were extracted in two different ways. First by extracting with the yarder to roadside landings, and secondly by yarding within the stand and forwarding with a grapple-skidder to a landing for processing.

Yarding Study

Detailed time studies were conducted to collect data on every machine work cycle: outhaul, lateral-out, hook, lateral-in, inhaul, unhook, and delays. For each cycle, number of logs (TIMBCO) or tree-lengths (CAT), yarding distance, lateral distance and slope were collected. Whenever road and landing changes occurred, the rigging and set-up times were also measured and recorded. Time elements of the road/landing changes were also recorded in centi-minutes with a stopwatch. The distances between road/landing changes, and lateral and yarding distances were measured in meters using a rangefinder. The average piece volume for each site was calculated by sampling piece size at landing and using log-scaling information provided by the mills.

A cost appraisal procedure was developed to evaluate the equipment investment, as used and re-built machines (Cothren 2002). Investment was estimated as 50% of the initial value (20% salvage and 30% major overhaul) plus the value of the yarder attachments: tower, winch and carriage. The owning, operating and labor cost per hour for yarding were computed using the Miyata machine rate calculation method including labor cost ($20.00/hr) and fringe benefits (40%) (Miyata 1980).

- ❑ TIMBCO T-425 yarder: ($ 315,000) (0.5) = $ 157,500
  CAT 315-L yarder: ($ 280,000) (0.5) = $ 140,000
- ❑ Tower, winch, and carriage = $ 40,000. It was considered the same for both machines.
- ❑ Total investment
  TIMBCO T-425 yarder: $ 197,500
  CAT 315-L yarder: $ 180,000

RESULTS AND DISCUSSIONS

The equations for predicting delay-free cycle time for each operation were developed with the number of logs/tree-lengths, lateral distance, and the yarding distance as significant independent variables at a level of 95% ($p < 0.05$). Ground slope was found not to be significant at the same significance level in both operations. Multiple regression analyses are illustrated in Table 3 and 4.

Table 3. Yarding cycle elements, independent variables and statistics for the TIMBCO yarder.
(N=218 observations)

Yarding phase	Min/cycle	(% cycle)	Equation	R²	SE
Travel empty (Outhaul)	0.33	6	Y (centi-min)= 20.0780 + 0.4883 (X) X = 261.34 ft (Yarding distance)	0.30	11.98
Lateral outhaul	0.39	6	Y (centi-min) = 39.26	-	-
Hook	1.92	32	Y (centi-min) = 192.22	-	-
Lateral inhaul	0.21	4	Y (centi-min) = 8.1016 + 0.8601 (X) X = 15.17 ft (lateral distance)	0.26	18.63
Travel loaded (Inhaul)	0.59	10	Y (centi-min) = 58.61	-	-
Unhook	1.44	25	Y (centi-min) = 144.31	-	-
Delay-free cycle	4.88	83	Y (centi-min) = 301.0938 + 27.4456 (X1) + 0.2961 (X2) + 0.2312 (X3) X1 = 3.81 (# logs) X2 = 261.34 ft (Yarding Distance) X3 = 15.17 ft (Lateral distance)	0.28	102.47
Yarding delays	0.46	8			
Road/land. changes	0.51	9			
Average cycle	5.85	100			

Table 4. Yarding cycle elements, independent variables and statistics for the CAT yarder.
(N=237 observations)

Yarding phase	Min/cycle	% cycle	Equation	R²	SE
Travel empty (Outhaul)	0.21	4	Y (centi-min) = 9.4824 + 0.05668 (X) X = 199.40 ft (Yarding distance)	0.52	8.57
Lateral outhaul	0.20	4	Y (centi-min) = 12.2712 + 0.4041 (X) X = 19.82 ft (Lateral distance)	0.19	22.00
Hook	1.45	29	Y (centi-min) = 145.36	-	-
Lateral inhaul	0.16	3	Y (centi-min) = 9.7074 + 0.3469 (X) X = 19.82 ft (Lateral distance)	0.23	16.75
Travel loaded (Inhaul)	0.54	11	Y (centi-min) = 36.96843 +0.0830 (X) X = 199.40 ft (Yarding distance)	0.26	22.37
Unhook	1.23	24	Y (centi-min) = 122.50	-	-
Delay-free cycle	3.79	75	Y (centi-min) = 267.3049 + 0.26540 (X1) + 15.4750 (X2) + 0.61018 (X3) X1 = 199.40 ft (Yarding distance) X2 = 3.01 (# logs) X3 = 19.82 ft (Lateral distance)	0.21	78.78
Yarding delays	0.61	12			
Road/land. changes	0.67	13			
Average cycle	5.07	100			

The variability of some of the cycle time elements was not totally captured by the independent variables that were measured especially in elements, such as in the hook and unhook times. In the case of the hook time, there were other factors such the terrain

roughness and worker fatigue associated with longer yarding/lateral distances that might explain the high variability in cycle times. In the situation of the unhook time, the machine alignment with the yarding corridors to obtain the required deflection in most of the yarding turns was another factor that might also explain the degree of variability of this activity.

The resulting delay-free cycle time was 28% longer at the TIMBCO site (4.88 min) than at the CAT site (3.79 min). Hook time was the longest time element of the yarding cycle (30% cycle) for both operations. Unhooking was the second most time consuming element (25% cycle).

Landing and road changes on average, took slightly longer (0.67 min / turn) at Heinaman Creek (CAT yarder) than at Syringa South (0.51 min / turn). This was because the CAT yarder was used both on the roads and within stands, with a longer lateral distance: 18.92 ft vs. 15.17 ft, as well as with a larger average piece size: tree-length 50.00 ft^3 vs. logs 19.42 ft^3 for the TIMBCO.

The average set-up and rigging time for road/landing changes was 9% (TIMBCO) and 13% (CAT) of the average yarding cycle time, which may be explained by differences between time spent rigging skyline corridors and time spent on moves between settings. In the case of the CAT settings, most of the set-up time was spent to move between settings within stands. Average road/landing changing times ranged from 26.8 minutes up to 27.2 minutes respectively. Yarding productivity and costs are illustrated in Table 5.

Table 5. Yarding production rates and costs

	TIMBCO Yarder	CAT Yarder
Average logs per turn	3.81	3.01
Avg. volume per log, ft^3	19.42	50.00
Utilization rate (%)	78	70
Machine rate, $/PMH	163.37	133.11
Production rate, ft^3/PMH	532	1,052
Yarding costs, $/ft^3	0.31	0.13

CONCLUSIONS

Non-guyline yarders are innovative technologies and demonstrated a good potential to efficiently remove trees in environmentally sensitive areas. Both non-guyline yarders are highly productive operations in the proper settings when compared with conventional skyline systems primarily due to faster road changes (less than 30 minutes) and short yarding distances (average <328 ft). The average piece size removed (cut-to-length vs. tree-length) and crew size (2 or 3-persons) greatly affected production rates and costs.

Both modified yarders were shown to be highly mobile and flexible equipment in commercial thinning because of the lack of guylines resulting in faster moving times for operating and set-up/rigging. The operational capability of yarding within stands without fastening guylines of the tower may allow efficient log extraction in the areas where the logs can not be skidded by ground-based equipment to the landings or on highly environmentally sensitive areas. They can work effectively off established roads and access areas that would otherwise require additional road construction. In these situations this type of yarders have unique applications compared with conventional yarders.

One of the major drawbacks of the non-guyline yarders observed was a decreased stability during lateral-in and inhaul operations when some hang-ups and wire crosses occurred. The short yarding/lateral distances that were used mean that these yarders require more frequent skyline road changes than the conventional yarding equipment.

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Economics of an Integrated Harvesting System in Fuel Reduction Thinning in Western Montana

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INTRODUCTION

Mechanical thinning combined with biomass harvesting of small-diameter trees has been increasingly considered in the Inland Northwest of the United States to reduce the risk of wildfires. Removing low-value biomass from the forest significantly increases the total costs of treatments, especially with small-diameter stands since harvesting production declines as tree size and removal intensity per acre decrease (Hartsough et al. 1997, and Hartsough 2003).

An integrated approach to harvesting both roundwood and biomass simultaneously is often preferred in fuel reduction treatments in which thinning-from-below is used. It effectively reduces the risk of forest fires by removing ladder fuels in forest stands and maximum utilization of forest biomass can be achieved. Harvesting both roundwood and biomass within an operation allows for the small-diameter trees and logging slash in many overstocked stands to be recovered profitably.

Forest biomass produced from fuel reduction thinning creates an opportunity for generating power. This bio-energy may be a substitute for fossil fuels under certain conditions, contributing to a reduction in emissions of gas that affect climate changes (Han et al. 2004). However, the economics of fuel reduction thinning need to be evaluated due to high costs for thinning and transportation as well as low market value of thinning products. The objective of this study was to evaluate the economics ($/acre) of an integrated whole-tree harvesting system and transportation to achieve fuel reduction objectives and maximum utilization of forest biomass in a small-diameter stand.

STUDY METHODS

The harvesting system examined in this study was an integrated whole-tree system that included a feller-buncher (Timberjack 2628), a grapple skidder (John Deere 648E), a stroke-processor (Daewoo DH 280), a mobile chipper (Bandit Model 3680 Beast Track), a loader (Kotmatsu), and a crawler tractor (Dresser). A self-loading truck-trailer (Kenworth / Peerless) loaded the saw logs for transport to a sawmill, and a front-end loader (CAT 950) with a bucket loaded the hog fuels into a 45-ft chip-van truck (Kenworth) for transport to a co-generation plant. With an integrated harvesting approach, logging residues and non-merchantable trees are chipped into biomass fuel (hog fuel) for energy production, at the same time merchantable saw logs are recovered from the roundwood production.

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The study site (19.53 ha) was located in the centralwest Bitteroot Mountains of Montana, 50 miles SE of Missoula in private forest lands (Burnt Fork Ranch). The dominant species on the site were Douglas-fir (*Pseudotsuga menziessi*) (83%) with some scattered Ponderosa Pine (*Pinus ponderosa*) (17%). The average stand age was 35-years. The prescription included removal of all suppressed trees and trees less than 16 inches diameter at breast height (DBH) through a low thinning (thinning–from–below), leaving dominant and co-dominant trees. A final density of approximately 40 trees per acre was required with a shift to Ponderosa Pine as the dominant species. Figure 1 illustrates the diameter distribution of the trees thinned and the final stand density.

Figure 1. Tree size distribution in the study area

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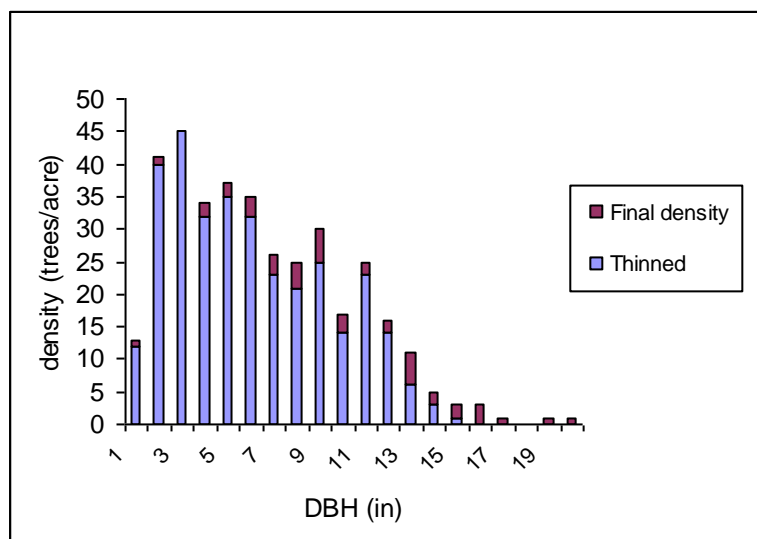
Tree sizes were categorized into three average DBH classes (3, 7, 12 in.), which were used to estimate tree volume, harvesting production, and product recovery. Merchantable volumes were calculated for each tree using a parabolic formula. Bark added 9% of the bole volume, and crown volume was estimated based on the crown weight table and a conversion factor of 25 lb/ft^3 (Brown et al. 1977). During the harvesting operation, trees to cut were selected by the feller/buncher operator. All skidding was done on favorable grades with slopes not exceeding 30% and skidding distances averaged 1,088 feet.

Saw log volumes were obtained by scaling random samples of the two forest species. Weight and moisture content of biomass chip-vans were recorded to calculate product recovery for both products. Production rates were measured in units of cubic feet for saw logs and in short green tons (2,000 lb/ton) for the hog fuels. Number of pieces handled were also recorded during random hourly sample periods for the felling/bunching, skidding, processing, loading, and chipping operations.

Detailed time studies were conducted to collect data on felling, skidding, processing, chipping, and saw log loading. Small delays (less than 15 minutes) and production rates

were also captured. The recorded data included productive cycle time elements and independent variables associated with each activity. Shift level time studies were conducted to gather data on scheduled hours, daily production, and large delays (over 15 minutes). Productive time elements and small delays were recorded by a stop-watch in centi-minutes. Statistical Analysis System (SAS) software was used to perform multiple regression analyses to predict delay-free cycles times. The significant independent variables were selected from the stepwise regression analysis when the p-value was less than 0.05.

Machines rates were calculated for each operation in terms of hourly cost for both fixed costs (owning costs) and variable costs (operating costs) based on productive machine hours (PMH). These calculations included labor cost ($13.50/hr), and fringe benefits (40%). Production costs for thinning products were calculated by using an apportioned allocation method (Hudson et al. 1990), in which felling/bunching and skidding were allocated jointly to both products. Processing was allocated only to saw logs and chipping/loading and cleaning biomass were allocated only to hog fuels. Loading/transportation were calculated for each thinning product. Production costs for saw logs were converted from ft^3 to MBF with the conversion factor 210.08 MBF/ft^3. Production costs for hog fuels were converted from green tons to BDU by using three different conversion factors at different moisture content (MC) levels. Current market prices for small-diameter saw logs and biomass fuels in the Inland Northwest were used to estimate potential revenue ($/acre) from selling thinned materials. Net returns ($/acre) were then calculated for each product recovery, and economics was defined by a cost-benefit analysis on a per-acre basis.

RESULTS AND DISCUSSIONS

The average volume per tree removed was 12.15 ft^3 and the average removal volume was 3,875 ft^3 per acre. The treatment left a residual density of 43 trees per acre (92% of Ponderosa Pine). The average removal was 1.59 MBF/acre for the saw logs, and 14.82 BDU/acre for the hog fuels. For each stump-to-mill operations; delay-free cycle time, independent variables, statistics and regression relationships were tabulated and are shown in Table 1.

Table 1. Delay-free cycle time, independent variables and statistics, and total cycle time

Operation	Regression Model	R^2	N	Y=Delay-free Cycle Time (Min / cycle)
STUMP-TO-LANDING				
Felling/bunching	Y (centi-min)= 23.4733 + 11.5230 (X) X= 3.00 trees	0.67	437	0.58
Skidding	Y (centi-min) =175.1519 + 1.668 (X) X= 331.69 m (skidding distance)	0.90	77	7.28
Processing	Y (centi-min)= 43.0837 + 48.9853 (X) X = 1.33 logs	0.45	451	1.08
Chipping/loading	Y (centi-min) = 19.2610 + 15.9740 (X) X = 2.65 trees	0.56	547	0.62

Cleaning				0.50
TRANSPORTATION				
Saw log loading	Y (centi-min)= 20.7010 + 17.2969 (X) X = 1.31 logs	0.45	520	0.43
Saw log transportation (*1)				202.00
Hog fuel loading				1.02
Hog fuel transportation (*2)				275.00

(*1) Transportation distance: 48 miles
(*2) Transportation distance: 52 miles

The productivity of felling/bunching operations was low because of the small volume per piece, as well as the small amount of saw logs volume (17% of the harvested volume) in the study area. Skidding productivity was also low due to long traveling distances (average skidding distance 1,088 ft), but there was much volume (83% of the total harvest) of forest biomass for chipping. The average speed for transportation was 32.50 miles/hour over a 48-miles hauling distance for the saw logs, and 33.38 miles/hour over a 52-miles transportation distance for the hog fuels. Table 2 summarizes machines rates, production rates, and production costs for each stump-to-mill operation.

Table 2. Productivity and costs of the integrated whole-tree harvesting system

Operation	Machine Rates	Production Rates			Production Costs		
	($ / PMH)	Saw log (ft³/PMH)	Hog fuel (gton/PMH)	($/ft³)	Saw log ($/MBF)	Hog fuel ($/gton)	($/BDU)
Felling/ bunching	78.08	858.68	19.32	0.0909	19.10	4.04	8.24
Skidding	45.69	781.89	17.59	0.0584	12.28	2.60	5.30
Processing	69.94	1,098.73		0.0636	13.37	-	-
Grinding	84.58	-	25.16	-		3.36	6.45
Biomass loading	56.25	-	25.16	-		2.24	4.29
Biomass cleaning	39.13	-	54.30	-		0.72	1.38
Saw log loading	56.65	641.59	-	0.0883	18.55	-	-
Saw log transportation	56.65	222.41	-	0.2547	53.51	-	-
Hog fuel loading	38.45	-	41.37	-		0.93	1.43
Hog fuel transportation	53.46	-	5.06	-		10.57	16.28
Total Costs				0.5559	116.81	38.51	43.37

The apportioned allocation method for both thinning products gave a total production cost per acre of $ 828.12. The potential revenue per-acre basis was estimated in a total at $959.75/acre based on the current market prices around the study area: $362/MBF for saw logs and $26/BDU for biomass fuels. Saw logs made the high contribution with 60% of total revenue ($ 959.75/acre). However, it represented only 17% of the harvested volume. Hog fuel contributed 40% of the total revenue while representing 83% of the harvested volume. Saw log production had a positive net return while hog fuel gave a negative net return. The overall economics gave a positive net return. The economics for each thinning product in an acre basis is illustrated in Table 3.

Table 3. Economics of the integrated whole-tree harvesting system

Products return	Revenue	Cost / acre		Net
	($/acre)	($/acre)	($/acre)	
Saw log	574.42	185.36	389.06	
Hog fuel	385.33	642.76	(257.43)	
Total	959.75	828.12	131.63	

CONCLUSIONS

The integrated whole-tree harvesting system was effectively used to accomplish fuel reduction objectives for the thinning prescription, leaving a small residual density of 43 trees per acre (92% of Ponderosa Pine), and minimizing the potential for fire hazards in the study area. The harvested tree size was averaged at 7-inch DBH with removal of 1.59 MBF/acre of the saw logs and 14.82 BDU/acre of the hog fuels.

Saw logs made high contribution with 60% of the total revenue, while hog fuels contributed 40%. However saw logs represented only 17% of the total harvested volume. The harvesting cost of the biomass fuels component was balanced with the high revenue that was obtained from the roundwood production. This indicates that net returns of an integrated whole-tree harvesting system might be increased with an increase in the saws log component of the system. This will also depend on species, tree size, transportation distances and market values of the thinning material. The economics of the overall operation gave a positive net return although the harvesting costs were relatively high (saw logs $ 116.81/MBF, and $ 43.37/BDU for hog fuels), and the prices of thinning products were considered to be low. The saw log production gave a positive net return, however the biomass fuels operation was unprofitable.

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PRODUCTION ECONOMICS OF HARVESTING YOUNG HARDWOOD STANDS IN CENTRAL APPALACHIA

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ABSTRACT

Three harvesting systems of chainsaw/cable skidder, fell-buncher/grapple skidder, and harvester/forwarder were simulated in harvesting three hardwood stands of 30 to 50 years old in central Appalachia. Stands were generated by using a stand generator and harvesting prescriptions included clearcut, shelterwood cut, selective cut, diameter limit cut, and crop tree release cut. The interactions among stands, harvest prescriptions, and harvesting systems were evaluated in terms of production/cost, and traffic intensity. Results should be useful for planners, loggers, and foresters to efficiently manage and utilize small diameter materials in the region.

INTRODUCTION

Harvesting young stands of high densities and with small diameter trees is becoming a concern to forest products companies, loggers, and landowners in order to reduce fuel loading and improve residual stand health and timber utilization. However, such a harvesting usually is more labor intensive and not cost-effective due to the small piece size processed and the unmerchantable harvested products. LeVan-Green and Livingston (2001) reported that average costs for thinning on small diameter trees is approximately $70/ton while traditional markets for thinned material can only pay approximately $25/ton for energy and $35/ton for chips.

Production and economic feasibility of thinning or partial cutting have been reported by many researchers in different regions. Miller (1993) studied the financial aspects of partial cutting practices in uneven-aged central Appalachian hardwood stands. He reported that single-tree selection is good for regeneration of a desirable, commercial tolerant species. Miller and Baumgras (1994) evaluated four silvicultural practices (single-tree selection, group selection, two-age management, and even-aged management) for managing eastern hardwoods in terms of economic feasibility. They indicated that two-age management gave the highest production rate for the sawtimber only option and single-tree selection had the lowest production rate.

Research on the interactions of stand conditions, machine attributes, and harvest prescriptions especially for harvesting young hardwood stands appears to be lacking in the region. Such a lack of information has resulted in management decisions being based on either experience or very limited field tests. The objectives of this study are to (1) generate three Appalachian hardwood stands of 30, 40, and 50 years old, respectively, (2) perform harvesting and extraction operations on these three stands under different harvesting prescriptions by using a computer simulation model, and (3) statistically evaluate the production/cost effectiveness of the alternative harvesting systems.

MATERIAL AND METHODS

Stands

Three natural young hardwood stands of 30, 40, and 50 years old in central Appalachia were generated using a 3D stand generator (Wang et al. 2002). Each stand was 1.0 acre in size and with random distribution. Stand densities were 531, 374, and 290 trees per acre 30, 40, and 50 years old stands, respectively. DBH averaged 5.2, 6.6, and 8.3 inches while the average total height varied from 69.6, to 54.7, and to 55.7 ft. for these three stands, respectively. Major species included sugar maple, American basswood, sweet birch, black cherry, yellow poplar, and black cherry.

Harvesting Systems

Two commonly used harvesting systems of chainsaw (CS)/cable skidder (CB) and feller-buncher (FB)/grapple skidder (GP) in central Appalachia together with harvester (HV)/forwarder (FW) system were examined in the simulation study. Functions that were modeled for each machine were as follows (Wang and Greene 1999, Long 2003):

Chainsaw: walk to tree, acquiring, cutting, and topping/delimbing;
Cable skidder: travel empty, choke, travel loaded, and unchoke;
Feller-buncher: drive to tree, cut tree, drive to dump, and dump;
Grapple skidder: travel empty, grapple, travel loaded, and release;
Harvester: move, boom extend/retreat, cut, swing boom, processing, and dumping;
Forwarder: move to load, load, travel loaded, and unload.

Felling simulations were performed on a 1.0-acre plot, which was replicated 36 times and gave a total of 36 acres of each stand for extraction simulations. The felling machine was first located at one end of the plot, then it moved parallel to a swath of trees. When the end of the swath was reached, the machine turned back and started another nearest swath until all trees selected to be cut were felled (Wang and Greene 1999). For the extraction simulation, landing was assumed to be in the middle grid at the bottom of the logging site and the main skidding roads were located in the middle of the logging site for cable and grapple skidders. Forwarder followed the trail of the harvester.

Four travel intensity categories were used to monitor the traffic of skidders and forwarder (Carruth and Brown 1996):

TI1 – Trees on the plot have been felled.
TI2 – Trees that stood on the plot have been removed and no other traffic has passed through the plot.
TI3 – Trees that stood on the plot have been removed and trees outside the plot have been skidded through the plot. Passes with a loaded machine are between 3 and 10.
TI4 – More than 10 loaded machine passes have been made through the plot.

Harvesting Prescriptions

Five different harvesting methods were examined including clearcut (CC), shelterwood cut (SW), crop tree release cut (CT), diameter limit (DL), and selective cut (SC). The smaller trees were removed in favor of desirable shade-tolerant trees for the shelterwood cut while the selective cut removed dominant trees and stimulated the growth of the trees of lower crown classes. The diameter limit cut removed all trees larger than 12 inches DBH. Taking stumpage price into consideration, crop tree release cut removed 80% of the basal area and released valuable species such as black cherry, red oak, walnut, and hard maple selective cut removed 30% of basal area.

Data Analysis

A three-factor, full factorial design (3x3x5) was implemented for the experiment. There were a total of 45 treatment combinations. Each combination was replicated three times for a total of 135 felling simulation experiments. Another 135 extraction simulations were conducted based on felling results. Data were analyzed using analysis of variance (ANOVA).

RESULTS

Felling Operations

Average DBH of felled trees varied from 6 to 17 inches while average total height was between 50 and 81 feet (Table 1). Volume per felled tree changed from 4.5 to 35.3 ft^3. Volume per acre removed was between 713.6 and 1997.8 ft^3. Distance traveled between harvested trees differed significantly among stands, and between

harvester and chainsaw or feller-buncher. Harvester always presented the least ground travel distance and was about half the distance by a feller-buncher or a logger with chainsaw. This was due to the harvester can cut several trees at one machine stop.

Cut time per tree differed significantly among stands (F = 88.62; df =2,134; P = 0.0001) and felling machines (F = 260.36; df =2,134; P = 0.0001). It was not significantly different among clearcut, shelterwood cut, and crop tree release cut because these three harvest methods removed trees of similar sizes. Felling cycle time differed significantly among machines (F =2470.86; df =2,134; P = 0.0001) but it was not significantly different among stands.

Felling productivity was significantly different among stands (F = 5828.57; df =2,134; P = 0.0001) and among felling machines (F = 9135.05; df =2,134; P = 0.0001) with 595.16 ft^3/PMH for clearcut and 386.57 ft^3/PMH for shelterwood cut. Hourly felling production increased with the DBH of felled trees. Harvester was more sensitive to DBH than feller-buncher and chainsaw. Feller-buncher felling consistently presented the higher productivity compared to chainsaw and harvester felling.

Extraction Operations

Bunch size averaged 22.6, 51.8, and 112.6 ft^3 for 30-year-old, 40-year-old, and 50-year-old stands, respectively (Table 2). Turn payload varied from 86.1 of grapple skidder, to 109.5 of cable skidder, and to 411.2 ft^3 of forwarder. Average extraction distance (AED) varied among stands, harvest, and machine. Forwarder resulted in a longer forwarding distance of 1041 feet due to its larger payload. Average skidding distances with cable and grapple skidders were similar and ranged from 700 to 805 feet.

Average skidding time was 16.0 and 12.9 minutes for cable and grapple skidders, respectively. Forwarding cycle time averaged 38.9 minutes. Extraction cycle time differed significantly among extraction machines (F = 875.09; df = 2,134; P = 0.0001). TI2 differed significantly among stands (F = 40.20; df = 2,134; P = 0.0001) and extraction machines (F = 466.85; df = 2,134; P = 0.0001). Both TI3 and TI4 were also significantly different among stands and among extraction machines. Extraction productivity averaged 253.4, 589.4, and 803.1 ft^3 per PMH for cable skidder, grapple skidder, and forwarder, respectively. It differed significantly among stands (F = 1005.25; df = 2,134; P = 0.0001) and extraction machines (F = 8366.77; df = 2,134; P = 0.0001).

Cost and System Analysis

The harvesting systems were balanced and compared based on their cost and production rate. One chainsaw and one cable skidder were used for the chainsaw/cable skidder system, one feller-buncher and two grapple skidders were used for the feller-buncher/grapple skidder system, and two harvesters and one forwarder were used for the harvester/forwarder system. Cost estimates of logging machines were calculated by using the machine rate method (Miyata 1980). Hourly cost of a representative chainsaw was $29.0/PMH in the region with a mechanical availability of 50% (Long 2003). Feller-buncher has an hourly cost of $94.6. Hourly costs were estimated at $48.6 and $44.3 for cable and grapple skidders. Operating harvester and forwarder could cost $99.5 and $72.6 per hour, respectively.

The productivity of chainsaw/cable skidder (CS/CB) system was 164.6 ft^3/PMH with the unit cost of $0.38/ft^3 in clearcut while system productivity decreased to 86.7 ft^3/PMH with the unit cost of $0.73/ft^3 in shelterwood cut. Compared with the manual system (CS/CB), the two mechanized systems of feller-buncher/grapple skidder (FB/GP) and harvester/forwarder (HV/FW) were much more productive. They required higher initial investment and maintenance fees. However, their relatively higher production somewhat offset the higher costs. System productivity increased while the unit cost decreased from chainsaw/cable skidder system to harvester/forwarder, and to feller-buncher/grapple skidder system. System production rate and unit cost also varied with harvest methods.

CONCLUSIONS

Felling production and cost were affected by tree size removed, harvesting prescriptions, and machines. Compared with chainsaw and feller-buncher, harvester was more sensitive to individual tree size. Feller-buncher was the more cost-effective and productive felling machine. Clearcutting always presented the highest productivity while the shelterwood cut was the lowest productive method. The crop tree release cut removed the smaller trees, which had almost the same silvicultural effects as shelterwood cut but without sacrificing the stumpage price. The productivity of crop tree release cut was similar to diameter limit cut and selective cut.

Extraction was mainly affected by payload size and average extraction distance. Due to its higher payload, forwarder was the most productive machine with an hourly production of 803.1 ft^3/PMH, which was about three times higher than that of a cable skidder. The lower productivity of cable skidder was partly caused by the time consumed for choking, which accounted for about 25 percent of the total cycle time of the cable skidder skidding. TI3 and TI4 was one of the most concerns because of the higher damage level to the soil. Because of the lower payload and more machine passes, the TI3 and TI4 level for both cable skidder and grapple skidder was up to 40% across the site in clearcut and still more than 20% with the other three methods (SW, CT, DL). However, TI3 and TI4 level was consistently less than 20% across the site with forwarder no matter what harvest method was used.

Chainsaw/cable skidder system was the least productive system in comparisons with harvester/forwarder and feller-buncher/grapple skidder systems. The feller-buncher/grapple skidder system was the most cost-effective in harvesting young hardwood stands under the simulated harvesting prescriptions. The simulated results in this study can be used as guidance for managing young hardwood stands in central Appalachian region. It is also helpful for evaluating different harvest methods and harvesting prescriptions. Future work should include the operating cost for marking trees, which is not negligible for crop tree release cut and selective cut. Residual tree damage is also a major concern of landowners and forest managers. This should also been cooperated into the simulation later.

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Table 1. Means and significance levels of felling simulation variables[1].

	Stand			Machine					Harvest		
	30	40	50	CS	FB	HV	CC	SW	CT	DL	SC
DBH removed (in.)	7.79c	9.72b	12.37a	10.41a	10.34b	9.12c	6.69c	6.10e	6.18d	13.95b	16.87a
Avg. total height (ft.)	57.80c	64.46b	67.25a	64.36a	64.29a	60.86b	53.36c	51.80d	51.37e	78.25b	81.06a
Volume per felled tree (ft^3)	4.57c	10.46b	22.30a	12.68a	12.66a	11.99b	5.90c	3.99e	4.64d	12.39b	35.28a
Volume removed (ft^3/acre)	713.65c	1157.60b	2124.01a	1313.99b	1313.28b	1367.99a	1997.82a	1280.90c	1478.64b	956.79d	944.62d
Distance traveled per harvested tree (ft.)	15.04c	17.31b	19.08a	21.38a	21.37a	8.68b	8.76c	9.00c	9.50c	21.74b	36.72a
Time per tree (productive min)	1.76c	2.19b	3.02a	3.26a	1.12c	2.59b	0.91c	0.95c	1.03c	2.99b	5.73a
Cycle time (min)	4.27b	4.12b	4.80a	3.26b	1.49c	8.43a	3.87c	3.93c	4.48b	4.60b	5.09a
Productivity (ft^3/PMH)	253.39c	433.07b	716.62a	234.07c	795.57a	373.44b	595.16a	386.57d	434.39c	497.00b	425.36c

[1]Means containing the same letter in a row are not significantly different at the 5 percent level with Duncan's Multiple – Range Test.

Table 2. Means and significance levels of extraction simulation variables.[1]

	Stand			Machine					Harvest		
	30	40	50	CD	GD	FW	CC	SW	CT	DL	SC
Turn payload (ft^3)	165.18c	196.13b	245.47a	109.53b	86.05c	411.19a	197.67c	185.21c	194.83c	226.02a	207.57b
Avg. extraction distance (ft.)	848.67a	865.41a	786.58b	753.77b	805.86a	1041.04a	650.04d	755.65c	653.06d	1018.95b	1090.07a
Bunch size (ft^3/bn)	22.63c	51.84b	112.59a	38.77c	76.07a	72.22a	29.48c	19.97d	23.28d	62.91b	176.13a
Cycle time (min)	23.33a	22.82ab	21.55b	15.99b	12.87c	38.93a	23.02b	19.77c	20.12c	23.53b	26.40a
TI1	58.33a	54.06b	52.94b	48.11b	39.18c	78.05a	44.14e	46.63d	51.36c	61.15b	76.28a
TI2	27.74a	23.41b	19.55c	26.67b	35.72a	8.31c	27.95a	29.11a	25.95a	19.52b	15.30c
TI3	13.20c	20.70b	23.02a	21.56b	24.44a	10.92c	27.86a	22.03b	20.23b	16.95c	7.81d
TI4	0.73c	1.83b	4.49a	3.67a	0.66c	2.73b	4.05a	2.27b	2.46b	2.38b	0.61c
Productivity (ft^3/PMH)	444.81c	566.69b	634.46a	253.36c	589.42b	803.08a	561.62b	488.67d	527.02c	592.01a	573.79b

[1]Means containing the same letter in a column are not significantly different at the 5 percent level with Duncan's Multiple – Range Test .

Skyline Systems in Appalachia – 101 Tribulations

Jerry Okonski

Background

Skyline Systems, Inc

I have been directly involved in skyline logging operations since 1975, as a business owner, a practitioner, a trainer, and a consultant.

Although most of our operations have focused within the Western Montana and Northern Idaho region we have had the opportunity to log on the West Coast, Southeast British Columbia and the forest regions of Chile.

Our approach has been to establish a business within the Appalachians, and to continue with it for at least five years to establish a skyline logging business, whether as practioner/trainers or to provide training and consulting services.

Move to Appalachia

People ask why we decided to establish a skyline yarding business in Appalachia. Ever since the late 1970s, I have kept a nominal eye upon what progress was being made in this region.

Where are we specifically located in the Appalachia region? The area of interest encompasses where the borders of Virginia, Kentucky, and Tennessee meet.

Prior to the move, we set up reconnaisance missions and visits with interested producers in the area. They realized that it was necessary to have fulltime skyline capability in the area, both in economic and environmental terms. The producers were confident that our vision of skyline operations was feasible.

Everyone realized the labor market would be a real challenge, but not insurmountable.

As we begin our third year of operation I will review our efforts, including the natural factors that we must contend with, our employees, machinery and methods, and our results.

Natural Factors

Climate

There are swings in the type of weather that are sometimes confusing – for example, a day of 18 degree freezing, then a jump to 50 degree spring-like weather, then the next day a blizzard dropping 6 inches of snow that melts within 2 days. This variability keeps the ground wet. The result is a sporadic "breakup" condition from November through March/April.

Unless we are working from stabilized roads it means that we must contend with a lot of mud. At times, it feels like one is walking in a pool of Ready-Mix on the landing.

At the other extreme is the hot and humid weather that saps your energy. The spectacular lightning storms in the late afternoon result in an immediate suspension of operations – either we wait it out, or we go home.

This warm weather also brings out the critters. Timber rattlers and copperheads in our experience have not been lurking behind every bush, but they do keep us scanning the ground and watching where we place our hands or set our butts.

Forest Resource

Every acre that we have encountered has been logged previously. Old photos show the large size of the wood when logging operations using steam machinery commenced in the late 1800s and at the turn of the 20th century.

The resultant cutover forest lands were not replanted, but a continuous forest cover exists today through natural regeneration, except for areas of habitation and strip mines.

Typical stands average 3 to 8 MBF per Acre (Doyle Scale). Occasionally we see stands in the 10 to 18 MBF/Acre. Aspect and microsite changes bring about noticeable changes in species composition.

Terrain

Numerous rock outcrops and cliffs are typical. Finding a single span layout requires considerable ground work. Intermediate supports are often required when we can't find suitable single span deflection.

Bench roads from mining have cuts 40-50-60 feet high that make setting our guylines a real challenge. These areas significantly extend our setup time.

Culture

Employment officials have told me the area had a hard working labor force. After more than a generation of "Great Society" programs which enabled a large number of people to live without working, many workers lack any kind of work ethic. This is a constant challenge

From an economic perspective, coal is king. A variety of coal mines, including strip, underground, and bench mines, still contribute a large percentage to the area's economy.

Infrastructure

There are many private landowners ranging from a few acres to thousands of acres of forest. The owners also range from individuals to large forest management organizations or subsidiaries of large corporations.

One owner may hold the timber rights, another may hold the surface rights, and still another may hold the mineral rights on the same piece of property.

The nature of the topography results in highways that tend to be narrow and curvy two-lanes. Many communities were isolated until better roads were built in recent years.

Forest roads in some areas also have gas and oil pipelines traversing along the road's edge. These pressurized lines present obvious dangers, especially when heavy equipment is working near them: damaging a line can cause a spectacular explosion.

Men, Methods, Machinery

Men – Crew Formation

We began to hire our crew through the Virginia Employment Commission. They have been very helpful and responsive to our needs. We have gone through the hiring-firing-quitting process with many young men in the 20- to 36-year old bracket. It has been very disappointing to see the effect that drugs and alcohol abuse have had upon able bodied young men.

The crew that we now have is the result of a very frustrating filtering process. It is not easy to get up early and come home late, travel long distances to the jobsite, and work in all weather and terrain conditions.

Cross Training

Through cross training we are trying to create a "Universal Technician".

It is not a smoothly scheduled training process. The development path of each employee is irregular and uneven. As one man reaches a basic level of productivity and competency, we try to introduce him to another task.

A small crew also needs this flexibility so we can cover for one who is absent from work for whatever reason.

N.E.W.

Whatever the task assigned to an inexperienced person, there will be some form of "New Employee Wreckage" (N.E.W.). Pigtailed mainlines, crushed chainsaws, lost chokers, and dented guarding are a sampling of the many items of N.E.W. that we have incurred above and beyond normal wear and tear. Some incidents of N.E.W. have been through pure carelessness, but for the most part are the result of learning the limits of operability.

Future Effort

We have a core of employees that seem to be interested in becoming skyline loggers.

We will strive for crew stability – to stop losing time and money from training new employees, to stop committing the same learning mistakes, and to reduce damage to the equipment.

We will continue to provide Master Logger/SHARP Logger Certification and Game of Logging chain saw safety training.

Methods

Strategic Planning

We are striving for a one-year lead time for job planning. This would allow freshly built roads to stabilize over a period of time. It would also provide flexibility in changing from one project to another depending upon timber supply requirements.

Limited options at the present time lead to inefficiency and lower productivity. This includes when the construction company is building the road immediately ahead of us.

We are somewhat optimistic that our planning horizon will increase during the next year.

Operational Planning

Over the years, cable logging operations have been attempted in various parts of the Appalachians. Except for research purposes, they were regarded as clearcut harvesting systems using power and more power.

Within our area, two skyline logging operations were 'subsidiaries' to conventional logging companies. There was no dedicated crew for each machine, and the owners also tended to be the yarder operators. They did not know much about rigging layout. They have since been sold.

One of the strong points of Skyline Systems Inc. is operational planning. We generally know what to do and how to plan a specific harvest project. We are also dedicating 100% of our efforts toward implementation of skyline logging operations.

The US Forest Service logging engineer for the Washington and Jefferson National Forests stated that we were the first to use Intermediate Supports commercially as well as routinely perform partial cutting operations within the region.

Finesse over Power

Our approach is to use more finesse rather than power in overcoming production problems. This implies that we must know beforehand what needs to be done. We develop a detailed plan and layout before cutting.

The timber fallers are being trained to cut for payload and to save residual timber; the yarding crew is being trained to remove the felled timber at a good rate of productivity while minimizing damage to the residual.

Conveyor Belt

Skyline operations are very different from conventional logging operations. A useful analogy for a skyline system is that of a conveyor belt: a weakness in such a system, such an element as simple as a bolt, can shut down production for hours.

Normally, conventional loggers have two to three pieces of equipment. When one of these pieces breaks down, the other can still produce until repairs are completed.

Specifics

Layout

Three to five MBF per acre does not leave much room for error. One needs to know exactly where and how the next landing will be rigged.

Any questionable corridor is profiled and analyzed. All corridors are laid out with a compass. Anchor and support points are marked – normally these are the tailtrees, tailholds, intermediate supports. On some projects, every potential skyline road is profiled and analyzed.

So far, we have spanned out to 1900 ft. over one intermediate support.

Felling and Bucking

Trees are directionally felled as best as can be done with fallers' experience levels.

Bucking tops and cutting for payload are critical to the success of the whole operation. Without good quality felling and bucking, the task of the chokerman to avoid overstressing the system becomes a frustrating exercise.

Landings and Rigging

Landing types and sizes vary – from 12 foot wide bench roads with 50 foot high walls to ample two step landings.

Machinery

Our equipment consists of a truck-mounted three drum yarder with haywire, Acme 15 radio controlled carriage, Cat 320 Forestry Machine with a Hultdins grapple saw, and a D6D dozer used for miscellaneous chores.

The combination works well – although setup times can be excessive when the high walls get tall.

The Acme carriage has performed well despite the brutal treatment it has received while training chokermen and yarder operators. It has a simplified design compared to our older radio-controlled carriages.

The Cat 320 forestry machine with the Hultdins grapple saw has performed especially well for us. It has been an excellent tool for handling those occasional treelengths that come to the landing. It is also great for long butting.

We use an excavator boom because we need below grade reach more than we need to reach high. We also use a low cab. Although there is a slight disadvantage while loading a truck, it is of far more advantage to us to be closer to the ground.

We have eliminated the need for a chaser and his exposure to hazards. In this way we have two operators that work together on the landing. Our yarder is designed for the operator to easily exit the machine and unhook a turn. The loader operator is also close to the turn, in the case that it is easier for him to unhook.

The 320 operator measures and evaluates how to extract as much 'grade' out of each log. He also sorts, decks, manages the slash, and loads trucks.

This system seems to be sized well for the wood we have yarded.

To date, the overall system has worked well for us on any type of landing. The greatest disadvantage has been the setup time when we have our guyline anchors on the slope above the highwall.

Repair and Maintenance

This area needs the most improvement.

Results

As we gained actual field experience, we had to revise our daily production downward. Original volume projections were 15 MBF per day, then revised downward to 12 MBF, and further revised to an 8-10 MBF per day average on Doyle Scale.

Eighty pieces per day, as counted by the yarder operator, will normally get us 10 – 12 MBF per day. This requires 2 fallers each to cut 40 trees with grade logs per day. It requires about 6 hours of yarding time – 14 treelength logs per hour or 2 pieces every 8.5 minutes. It will take an experienced crew to obtain this on a daily basis.

We must strive to achieve that full day of production without cycle time delays due to bad hookups, poor corridor clearing, too many tree lengths, logs buried under tops, etc.

We are still far from our original goal of 15 MBF/day. A 10-12 MBF/day is more reasonable based upon day-to-day operations.

However, I am confident that we can accomplish our mission as we continue to improve our strategic plans, training, having faith in our employees, and keeping our machinery in a well maintained condition.

The New Zealand Forest Industry
Accident Reporting Scheme (ARS)

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ABSTRACT

Since 1984 New Zealand has had a national Forest Industry Accident Reporting Scheme (ARS) which collects injury and near miss reports from forest companies. The ARS is used by the Centre for Human Factors and Ergonomics (COHFE) (formally the Logging Industry Research Organisation) to guide its forest industry injury prevention research and development programme. The scheme covers both silvicultural and logging sectors. The ARS contains details of lost-time, minor (less than one full day absence from work) and near-miss incidents. The New Zealand forest industry strongly supports the scheme, resulting in the large majority of reported forest injuries being included in the database. In turn, COHFE provide quarterly and annual summary injury data to forest company contributors and the wider audience in New Zealand, along with research reports and general injury prevention information. Most importantly from a research perspective, the injury data received from forest companies also enable COHFE to examine trends and patterns in logging injury data, and to target their wider human factors, safety and health programme at key risk areas. The scheme also provides for baseline data and other evaluation measures helpful in intervention research. All reports and summary documents can be accessed and downloaded from the COHFE website (www.cohfe.co.nz).

The ARS has been used to guide numerous industry initiatives and research programs.
Most recent examples include: Seasonal effects of dehydration, Felling injuries, Musculoskeletal disorders in logging, Chainsaw lacerations and foot protection and Skid site / landing injuries.

Recent developments, in response to industry requests, include the generation of 12 month rolling average information for logging lost time injury rates and the current development of a web-based search tool to access the logging ARS. COHFE has been working with forest companies to collect injury and incident reports electronically. A significant cost of running the ARS is manual data entry. However, even with electronic data entry each record must be checked and categorized to simplify later data analysis.

INTRODUCTION

Internationally, forestry operations have had a high injury rate (Myers & Fosbroke, 1994). In New Zealand the highest forestry injury rates are reported in logging operations (Kawachi *et al.*, 1994; Parker *et al*., 2003). In the period Janaury to December 2002 there were 437 injuries reported in logging and 119 resulted in at least one day off work and a total of 1852 work days lost.

Limited resources for research and development mean efforts must be directed where the greatest need and greatest gains can be made. Detailed accident information is essential to identify areas of need and guide efforts of researchers to reduce accident frequency and severity.

ACCIDENT REPORTING SCHEME (ARS)

In 1980, Swedfor Consultancy of Sweden was contracted to develop "safer felling and delimbing techniques for New Zealand conditions". The Logging Industry Research Association (LIRA) was asked to provide the consultants with specific information on felling and delimbing accidents. However, only limited records existed. No industry-wide data collection scheme existed. An ARS was successfully piloted in the Bay of Plenty region of the North Island. In 1983 the ARS was expanded to cover the whole New Zealand logging workforce (Prebble, 1984). In 1992 a siliviculture ARS was established to record injuries in tree planting, pruning, spraying and releasing, thinning to waste and other silvicultural activities (Ashby & Parker, 2003). In 2003 a sawmilling ARS was piloted with the a small number of sawmills (Tappin *et al*., 2003). The sawmilling ARS will be extended with time to cover the whole of New Zealand.

ARS DATA COLLECTION

Forest and sawmilling companies send injury and near miss records to the ARS either as paper incident reports or as electronic spreadsheet downloads from their own safety management systems. The records are scanned and filtered to ensure categories and definitions meet the ARS criteria and then entered to the ARS. All records are anonymous. Annual and quarterly reports are prepared for industry and published on the COHFE web site. Occasional reports on specific injury events are also published. For example Felling injuries – Ashby *et al*., 2002; Musculoskeletal injuries – Ashby *et al*., 2001. Reports are also prepared for academic journals. Data received allows COHFE to identify specific hazards and broad trends in injury cause and type. The logging ARS now has almost 13,000 records of injuries and near miss events. The silviculture ARS has 3,500 records and the sawmilling ARS has a few hundred records.

The ARS uses the following definitions for injury or incident type:
- Lost time injury - the injury causes the injured person to miss one or more day's scheduled work
- Minor injury – an injury occurs, but no lost time as defined above
- Near miss incident - the incident could have resulted in an injury, but no injury occurred.

The number of injuries and incidents recorded by the ARS are detailed by year in Table 1. Over time there has been a steady decease in the number of lost time injuries reported. Over the same period the annual forest harvest has increased in New Zealand resulting in a decreasing lost time injury rate. The reporting of minor injuries has improved over that time and there has been a dramatic increase the reporting of near-miss incidents. This indicates the importance the New Zealand Forest Industry places on injury prevention and the safety of its workforce.

Table 1 - Injuries and incidents recorded by the ARS from 1997 to 2002
(Calendar year – January to December)

Year January to December	1997	1998	1999	2000	2001	2002
Fatal injuries	7	5	5	3	3	4
Lost time injuries (LTI)	172	115	138	122	122	119
Minor injuries	103	147	250	265	280	318
Near miss incidents	147	183	304	483	763	1205
Lost time injuries/million hours	29	17	20	11	16	17
Annual harvest (million m³)	16.9	15.3	17.8	19.3	20.7	22.6*
Lost time injuries/million m³	10.2	7.5	7.8	6.3	5.9	5.3

*Source: Provisional data, Ministry of Agriculture and Forestry, Round wood removals

ARS DATA ANALYSIS

Data from the ARS is reported back to industry through quarterly reports, annual summary reports and special reports on particular injury types or parts of the logging or silviculture operation. Detailed below is the felling injuries section taken from the annual logging report for the period January to December 2002.

Felling Injuries 2002

The 38 felling lost time injuries that occurred in 2002 resulted in a total of 667 days lost. This is considerably more than 2001, when 24 lost time injuries resulted in a total of 460 lost days were reported. There were also 77 minor injuries reported in 2002.

Most lost time injuries (31) resulted from 'struck by' events including:
- hit by a tree or spar – 17 lost time injuries and a total of 451 days lost
- hit by sailers and cones – 7 lost time injuries and a total of 40 days lost.
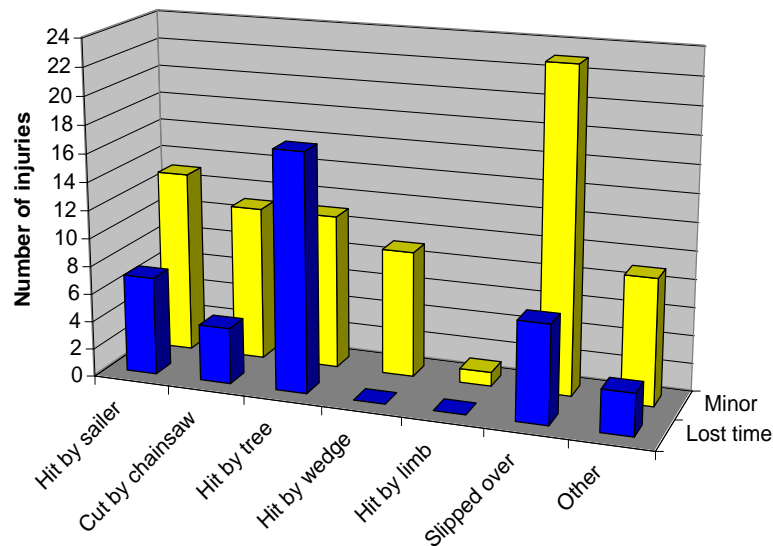

Figure 1 - Lost time and minor injuries in felling by cause of injury, 2002

Skid work Injuries 2002

There were 32 lost time injuries in skid work resulting in a total of 466 days lost. There were also 106 minor injuries reported.

The main causes of lost time injury were:
- Being hit by machine or by material moved by machine, nine injuries, total of 176 days lost
- Being hit by a rolling log, six injuries, total of 81 days lost
- Cut by chainsaw, five injuries, total of 31 days lost
- Being hit by a log or limb when cut under tension, four injuries, total of 129 days lost.
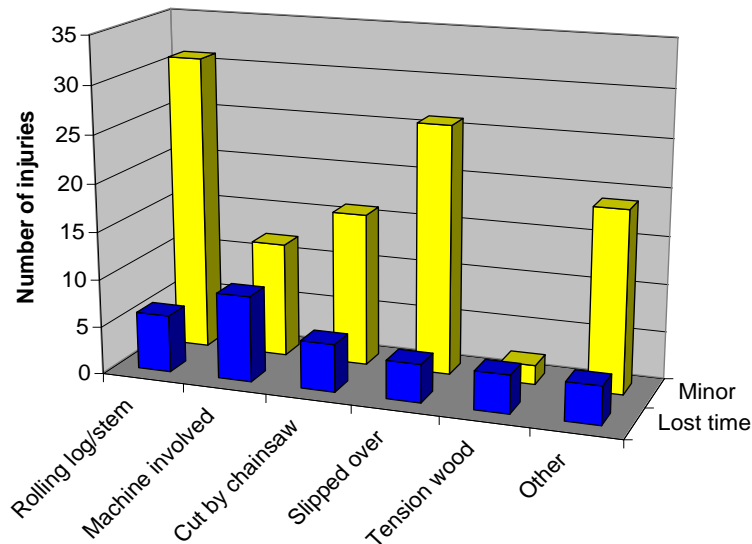- Slipping or tripping over, four injuries, total of 14 days lost

Figure 2 - Lost time and minor injuries in skid work by cause of injury, 2002

The number and severity of injuries resulting from being hit by a machine or material moved by a machine highlights the need for care around machines on the skid. The most severe injuries resulted from fractures when a stem or log was moved by machine and hit the skid worker. The number of slips, trips and falls on the skid has reduced considerably since last year. This may be due to tidier skid sites with less slash and waste wood (especially slovens) lying about.

ARS USED TO GUIDE RESEARCH & DEVELOPMENT

Extensive examples of how the ARS has been used to drive the COHFE Human Factors forestry research and development programme are detailed elsewhere (Parker, Bentley & Ashby, 2002). Two examples are outlined below.

1.   Rear Vision for Highly Mobile Forestry Machines

The Bell Logger is a three-wheeled, fast highly mobile forestry machine used in close proximity to workers on foot. It, along with other machines, inadvertently collide with workers, other machines or logs which subsequently hit workers. Mobile machine related injuries on the skid site are a significant problem resulting in 1304 lost work days in the period 1995 to 2002. To date the only successful way to prevent injury to workers on foot is to completely remove them from the work area. This is often operationally difficult and does not prevent collisions between machines or objects. One potential solution is to improve the rear vision of the machine operator (Parker, 2003).

A rear view video system was installed in a Bell logger. Video records of Bell Logger movements and operator head glance direction were analysed to characterise the operating environment and style without and with the rear view camera system.

The normal operational environment of the Bell logger operator is characterised by frequent machine changes in direction (eight to 10 per minute) and frequent head movements (four to five per minute) to see if the way is clear. Results indicate that the rear vision camera system appears to have potential as a valuable

addition to the Bell Logger operating under typical New Zealand forestry conditions and resulted in a 20% increase in Bell Logger activity.

2. Development of the Sabaton™ Foot Protector

Chainsaw laceration of loggers' feet is a common injury. Data from the ARS indicated there were six injuries in 2002 resulting in a total of 63 days off work. Most (95%) of foot chainsaw lacerations were to the left foot, and a survey of 60 injured loggers identified the area behind the big toe as the most at risk.

No fully practical cut resistant boot currently exists for loggers. Current chainsaw cut resistant footwear consists of either rubber boots or fabric kevlar foot covers. Rubber gumboots are hot, do not allow perspiration to escape and offer little ankle support. Kevlar foot covers are a single use solution. They must be replaced once cut.

In an attempt to develop rugged and practical chainsaw cut resistant foot protection for loggers, COHFE researchers investigated protective footwear from the past. Foot armor worn by medieval knights was developed to be flexible, to allow combat on foot, and smooth to deflect blows from weapons. These same qualities are required by loggers. Prototype sabatons were tested in field trials with loggers and design modifications made until a practical foot protection device was developed. Development is continuing.

FUTURE DEVELOPMENT OF THE ARS

The ARS is currently being developed to allow web based queries of the database. This work is being funded by the New Zealand Accident Compensation Corporation (ACC). Users will be able to generate customised summaries of data and compare their own company to the national average for benchmarking purposes. The ARS is an example of a successful long term collaboration between industry and science.

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COMPARISON OF ERGONOMIC PERFORMANCE FOR A SKIDDER OPERATOR USING STEEL WIRE AND SYNTHETIC ROPE WINCH LINE

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ABSTRACT - The use of a synthetic fiber (Ultra High Molecular Weight Polyethylene, UHMWPE) rope as a replacement for steel wire rope winch line on a rubber-tired skidder for logging operations is presented. Past and ongoing research shows ergonomic gains and other operational effectiveness. Paper presents research results on work effort required for operators setting their own chokers. Differences in heart rates, and task times are compared. Increased productivity with the synthetic winch line is estimated. Subjective evaluations by trial users are summarized. Potential social and environmental benefits are discussed. Benefits include tradeoffs from improved technology to reduce operational restrictions and operational costs. The research is funded by Oregon Occupational Safety and Health Administration grant to ergonomically redesign worksites for employees.
KEYWORDS: fiber ropes, harvesting, line logging

INTRODUCTION
The potential for rope constructed of ultra high molecular weight polyethylene fibers (UHMPWE AmSteel® Blue 12 strand braided rope[1]) to replace steel wire rope in logging applications has been shown at previous COFE meetings (Garland et al., 2001; Pilkerton et al., 2003). The rope's strength is similar to steel wire rope of the same nominal diameter but only about 1/9th the unit weight. The Oregon Occupational Safety and Health Administration funded grants to evaluate synthetic rope for ergonomic improvements for employees in the logging industry.

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 logging (Pilkerton, et al., 2001). The obvious lower weight per unit of length and lack of stored torsional energy are significant differences to steel wire rope. Thus, the rope may be more easily pulled over difficult terrain and logging slash, reduces fatigue, and possibly reduces slips and falls. Synthetic rope also produces no "jaggers", eliminating puncture wounds and lacerations. Canadian researchers recognized the potentials of synthetic mainlines on skidders and investigated abrasion and strain generated by mainline choker sliders (Golsse, 1996; LaPointe, 2000). An Oregon logging contractor recognized the potential and installed a synthetic winch line because of OSU's research efforts (Crouse, 2003).

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[1] AmSteel® Blue is a product of Samson Rope Technologies, Ferndale, WA. Mention of trade names is not an endorsement by Oregon State University.

This study reports on the first operational trial of operators setting their own chokers behind a rubber-tired skidder using a synthetic winch line. Additional research was conducted to evaluate physical workloads through heart rate and recovery times for this activity and its elements. Subjective comparisons were solicited and recorded.

STUDY METHODS
In the Summer and Fall 2000, field trials were conducted with the OSU Forest Engineering Student Logging crew on the OSU McDonald-Dunn Research Forest north of Corvallis, Oregon. Heart rate and subjective evaluation data were collected to evaluate the physiological and emotional response between using traditional steel wire rope and synthetic 12 strand braided AmSteel® Blue rope (Samson Rope Technologies, 2003) in logging with a skidder winch line.

The study group was comprised of 2 females and 5 males. Ages ranged from 20 to 47 years, averaging 29 years. All participants self rated their physical fitness as "Good" and free of physical limitations.

A John Deere 540B rubber-tired skidder with a winch drum and swing boom arch grapple was used. The winch line ("bull" line) on the skidder was either a 9/16-inch swaged IWRC steel wire rope or a ¾-inch 12-strand braided synthetic rope. Each worker pulled the bull line and set a choker for a series of 5 turns. Distances (10 – 99 feet), slope percent (-55 to +52), and uphill/downhill were randomly assigned for each turn.

Heart rate data were collected using the Polar Advantage monitoring and recording system (Polar Electro Oy, 1998). Heart rates (beats per minute, bpm) were recorded every 5 secs. Time to complete task elements were compiled from the recorded heart rate – time relations based on data markers applied by pushing a button on the wristwatch style data logger.

After each trial, the worker completed a subjective evaluation form to rate the effort required for a given task and rope type in comparison to the base task. The base task for the skidder trial was pulling a 150 feet of 5/8-inch steel wire rope (111 pounds) 300 feet on a gravel road of 4 percent grade. The forms had a linear scale, with midpoint being the "Same" effort comparatively. The left endpoint was labeled "Extremely Easy" and the right endpoint labeled "Extremely Difficult". The linear difference between marks was recorded as a unit less value measured from zero (extremely easy) with an engineers scale.

RESULTS

Field Trials
Figure 1 shows a sample trend of the heart rate data record for steel and synthetic ropes for 5 turns each. Turn outhaul (pull to log) distance, slope, and uphill/downhill variables are not consistent for steel and synthetic. Peaks generally correspond to end of line pulling element. Figure 2 shows the heart rate exertion levels for a 24 year old male for pulling a ¾-inch synthetic winch line. Eighty percent of the time the operator's work intensity is in the heavy work or more strenuous categories.
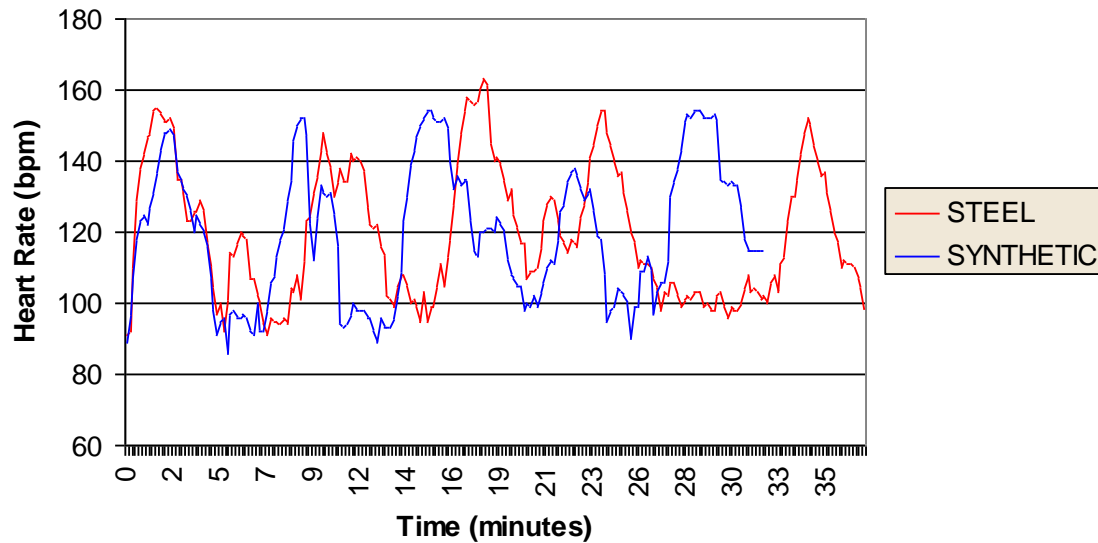
Figure 1. Heart rate traces as a function of time for 5 turn cycles. Elements include lateral out (pull to logs), hook, return to skidder, winch in, and unhook.
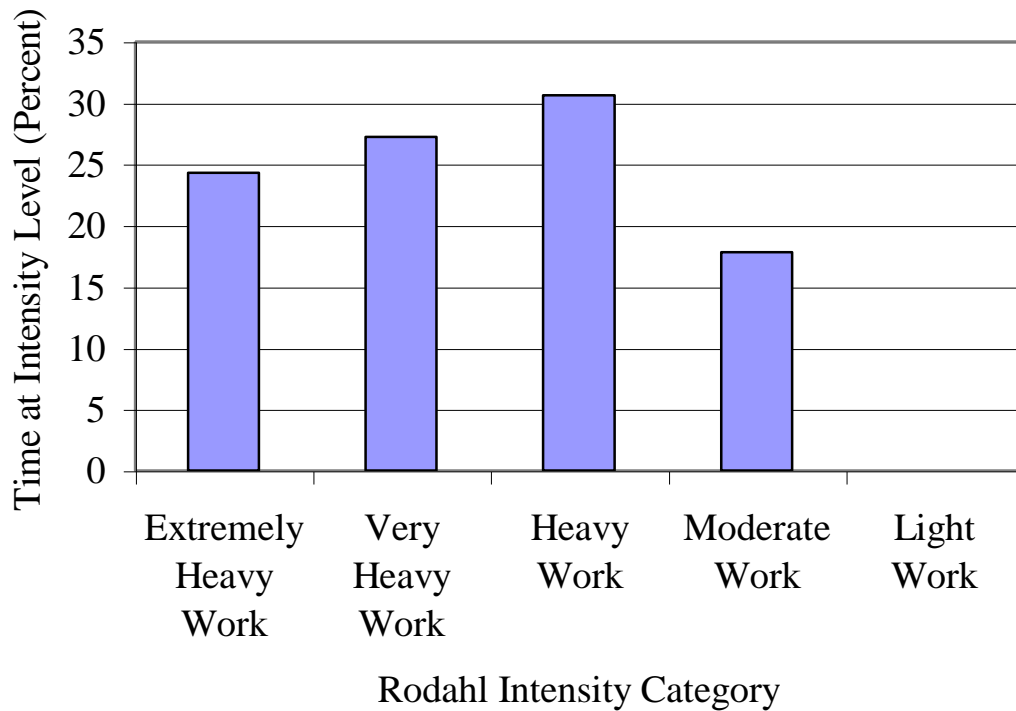

Figure 2. Heart rate exertion intensity, percent time by Rodahl Categories, for a 24 year old male pulling a ¾-inch synthetic winch line.

A standing, at rest, heart rate of 70 bpm was assumed for all individuals. Heart rate exertion intensity zones (average person, 20-30 years of age) can be described as follows (Astrand and Rodahl, 1986):

Heart rate (bpm)	Exertion Level (onset of)
< 90	Light Work
91 - 110	Moderate Work
111 - 130	Heavy Work
131 - 150	Very Heavy Work
151 - 170 +	Extremely Heavy Work

The reader should be cautioned to keep these values in mind when reviewing the results. The initially tendency is to think of a 15 bpm difference as small. However, this represents a 20 percent increase over the standing at rest rate. A 15 bpm increase can move an individual from one exertion level to the next.

The outhaul (pulling line to the logs) element was the focus of the difference in rope type. Heart rates, on average, were statistically similar. However, task time was 0.5 minutes faster with the synthetic rope (Figure 3). Heart rates were lower for all elements when using the synthetic rope. There appears to be an exertion carry-over effect into the next element, ie, when hooking the turn. This activity occurs right after the line pulling element (outhaul).

Still heart rates are 70-85 bpm higher than the initial heart rate of 70 bpm. Heart rates increased 10 – 15 bpm with sustained activity (over the first turn) during the 5 turn sequence. ANOVA analysis showed significant differences in average heart rate for rope types and gender (main effects) and slope gradient, distance pulled, uphill/downhill (covariates).
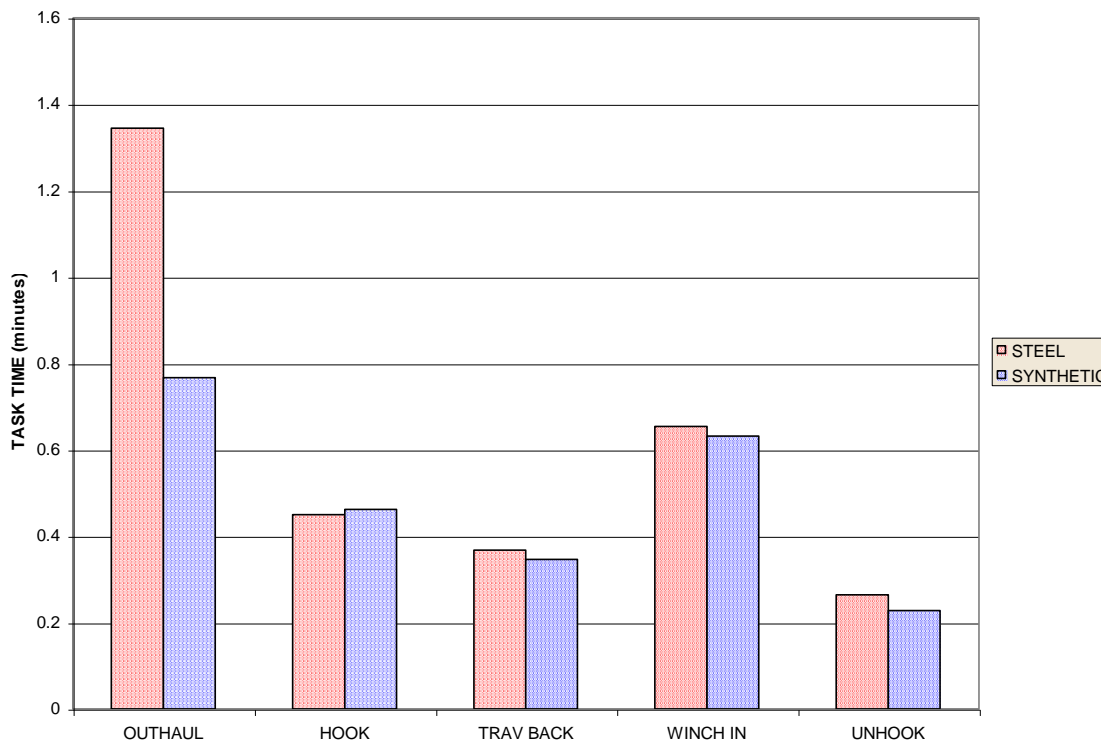

Figure 3. Average skidding task times by activity element for all 7 worker's series of 5 turns for steel and synthetic winch lines.

Subjective Analysis
Evaluated numerically, synthetic rope was subjectively considered 20 percent easier downhill and 15 percent easier uphill when pulled off the skidder bull winch (Figure 4). A t-test on the mean subjective values failed to show a statistical difference in the ratings. Analysis of Variance showed a statistical difference by slope and gender.
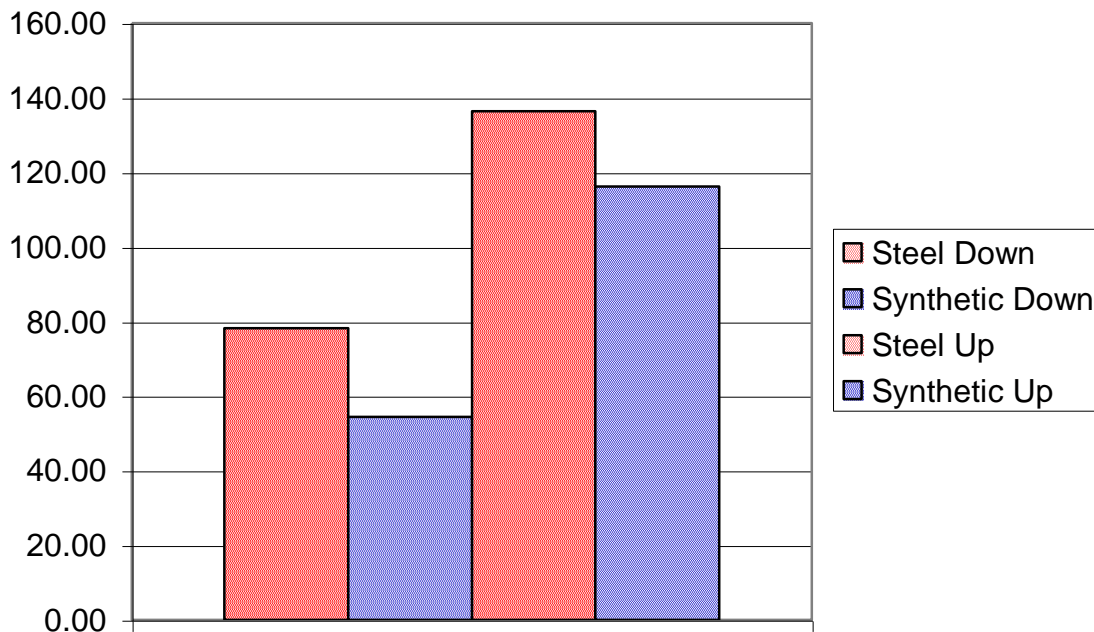

Figure 4. Average (n=7) subjective rating for steel and synthetic skidder winch line pulling. Scale is unit less, relative response to base case task, where zero is considered "extremely easy".

Numeric results of the subjective analysis are informative, but the worker comments are also interesting. Negative comments noted tendency for synthetic rope loops to catch on slash. Overall, synthetic rope was well received, especially by those who have cut their hands on a jaggered steel cable. Not surprisingly, the subjective views of the workers favor synthetic rope over steel wire rope. Recorded observations include:

   - "Much easier, almost the same as just walking without anything."
   - "Hardly like pulling anything."
   - "Felt like leading a good horse."
   - "Both directions were easier than dragging cable (steel, sic) on road."

DISCUSSION
Differences in heart rates were not readily evident for several possible factors. First, there was a wide variance with the data for 5 turns of different distances, slopes, and direction (up/down). Secondly, the thin and ravelly soils, coupled with thick slash, made outhaul traversing physically demanding. The third factor, malfunctioning of the free spool, was suspected during the trial and verified afterwards.

Mechanical difficulties of the skidder winch to free spool (made obvious using the synthetic rope) likely also affected the statistical perception on ease of use. This likely affected the perception of the effort required for the steel winch line as well. After the study, the winch was dismantled. The clutch packs in the winch had been damaged and caused the inability of the drum to free spool properly.

This led to the development of alternative methods of pulling the line off the winch. The typical method with steel is to grab the line, lay it over the shoulder, and use the leg driven upper body to pull line to the logs. The synthetic rope could be easily pulled off the drum, coiled or piled on the ground at the back of the skidder for the approximate distance out to the logs. The operator then would walk out pulling the slack rope to the logs. One potential negative comes from this technique. The operator would no longer put the rope on the shoulder (upper body technique), but rather pull the rope along behind like pulling a rolling suitcase. This could create arm / upper shoulder injuries if the rope snagged and sharply pulled the arm rearward. We observed the potential, but did not experience injuries.

Other cooperators using synthetic rope as a winch line experienced similar drum free spooling difficulties. The primary reason is the "free spool adjustment" is set tight (high resistance to free spool) to minimize the tendency of steel wire rope to release the potential energy stored on the wrapped drum. The wire rope expands beyond the wrapped position, sometimes spronging wildly if pulling motion is stopped suddenly and the drum has rotational momentum. This creates a misalignment of the rope on the drum, like the backspooling of a fishing reel. Delays are associated with improper spooling. Failure to properly spool the steel line generally results in a stuck line the operator can not pull off by hand. To free the line, it must be attached to a stump or tree, and then the skidder is driven ahead to pull the line free.

The cooperators have experienced few, if any, spooling problems or hang ups with synthetic winch line. Most cooperators adjusted the free spool mechanism to a low resistance for the synthetic rope which does not expand on the drum. Productivity gains are likely experienced with the reduction of improper spooling and/or the elimination of a stuck winch line.

Increased Productivity
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 skidding

distances. 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.

Anecdotal evidence from contractors suggests they add additional distance to their line pulling rather than taking time to position the machine closer. Further designed studies should document these differences. Two contractors spliced additional synthetic rope onto their winch lines, whose initial length was based on their steel winch line.

Social And Environmental Benefits
Timber harvesting work has a reputation for being "difficult, dirty and dangerous" compared to work in urban occupations (Garland, 2001). At the same time, financial benefits, autonomous work environments, and the satisfaction of overcoming challenges seem to compensate in part for the negative aspects of forestry work. Using new technologies like synthetic rope to reduce workloads is seen as a positive move to consider workers' health and safety. Several benefits can be seen:

   - New recruits to the sector see lighter workloads in entry-level tasks
   - Existing workers see a 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
        the workloads are more in line with capacities of older workers.

While new technologies cannot fully compensate for negative aspects of forest work (steep terrain, weather, job hazards, etc.), synthetic rope offers a positive statement and result for forest workers.

Improvements in environmental performance with respect to ground based skidding activities are also likely. Ewing (2003) reports on the reduction for machine travel into riparian zones with the use of a synthetic mainline. Guidelines for minimizing area impacted by skid trails are dependent on operators pulling winch line laterally a designated distance. In practice, steel wire rope is a physical and mental barrier to achieving desired lateral outhaul distance. Synthetic mainlines increase the likelihood of meeting environmental objectives. The use of synthetic mainlines could reduce operational restrictions put on operations, avoiding the need for more expensive systems to achieve the stand management objectives.

SUMMARY
Beneficial improvements are possible with the introduction of synthetic rope as an alternative to steel wire rope winch lines. These include reduced physical impact on workers, productivity improvements, and reduced impact logging. Synthetic winch lines have been well received by contract loggers using them. Application of synthetic ropes to harvesting activities are significantly increasing, as evidenced by the number of operators independently implementing them as a result of the OR-OSHA worksite redesign grant research. These loggers are looking for other innovative applications of synthetic rope including chokers, running lines, truck wrappers for load securement, and so forth.

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COMPARING THE PRODUCTIVITY OF A CUT-TO-LENGTH HARVESTER OVER TIME

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ABSTRACT -In May of 2001 a detailed time study was performed on a John Deere 653E harvester with a Fabtek 18-in four roller processing head. The harvester was working in a cut-to-length (CTL) system thinning natural pine/hardwood stands in west central Georgia. In January and February of 2004 a second time study was performed on the same machine and operator. The goal of the study was to test for differences in processing time on the same machine/operator combination over time. The stand conditions between the two sites were found to be significantly different. An analysis of covariance was performed to test for differences in processing time between the two studies taking into account the affect of the other independent variables. The analysis showed that there was not a significant difference in processing time between sites. This indicates that the machine/operator was consistent over time and different stands conditions.

BACKGROUND

Production studies are a proven tool to evaluate the performance of forest operations systems and individual machines. Productivity studies can vary in degree and complexity from gross time study, to work sampling, to detailed elemental time and motion studies. The fundamental purpose of time study is to quantify some measure of performance under a defined set of operating conditions. By measuring a sufficient sample of work cycles, a statistically-valid estimate of actual cycle times (either average or predictive equations) can be developed. A key challenge in designing a time study is to determine an adequate sample size. In forest operations, the variability of the basic cycles is often large. Some variability needs to be controlled or eliminated, while other independent variables of interest need to be explored over a range of values. Generally, collecting more data ensures a more confident estimate of productivity. However constraints on time, money, and labor often restrict the potential sample size. With a restricted sample population, conclusions from productivity studies often offer caveats about potential extrapolation of the results to other situations. It could expand the application of time study results if better information were available about the stability of basic operating functions.

The objective of this study was to determine whether measurements of a basic operational function (harvester processing) vary significantly over a wide span of time for a given machine/operator pair. The hypothesis was that a productivity equation developed from data at one point in time would be a valid predictor of the same machine/operator under similar conditions at a later point in time.

METHODS

The harvesting contractor purchased the harvester new in 1996. The owner has operated the machine exclusively since new and currently has 12,000 machine hours. The contractor works almost exclusively on the Ft. Benning military reservation. Both studies were performed on the reservation. The terrain was gently rolling with sandy soils. The timber stand was natural pine/hardwood mix.

In the initial study, 2001, study blocks were established in the stand ahead of the harvester. Tree data recorded for each block included species, diameter at breast height (dbh), and height for all trees marked for removal. Species and dbh were recorded for all remaining trees in the study block. In the second study, 2004, a study block was established in an area with a uniform distribution of trees. A tenth acre plot was established in the block. Species, dbh, and height were recorded for all trees within the plot. Height and dbh was recorded for all trees marked for removal in the remainder of the study block. In both studies, all trees marked for removal were identified with a numbered tag. A video camera was used to record the harvester as it worked through the study blocks. Post analysis was performed to extract elemental cycle times for the harvester.

The harvester worked in conjunction with a feller-buncher and two forwarders. In the 2001 study, the contractor used a Hydro-Ax 221 rubber tired feller-buncher fitted with a shear head. The feller-buncher worked through the stand felling all small trees and bunching them next to trees too large to shear. The harvester followed the feller-buncher through the stand, processed the piles and felled and processed the remaining large trees. In the 2004 study the contractor had replaced the Hydro-Ax 221 with a Hydro-Ax 611E rubber-tired feller-buncher fitted with a continuous sawhead. The Hydro-Ax 611E cut and piled all trees. The harvester followed the feller-buncher through the stand processing the piles.

This change in system makeup meant that a total cycle time to fell and process a tree could not be obtained as was done in 2001. The processing time per tree and per pile, however, could be calculated and compared to the 2001 data. The work cycle was defined as follows:

Move: Starts when the harvester's tracks begin to move and ends when the machine arrives at the next location and the tracks stop.

Reach: Starts from the time the machine stops moving and ends when the harvesting head is attached around the tree to be processed.

Buck: Starts when the harvesting head starts to process the tree and ends when the tree has been completely processed. The *Buck* element ranged from 1 to 4 separate elements according to the number of pieces produced per tree.

Delay: All time that does not fall within the other elements.

Analysis of Covariance was used to test for differences in processing time between the two studies and regression analysis was used to develop a regression equation to predict time to process a pile of trees.

RESULTS

In the 2001 study four study blocks were established totaling 0.98 ac. In 2004 two study blocks totaling 1.52 ac were established. Stand composition for both studies is given in Table 1 below. The stand basal area was 91.2 ft^2 and 114.3 ft^2 for 2001 and 2004 respectively. Trees marked for removal accounted for 35 percent (32 ft^2) of the stand basal area in 2001 compared to 33 percent (37 ft^2) in 2004. Hardwood accounted for 38 percent of the stand in 2001 compared to just 7.5 percent in 2004. Average stand dbh in 2001 was 8.6-in and 7-in in 2004. Of trees marked for removal, the average dbh was 9.5-in and 6.2-in in 2001 and 2004 respectively.

Table 1: Stand data for 2001 and 2004 production study on John Deere 653E harvester.

	2001			2004		
	Trees/Ac	DBH (in)	BA (ft^2)	Trees/Ac	DBH (in)	BA (ft^2)
Pine	105	10.0	75.4	370	7.2	110.3
Hardwood	65	6.3	15.8	30	4.9	4.0
Marked	56	9.5	31.7	175	6.2	37.2
Unmarked	114	8.2	59.5	225	7.7	77.1
Total	170	8.6	91.2	400	7.0	114.3

In the 2001 study the feller-buncher (Hydro-Ax 221) cut 42 of the 54 marked trees and placed them into 6 piles. The harvester processed the piled trees and cut and processed the remaining 12 trees. In the 2004 study the feller-buncher (Hydro-Ax 611E) cut and piled all 196 trees and placed them into 16 piles. The harvester processed all piled trees. Table 2 contains pile data for the 2001 and 2004 studies. The elements for each pile include *trees*, average *dbh*, *reaches*, *pieces*, *volume*, and *basal area*. The element *reaches* refers to the number of times the harvester "reached" to the pile to pick up trees. It was common for the harvester to pick up and process several trees at a time when the trees were small. The most trees the harvester processed at one time were 8. In 2001 there were less trees per pile but the average dbh per pile was larger.

Table 2: Tree pile data for 2001 and 2004 production study on John Deere 653E harvester.

	2001 (6 Piles, 42 trees)			2004 (16 Piles, 196 trees)		
	Avg	Min	Max	Avg	Min	Max
Trees	7.0	3.0	14.0	12.3	4.0	29.0
DBH (in)	8.4	7.3	10.6	6.8	5.0	10.8
Height (ft)	49.5	41.4	54.7	44.5	34.4	51.1
Reaches	5.7	3.0	11.0	5.0	2.0	11.0
Pieces	11.8	5.0	22.0	19.6	7.0	52.0
Volume (ft^3)	60.4	38.3	113.0	56.4	20.1	142.3
Basal Area (ft^2)	2.6	1.8	4.5	3.0	1.7	7.1

From the time study data it was known which trees were in which piles, but it was not possible to identify each individual tree when it was being processed. This was especially true when multiple trees were being processed at one time. Therefore, in order to make a comparison between the processing time for the harvester between 2001 and 2004 the pile data, not tree data, was used. Duncan's Multiple Range Test was used to test for differences between the means of the independent variables between 2001 and 2004 and Analysis of Covariance was used to test for the effect of year on processing time per pile. Table 3 lists the results of the Duncan's Multiple Range Test on the dependent and independent variables.

Table 3: Results of test for significant difference using Duncan's Multiple Range Test between the means of the dependent and independent variables for 2001 and 2004 production studies on a John Deere 653E harvester. Means with different letters indicate a significant difference at the 0.05 level.

	2001	Test for Sig. Diff. (0.05)	2004	Test for Sig. Diff. (0.05)
Process (sec)	120.3	A	103.9	**B**
Trees	7	A	12.3	A
DBH (in)	8.4	A	6.8	**B**
Height (ft)	49.5	A	44.5	**B**
Reaches	5.7	A	5.0	A
Pieces	11.8	A	19.6	A
Volume (ft^3)	60.4	A	56.4	A
Basal Area (ft^2)	2.6	A	3.0	A

The results of the Duncan's multiple range test indicate that there was a significant difference between the mean processing time, dbh, and height per pile for the 2001 and 2004 studies. All other variables were not significantly different at the 0.05 level. The Duncan's Multiple Range test only looks for differences between the means of the variables. To test for the effect of the independent variables on processing time between year Analysis of Covariance was used. The results of the analysis of covariance showed that year (p=0.3707) was not significant in predicting processing time per pile. The only independent variable that was significant in predicting processing time per pile was reaches (p=.0002). The regression equation for processing time (sec) per pile is: *Process = 5.89 + 19.78*Reaches, R2 = 0.93, P = .0001.* See Figure 1 for a plot of the regression curve and the data from the study.
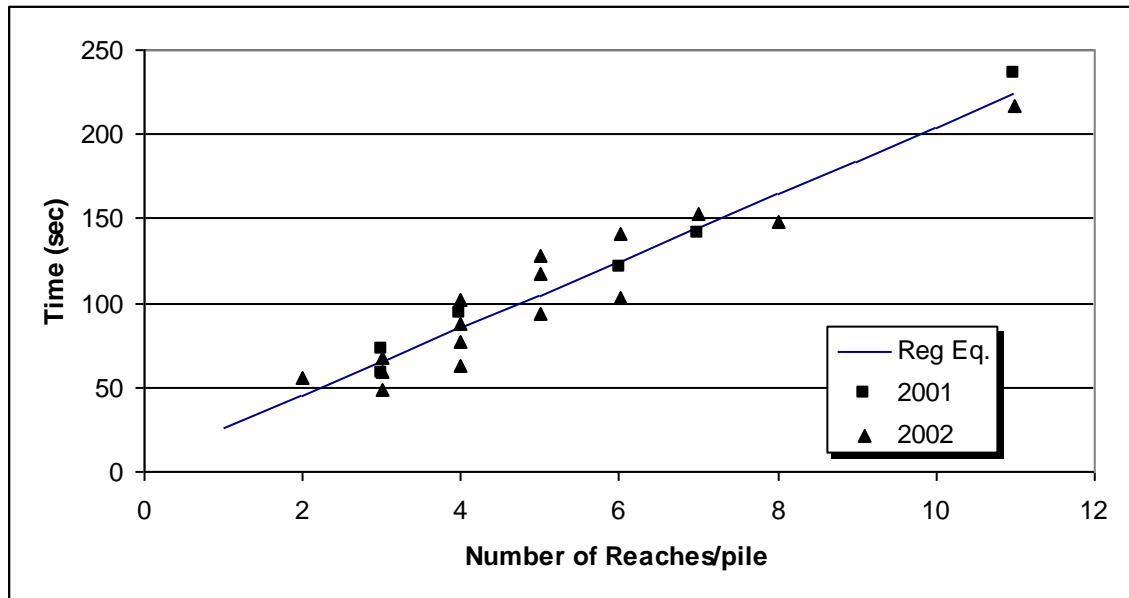
Figure 1: Plot of regression curve for processing time per pile for a John Deere 653E harvester.

CONCLUSIONS

The goal of this study was to compare the productivity of a tracked harvester over time. An initial study was in May of 2001. At the time, the machine was 5 years old and had approximately 9000 hours. In January and February of 2004 a second study was performed on the harvester. The machine/operator now has 12000 hours of operational time. Both the 2001 study and the 2004 study were performed on the Ft. Benning military reservation in west central Georgia.

The harvesting system had changed between the two studies. In 2001 the contractor ran a Hydro-Ax 221 rubber tired feller-buncher fitted with a shear head in front of the harvester to cut and pile all but the largest of trees. In 2004 the Hydro-Ax 221 had been replaced with a Hydro-Ax 611E fitted with a continuous saw head. The new feller-buncher cut and piled all trees for the harvester to process. Therefore, it was not possible to compare felling and processing data between the two studies, but it was possible to compare processing time.

The study results indicated that although the stand conditions (mean dbh and height) were significantly different between studies *year* was not significant in predicting processing time per pile. Regression analysis showed that the number of *reaches* the harvester made per pile to process the trees best predicted processing time per pile. *Reaches* can be considered a surrogate for grapple capacity and trees per pile. The results of the study indicate that it is more important to measure as many of the variables that might affect productivity and sample as wide a range of each as possible verses simply having a large sample size.

MODELING THE BEHAVIOR OF EXCAVATOR-BASED FOREST MACHINE ROLLOVERS

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ABSTRACT

The hydraulic excavator accounts for over 50% of construction equipment sales in the world due to its versatility and its ability to work effectively in a number of industries including agriculture, construction, forestry, and mining. Tracked feller-bunchers and log loaders are typical forest machines that use a hydraulic excavator as the base machine. Because of the popularity of this machine and the exclusion of excavator-based machines from international rollover safety standards, there is a significant safety concern for excavator operators. Current excavator cab designs may not provide sufficient operator crush protection in the event the machine overturns. Currently, the standard development process is hampered because there is little data available on impact loads generated on the cab during rollover. In this study, a three-dimensional dynamic computer simulation will be used to analyze the behavior of a rolling excavator. The model developed in the ADAMS dynamic simulation software package was used to evaluate the effects of upperstructure rotation, boom position, soil slope, and roll direction on the forces associated with the soil-machine cab impact. The results indicate heavier machines with higher cabs will experience higher impact values when the cab strikes the soil surface.

INTRODUCTION

The introduction of automation to forest harvesting operations has increased productivity and provided a safer work environment for those employed in the forest products industry. However, mechanized forest operations threaten an operator's safety as machine rollover, machine tip-over, fire, impact from a falling object, excessive vibration, and high noise levels can have adverse effects on a person's health and well-being. International and regional standards have been developed to insure forest machine operators are offered protection from these hazards. However, problems arise when the development of a machine has outpaced the drafting of standards or when a threat to operator safety has not been identified by standards development organizations.

Roll-Over Protective Structures (ROPS) are designed to reduce the probability of an equipment operator being crushed in the event a vehicle overturns. A ROPS offers protection from crushing in the lateral, longitudinal, and vertical loading

direction. A Tip-Over Protective Structure (TOPS) does not provide protection from vertical cab loading and are only installed on machines with little chance of rolling on to the roof of the cab. To insure a machine protects an operator during rollover, international and regional standards list machines that are required to install ROPS and specify the level of performance the ROPS must achieve on a given machine. ISO (International Organization for Standardization) standards 3471 and 8082 exempt machines from ROPS performance criteria if the cab and boom structure are located on a rotating platform (ISO, 1994). ISO 12117 specifies TOPS performance for excavator-based machines, but it only applies to machines with masses under six metric tons (ISO, 1997). The lack of required ROPS or TOPS on excavator-based machines is troubling, as many of these machines are designed to work on hazardous ground conditions, such as steep slopes and soft, unstable wetland soils. There are numerous logging safety organizations that report rollover of excavator-based forestry equipment in their newsletters and web pages. Among the organizations reporting excavator rollover accidents are: the Worker's Compensation Board of British Columbia, the Forest Resources Association, New Zealand Occupational Safety and Health Service, and WorkCover Tasmania.

One of the major obstacles in the ROPS standard development process for excavators is the lack of dynamic loading data for a wide range of excavator models. Also, full-scale physical testing of ROPS is extremely expensive. The cost of instrumentation, test site construction, and full-scale test machines restrict testing to a handful of machines under a limited set of conditions. Fortunately, new technologies have been developed to simulate the dynamic forces generated during a rollover event. The establishment of finite element methods, the development of multi-body dynamic simulation software and the evolution of the computer are the key components in the simulation, design, and development of ROPS. Computer simulations allow evaluations of ROPS structures to occur on a wide range of excavator models under a variety of conditions in a short period of time.

OBJECTIVE

The overall goal of this research is to provide assistance for the development of performance criteria for ROPS structures that can be installed on excavator-based machines. Specifically, this project is to develop a simulation model to allow analysis of typical excavators used in construction and forestry applications. The model will be used to examine the rollover behavior of excavators and validated with data collected during actual field tests by other research organizations.

RESEARCH METHODS

In order to collect the most accurate data on the impact event associated with excavator cab and soil surface contact it was decided that a three-dimensional (3D) modeling approach would best reflect the true rollover behavior of an excavator. The 3D computer model was developed using the MSC.ADAMS mechanical system simulation package, Version 12.0. ADAMS is an acronym that stands for Advanced Dynamic Analysis of Mechanical Systems. This particular package was chosen because of its widespread use throughout industry, the ability to quickly import parts from various computer-aided design (CAD) packages, and the simplicity of using a graphical user interface (GUI).

The development of solid models representing actual excavator-based machines was based on information contained in manufacturer specification sheets and field measurements. To create the 3D solid model, the major machine excavator components were drawn in AUTOCAD® 2002. The major components that were developed included: the undercarriage, the upper structure, the counterweight, the engine assembly, the engine, the cab, the riser, the boom, the stick, the thumb. There were a total of six excavator models which represented machines with masses between 10 and 60 metric tons in 10 ton increments. For each base excavator, three additional models with 457 mm, 1219mm, and 1829mm cab risers. All rollover simulations were conducted on a 30° slope.

The best solution for estimating these contact forces in ADAMS is to develop a nonlinear spring-damper system to describe soil-machine contact. Using force-deflection values for soils used to construct rollover test slopes used in previous off-highway vehicle rollover experiments, a suitable stiffness and non-linear exponent value for the ADAMS model were calculated. The values for the damping and friction were derived from examples used in literature and from recommendations made by the developer of ADAMS. These values produced a roll behavior consistent with the behavior observed during full-scale field tests.

To simulate a machine rollover, an excavator was leveled at the top of the virtual test slope. The upperstructure and undercarriage were place parallel to each other with the cab side of the machine closest to the slope. The tracks farthest from the slope were slowly lifted until the machine tipped. The boom was placed in a position that allowed all components to remain below the top of the cab. Figure 1, shows an example of the rollover simulation and the output.

Figure 1. ADAMS Model Examples
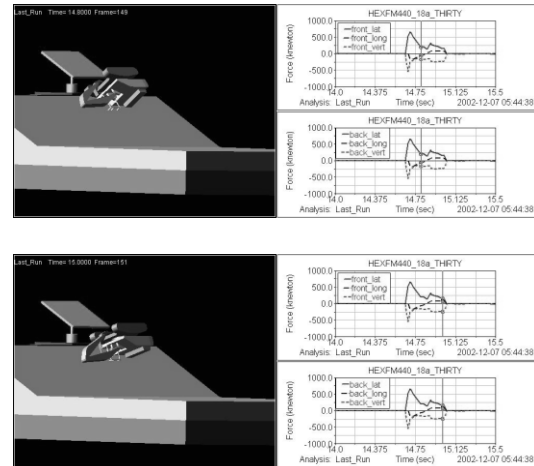
RESULTS AND DISCUSSION

Seventy-one three-dimensional models were developed based on dimensions from manufacturers specification sheets and field measurements. Each model represented a different machine type and a different type of configuration for the given machine. The rollover behavior of each model was simulated in ADAMS and a number of values that dictate the severity of the impact were measured and recorded. The machine variables studied include: roll direction, slope of the surface, position of the boom on excavator-based machines, and the height of the cab riser on excavator-based forest machines.

To validate the results of the ADAMS simulation, data collected during limited full-scale rollover tests were used. The data was provided by industry cooperators and the tests were completed on 12, 20, and 45 metric ton excavators. The full-scale testing and ADAMS simulation values were generally within 10 to 20% of

each other for impact magnitudes, rollover duration, and the values were identical for rotation magnitude (i.e. how many degrees did the machine roll through).

The lateral, longitudinal, and vertical loading values associated with the first impact of the cab with the soil surface are shown in Figure 2. Please note that the graphs report cab heights, this value is simply the height of the top of the cab when a given riser is used and there are two 30 metric ton excavators used in the analysis.

From the data presented in Figure 2, primarily the lateral loading graph, it is evident that the forces associated with the soil impact of a heavier machine are greater than those associated with the impacts of lighter machines. For reference, the load line
used to design ROPS for crawler tractors is specified on each graph. This load
line is a function of overall machine
mass. The data in Figure 2 also suggests that longitudinal loading is relatively small and remains fairly stable regardless of machine mass. However,

Figure 2. Lateral, Longitudinal, and Vertical Loading Values for 1st Cab-Soil Impact.
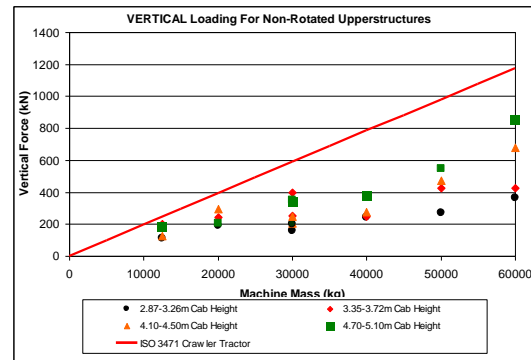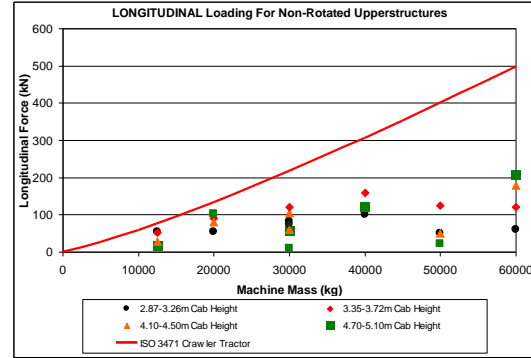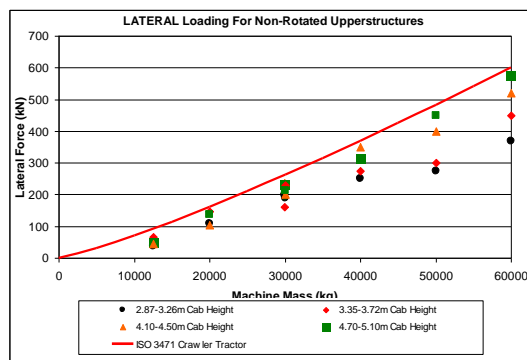
in this rollover testing scenario the machine was tipped without initial forward (or reverse) movement. If the machine is rolling directly onto the cab side of the machine, one would expect the longitudinal loading to be a minor loading component.

For the purposes of further studying the longitudinal loading component and additional rollover scenario was developed. In this new test, the upper structure of the excavator was rotated 45° towards the slope. Now, the machine would impact the front of the cab as well as the side. Figure 3, shows the longitudinal loading result of the rotated upperstructure test. Comparison of Figures 2 and 3, shows that rotating the upperstructure has at least doubled the longitudinal loading values.

Figure 3. Longitudinal Loading Values for Rotated Upperstructure.
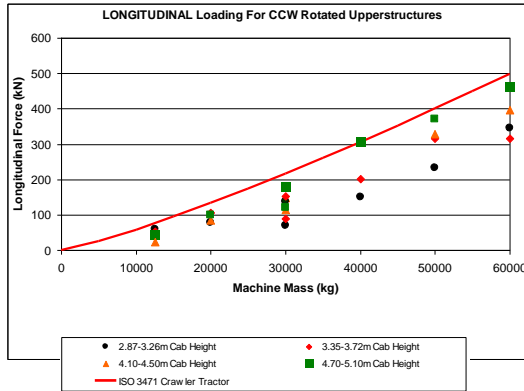
Further analysis was completed on factors such as boom position and roll direction. The boom position did not affect the impact force values that resulted from the excavator rollover. However, the boom position did affect the excavator roll behavior. When the boom was placed in a position such that is was significantly above the cab, there was a reduction in rotation magnitude of the machine. Roll direction did play an important roll in determining the impact magnitudes that occurred during a rollover. When the boom side of the machine struck the ground first, there was a reduction in the magnitude of impact forces. However, boom side rolls produce longer rotation durations from a time and magnitude standpoint. Cab side rolls are faster and usually much shorter. As an example, a 37 metric ton excavator rolled 360° when the cab side struck the soil first, but when the boom side of the machine struck the soil first the machine rolled 540° with a 25% reduction in peak cab loading.

CONCLUSIONS

- Excavator-based machines are currently excluded from ROPS design standards.
- Increasing mass and cab riser height will increase the impact force magnitude of a rolling excavator.
- Rotating the upperstructure of the machine can dramatically increase the longitudinal loading values.

- Boom position is not a significant factor influencing impact forces.

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ERGONOMIC RESEARCH IN THE NORDIC COUNTRIES RELATED TO WORK IN THE FOREST

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INTRODUCTION - The Nordic countries which constitute the north-western part of Europe (Denmark, Finland, Iceland, Norway and Sweden) are to a large extent covered by the Northern Boreal Forests. In early time it was the southern part which was most valuable and these belonged to the Boreonemoral forests.

However, when the industrial development made it possible to utilise the large stretches of coniferous forest (Norway spruce and Scots pine), another era of forest utilisation started.

In traditional Nordic life in the countryside, a combination of farming in the summer and work in the forest during the winter has been the most common way to make a living. In the last half of the nineteenth century however, the population increase in the Nordic countries led to migration. The surplus population moved into the cities where many of them got jobs in the industry, which at that time was under development, and most of the rest moved on to the United States and other overseas countries.

The change in population pattern which followed the industry development in the Nordic countries, led to new and unfamiliar living conditions for those who had to settle in a new environment. A practical question, like where these people should find a place to live – a new home – was of immense importance. Social unrest followed as a consequence of this. Politically this situation became of great concern, and in the 1880-90's the "worker-question" was much discussed. In many of the countries the first labour protection acts were passed in various parliaments. They most often were directed towards the conditions in the new industry.

However, in the countryside the situation also changed, but not so much attention was directed towards this worker protection. The purchase of large stretches of forest from farmers by industrial companies changed the situation for those working in the forest, and in many of the Nordic countries bitter conflicts took place.

The situation of the forest workers was the concern of many people not directly involved in the work organisation. Local physicians started to study the living and working conditions of forest workers, and as time went on, the staff of labour inspectors in the industry was expanded with inspectors for forestry. These people collected information about the living conditions of people working in the forest. What they especially found was how workers lived in cold and draughty log cabins with poor conditions for personal hygiene and also how heavy their work was requiring a daily energy consumption of more than 6,000 kcal/day. Also the composition of the meals were poor, with much fat and little vegetables. (TIGERSTEDT 1900, ANDERSEN 1932)

These pioneers, more or less, started the research which aimed to improve the working conditions in the forest. The technological development in Nordic forestry was slow, and all the time up to the Second World War the conditions only improved slightly. In some places, they built improved modern log cabins with the possibility to have a trained cook prepare the meals. But the real start of research in this field was during the Second World War in Sweden. Even if the Swedes managed to stay neutral during the war, they had problems with the import of supplies and had to ration food. Therefore they started a project to find out if the forest workers needed extra rations, and this was the start their research.

In the following I will try to give an overview of how this research developed, and try to point out some of the more important stages in the development. As I have been involved in this research for more than 40 years, my account will partly be personal. The selection of examples from the vast number of studies carried out will support my own view of the development. Thus, this treatise will not be a catalogue of ergonomic research carried out in the Nordic countries since the Second World War.

1945-1960 - Manual and motor/manual work

<u>Research on work physiology</u>

The first study was in Sweden. Nils Lundgren, one of the pioneers of practical work physiology, studied the energy load during practical work (cutting) in the forest. Similar studies had been carried out by Hilf, Strehlke and Gläser in Germany in the 1920's and 30's, but Lundgren's studies were the first in the Nordic countries. (LUNDGREN 1946)

After the war, it was of great importance to increase the activity in the forest. Both in Finland and Norway a large part of the country had been damaged during the war and it was a great need for lumber in the reconstruction work. In Finland they had a tradition of competitions between forest workers. M.J.Karvonen, also a work physiologist, started studies on the working capacity and work output during competitions of the participants in the contests (KARVONEN 1958). In Norway, a large cutting study was carried out at the end of the 1940's. The primary aim was to find out how the production varied with various factors like tree size, climate, terrain etc, but Ivar Samset who was responsible for the study made a co-operation with a physician who had special interest in heavy manual work, Birger Tvedt. Together they also carried out studies of working capacity and work load during cutting. (SAMSET 1950)

As time went on, work physiological studies became a standard part of research work in the forest operations area. Especially in Sweden, they organised a co-operation between forest research people and work physiologists, and this group made studies on cutting, (LUNDGREN, SUNDBERG & LINDHOLM 1955), manual handling of timber, (SUNDBERG 1960), horse transport (AGER 1958), planting (CALLIN & HANSSON 1959) etc.

Even later similar studies have been carried out. In the 1960's a new Norwegian cutting study was carried out and 17 forest workers were studied during several days when their heart rate was continually monitored and samples were taken of oxygen consumption during work. It turned out that they utilised between 40 and 50 % of their work capacity, and the absolute energy consumption during felling and trimming was of the same size as in Lundgren and Karvonen's studies. (SAMSET et al. 1969) At the same time, a study of daily energy consumption based on nutritional recording, showed that the daily energy consumption had been reduced from approx. 6.300 to 3.700 kcal/day. As the cutting studies demonstrated, this was not because the work as such was less strenuous, but that the working day was shorter and the cutters did not have to walk a long distance from the camp cabin to the cutting field. They could live in their home during the week and commute by car to the forest. This arrangement also led to an improved dietary regime.(TRYGG 1977)

In 1965 HANSSON (1965) published a report where two groups of forest workers were studied as pairs. Each pair consisted of one cutter with average performance and one cutter with higher performance than normal. Data from these pairs were recorded and analysed statistically with a discriminant analysis. It turned out that the factors that were different for the two groups were work capacity and similar properties like experiencing fatigue, how fast they worked, the amount of personal time lost etc. The need to make the work less strenuous was obvious.

<u>Rationalisation of manual work</u>

When Samset carried out his first study on cutting work (SAMSET l.c.) one of the things he wanted to explore, was how he could rationalise (systematically improve) the cutting work with introduction of power saws. The power saws imported from Canada were very heavy, and some of them had to be operated by two people. A two-person team was contrary to traditional work organisation in the Nordic countries, and the Nordic forest workers were very conservative. However, in Sweden they had started to develop a lighter one-man power saw, the BeBo, and in Norway, saw development work also was on its way. In his study Samset addition to Canadian power saws tested the prototype saw called JoBu.

Under Norwegian conditions, it turned out that the best production results were obtained with the new prototype which was substantially lighter than the other saws. In any case, one-man saws were best with the small dimensions of trees in the Nordic forests.

The most heavy sub-operations during cutting, were peeling of the bark and delimbing the branches from trees. The peeling of the bark was relocated after a short period from the forest to stationary barking machines, first at the roadside or the river bank, but later at the wood-yards of the mills. The delimbing continued in the forest,

but a new technique with the use of modern direct-driven power saws was introduced in the 1960's. Unfortunately, the new technique at first caused a dramatic increase in accidents where cutters were injured by the chain, especially in the hands. Later on, it turned out cutters using the power saw for delimbing got "white fingers" (Raynaud's disease).

This situation led to intensive research to find out how these injuries and disorders could be avoided. Power saws were introduced with vibration-damping elements between the saw and the handles, the chain-brake was introduced, and safety equipment like protective trousers and gloves became mandatory for professional forest workers. (AXELSSON 1967, KYLIN et al. 1968, HELLSTRØM & ANDERSEN 1972 and others)

However, quite early it became evident that much could be achieved with proper training of the forest workers. Just after the Second World War, a system using travelling instructors giving courses locally in the forest communities was tried with some success. Forest workers with an efficient working technique were selected for instructors. In the beginning of the 1970's, this idea was taken up again, but this time a support system for the instructors was established. After an instructor's training course of six weeks that ended with a trial instruction (with a qualified group of external examiners present), the instructors set out to give standardised courses for small groups of forest workers. They worked together with the participants for some days and corrected them. The participants then trained by themselves for a period, and finally, the instructor came back to make necessary corrections.

Also a support organisation for the instructors was established. They came together at regular intervals to exchange experience. Instructors also spent time to find good solutions to problems which they became aware of during their work. The staff involved in ergonomic and safety research also took part in these instructor gatherings.

1960-1980 – Early mechanisation

Ergonomics

The Second World War led to a large input of research on the human operators' possibilities to handle situations which involved complicated technical equipment (radar, complicated artillery systems, bombers etc.). This research involved many people from the scientific community with different backgrounds: Occupational medicine, physiology, psychology, technology etc. After the war, many of those involved wanted to continue their research, but in civilian fields. They named the new field *ergonomics.*

The introduction of ergonomics also had an impact on forest research. As the war had had a great influence on the daily life for many people during more than half a decade, it would also have an influence on their future life. Many technical improvements had been the result of the war, and in some of the countries, the Germans had left behind war material that could be used in the forest. I know about places in Norway where the first motorised transport of timber was made with old German tanks. More importantly, the bulldozer was introduced for construction of forest roads.

Mechanisation of forest operations got its real start after the war. In the beginning much work was concentrated on the development and adaptation of the agricultural tractor for use in the forest. In Sweden, the development of tractors with tracks was part of their development work. However, it was when the frame-steered tractors from USA and Canada were first introduced that the mechanisation gained impetus.

In the middle of the 1960's it became evident that the future for forest operations would involve mechanised equipment. The research people involved in work physiology started to study the impact of the new equipment on health and welfare of the machine operators. In Norway a minor study was carried out in 1965 (AKERVOLD 1967) where the ergonomic conditions on three different skidders were studied. Almost simultaneously a much larger study was carried out in Sweden (HANSSON, KYLIN & GUSTAVSSON 1967). Based on the Swedish study the first ergonomic check-list for forest machines was constructed (HANSSON & PETERSSON 1969)

The first reports trying to give an overall evaluation of the ergonomic conditions were followed by studies concentrating on the various problems listed. Vibrations were covered in Finland by AHO & KÄTTÖ (1971) and in Sweden by HANSSON & WIKSTRÖM (1972). Working in artificial light was covered by TELJSTEDT (1970).

In the Nordic countries the forest research institutes involved in forest operations had started a sort of co-operation through what was called "The Nordic Council for Work-Studies in Forestry". This organisation took the initiative to obtain funding through The Nordic Council – which was forum for co-operation between the Nordic countries. The National Assemblies and Governments in the various countries were involved in this activity, and each country had to contribute to funding for various activities of common interest. The Nordic Council for Work-Studies in Forestry was able to get funding for the first time in 1969. Four joint projects were started, and organisations in Denmark, Finland, Norway and Sweden were responsible for the co-ordination of the projects. The Norwegian project had the title "The relationship between man and machine for forest machines".

Special problems that were covered in this project were driver shocks and jolting during transport over rough ground, work in artificial light, shift work, anthropometric data from male workers in the forest etc. Nordic projects covering various ergonomic problems in forestry continued all the time up to the 1990's.

At the same time as studies on the machines, the health review of operators showed they had major problems with pain in the shoulders and neck. This led to intensive research on how manoeuvring systems could be designed to reduce the load on muscles in the arms, neck and shoulder. The development of mini-levers was one of the results from this research (ATTEBRANT 1995). However, research on these operator problems is still going on.

Forest worker health

As many of the research workers involved in the early research on working life in the Nordic forests had a medical background, it was quite natural that the health condition of the forest workers would come into focus. The first comprehensive study of forest workers' health was carried out in 1967 by The National Institute of Occupational health in Sweden. They took the initiative to conduct a large survey of health conditions of workers in forest operations. The participants were engaged both in motor/manual work and as machine operators. (KYLIN et al 1968).

These studies did not only cover health conditions, but also the biological properties of the workforce in the forest. In connection with the Nordic project, various studies on both special conditions during forest work and biological properties of forest workers were carried out (SKROBAK-KACZYNSKI & ANDERSEN 1974, 1975 etc.)

The main health problems uncovered during these studies showed that the heavy work in the forest strained the locomotive system, and principally, back trouble was common among the forest workers. As a consequence of the new laws on workers' protection in the 1970's, regulations were issued which called for the establishment of a health service within the forest companies. During the 1980's much work was done to find proper models for how this health service could be organised. In Sweden a major program was carried out from 1980-87 to develop support for the various forest companies' occupational health services. This research also included the construction of a database with health data from 24 forest companies. PONTÉN (1988) processed data from 7.200 employees from these companies, 4.800 of whom were performing practical work in the forest (cutting and machine operation). The processing of the data was partly used to supply the various companies with data about the health condition of their forest workers, but the data was also of great value giving priority to development measures for the machine manufacturers.

A similar program, but on a much smaller scale was carried out in Norway. Here special emphasis was put on the motor/manual work and a close contact with the instructors mentioned above was established. (VIK, HAGEN & TEIGE 1988)

Work satisfaction

The reconstruction of society after the Second World War led to many discussions about how the society should be developed. As part of this discussion, also an interest in how the work should be organised started in the 1950's. In Norway an agreement was made between by the major trade-union and the employers' association in 1962 that experiments should be started with various models of workers participation in the management process.

An institute at the Norwegian University of Technology was engaged in various projects. One of these was to study work organisations that was already in operation in various industries to find out to what extent the workers experienced autonomy, and to what extent.

These studies started just after the first skidder with an articulated frame had been introduced in Norway. This machine had been purchased in connection with a study tour professor Ivar Samset made to the US and Canada in the autumn of 1960. The skidder arrived Norway in 1961 and it took some time to find a company willing to test the machine in their operations. Finally, a test company was found in Central Norway not far away from the Norwegian University of Technology.

Professor Samset was very active part in the introduction of the skidder, and he suggested the company use a work organisation with five forest workers: Tree cutters and two machine operators. Team work was not a traditional way of organisation, and local discussions spread to the researchers in Trondheim, who wanted to include the team of forest workers in their study on autonomy. Their study (GULLOWSEN 1971) showed forest workers had a large degree of autonomy compared with the other groups in the study (mining, heavy industry). Studies made by the Norwegian Forest Research Institute at the same time (ARVESEN 1969) showed that the organisational model was very efficient and it was recommended that forest operations should be organised in partly autonomous teams.

 The studies were made in connection with an agreement between The National Union of Workers and The Norwegian Employers Association and ended with a publication where a set of requirements for a psychologically satisfactory work situation was defined (THORSRUD & EMERY 1969). These were:
- The need for a meaningful content in the work (demanding more than endurance and leading to a minimum of variation in the work)
- The need for learning something from the work
- The need for making decisions, at least within a limited field which the worker can call his own
- The need for esteem, at least a certain degree of support and respect on the work place
- The need to see some relationship between the work and the surroundings at least to such a degree that the worker can see some connection between the work he does and something that can be looked upon as useful and valuable
- The need to see the work as part of desirable future without necessarily imply advancement

When the Norwegian labour protection law was revised in 1976, these requirements were included in the law for workers. The law did not require that the workers should be organised in autonomous of semiautonomous groups, but that the workers should have the rights to influence their own work organisation.

In Sweden at the same time, similar research was going on. In connection with the survey of forest workers health, also an interview on the workers experience of their work from the point of view of work satisfaction was carried out. A report was published (GARDELL 1969), where among other findings, it was clear that the forest workers did not differ from industrial workers when it came to general work satisfaction, but they were more motivated and experienced less monotony. The forest workers felt a large amount of freedom in their work. The group studied by Gardell consisted of 310 forest workers with the majority as cutters and tractor operators. The rest consisted of horse drivers and operators of debranching and debarking machines. The workers with the most positive attitude to their work were the horse drivers, and the least positive attitude was found among the debranching and debarking machine operators.

The development of work organisation was an important issue in Nordic forestry in the 1970's. The possibility to make the working conditions better for the forest workers became more and more in focus. Research was made on the interaction between the forest workers and their supervisors. FRYKMAN (1980) studied the supervisor's working conditions and HARSTELA (1979) reviewed the situation how far the work organisation during logging operations could be improved. GUSTAFSSON et al. (1988) tried to design new forms of supervision where the workers themselves were educated to take much more responsibility. The possibility of planning their own work was an especially important issue for workers. .

Development of safety work

As mentioned earlier, a new worker's protection act was introduced in Norway in 1976. At the same time similar changes took place in the other Nordic countries. A dramatic increase in accidents in forestry in the 1960's put focus on the safety work in forest companies. The new acts had regulations on how to organise

safety work. In each company with a certain number of employees, a safety representative would be elected by law. Major companies had to establish safety committees.

In Sweden research was started to find out how safety work best could be organised to be effective while maintaining productivity during work. A program for action was developed (PETTERSSON 1981). This produced good results, and in some major companies, a reduction of 50% of the accidents could be found. However, the accident statistics generally continued to be too high, and research was carried out to find out how the forest workers reacted towards the safety regulations. When the number of accidents started to increase in the 1960's, they were due in the beginning to "kick-back" accidents during delimbing with the power saw that made up most of the increase. Intensive work was carried out both to find safe working techniques and also to improve the ergonomics of the power saw (protective devices, chain brake, vibration damping, heated handles etc.). However, the accidents that occurred during felling increased dramatically at the same time and drew attention. These were often fatal accidents. The Swedish Work Environment Authority made regulations for how felling should be carried out in a safe way, but the foresters in the field observed that many workers continued to use work procedures banned in the regulations. In a study by LINDSTRÖM & SUNDSTRÖM-FRISK (1975) they found that the attitudes towards the safety regulations varied to a large extent. Many forest workers took chances during the work, motivated by the opportunity to earn more money during piece work. This and similar studies came at the same time as a severe strike in the forest and were instrumental to experiments with new wage forms.

Still more could be done. From 1976 forward, a new project was carried out where the importance of a safety organisation integrated into the organisation of production was emphasised. (AMINNOF & LINDSTRÖM 1981). However, since the finalising of this project, the forest operations situation, first in Sweden and later in all Nordic countries, has been dramatically altered.

1980-2000 – Fully mechanised forest operations

Changes in the work situation

The introduction of machines in Nordic forestry took place in the 1960's. At the same time manual work was made more efficient. Productivity increased in the Nordic forests, but at the same time the profitability decreased. This stimulated an intensive period of development work, and especially in Sweden and Finland, new mechanised equipment was developed and produced. Also much energy was invested in the study of suitable equipment from abroad.

During the 1970's processors and other advanced machines were introduced. In the beginning, the forest companies were able to invest in this machinery and they employed machine operators. For the smaller forest owners and especially farmers owning forest, the agricultural tractor was adopted for the use in the forest and development of special equipment (winches, light cranes, trailers etc.) took place in all the Nordic countries. This gave the farmers an opportunity to work in the forest during periods of the year when the activity on the farm was low.

The equipment development both in agriculture and forestry however, has led to less incentives for the farmers to do the forest work themselves. Also in farm forestry, mechanised methods have taken over. As the farmers themselves were not able to invest in the costly equipment needed, the forest owners' associations purchased the machines and established a service for their members. Today around 90% of the annual cut is logged with harvesters and forwarders.

In the end of the 1980's it became obvious that even the fully mechanised methods were not enough to guarantee satisfactory revenue. Both the forest companies and the forest owner's associations started to sell their machines to the operators. This was an important step which completely changed the working life in the forest. Since the 1990's contractors have taken over more and more of the activity in the forest. In 1999, 78% of the annual cut in Norway that was logged by contractors and only 16 % was cut by the forest owners themselves. This type of harvest statistic is not collected any more, but we have good indications that the amount logged by contractors is increasing.

Working conditions for contractors and their employees

The change in work organisation in Nordic forestry came very rapidly. In the beginning, many former machine operators were offered the chance to buy the machines they had been operating as employees earlier. In many

cases this was not a success. Operators had no knowledge about how to handle the economic part of the business, and problems in connection with tax rules were also problematic (DALE, HAGEN & STAMM 1992, LIDÉN 1995).

This led to many bankruptcies and many operators left the forest. However, as time has passed, the contractors gained more experience. They have organised themselves, and, new forms of how to organise the firm have been developed so the situation has improved. (NORIN 1994) Presently it seems that the number of contracting firms is at a reasonable level.

The entire time this development has been going on, several studies have been carried out in Sweden. BOSTRAND (1984) made a study where she summed up the development in the period 1969-81. In 1976 the machines operating in Swedish forestry were classed in the following way:

- 40%   Operated by a company employee. The machine belongs to the company
- 26%   Operated by a company employee owning the machine
- 34%   Owned by a contractor (who is not a company employee)

At that time, there were many complaints on the ergonomic conditions on the machines. The problems most often mentioned by the machine operators were noise, vibration, rigid working positions and dangerous situations during maintenance and repair work. The last was especially problematic during the winter in severe cold.

BOSTRAND (l.c.) also found that the machine operators experienced psychic stress in their work. They were not satisfied with their working hours and the work in processors was felt to be controlled by the machine. All these factors led to health complaints in neck, shoulder and arms. However, the machine operators had less sick-leave than comparable occupational groups. Those for whom impaired health was a major problem left the forest or received disabled benefits.

LIDEN (1986) continued with a new study where the focus was on the contractors. This was natural as the number of contractors was increasing, and in 1985 the distribution of machines was the following:

- 35%   Operated by company employee. The machine belongs to the company.
- 23 %   Operated by company employee owning the machine.
- 42%   Owned by contractor

The development showed that the machines were rather new. One third of the machines were older than six years, but this was not the case with the owners of one single machine which they operated themselves. In this case, two thirds of the machines were older than six years. During this period, the new machines had been improved from an ergonomic point of view, but still many complaints were recorded.

The health situation was similar to earlier studies in that, even if the machine operators complained about pains in neck, shoulder and arms and had back trouble, they still had sick-leave much less than for other comparable groups.

LIDEN (1995) made a new study. At this time she was more interested in the attitudes of machine operators working for forest companies and for contractors, but her main interest was contractors.

The study was carried out during the harvesting season 1992/93. At this time 70% of all machines used in industrial forestry in Sweden were owned by contractors. The contractors had established themselves because they hoped for freedom in their work first of all, because they were interested in machines, and because they hoped for an inspiring work.

One of the main findings of LIDÉN (l.c.) was that being a contractor could be looked upon more as a life-style than as an occupation. The contractors' willingness to work hard and to do a good job were assets for forestry. However, the work organisation places a strong responsibility on the forest industry to co-operate with the contracting business to achieve high productivity, and at the same time a high standard on their forestry and a good working environment for contractors and their employees.

A new philosophy on ergonomics of forest machines

The first ergonomic checklist that was published in 1969 and was revised several times. The continuous improvement of the checklist as new research results were incorporated made it a useful instrument for the development departments in Nordic forest machine manufacturers and for those outside the Nordic area.

In 1995 GELLERSTEDT (1995) presented a paper about the preparatory work for another edition. However, this time it was obvious that the old concept of purely ergonomic measures like access, space, seat, noise, vibration, light, climate, exhaust gases, safety etc. would not be enough to make substantial working improvements. Two new principal ideas were presented: The basis would be an ideal machine from the point of view of ergonomics and work environment. Also the organisation of work around the machine had to be taken into consideration.

The work was started as a Nordic co-operation. The major work was done in Sweden, but a project group with participants from Denmark, Finland, Norway and Sweden was active the whole period. First step was to collect all relevant data and present the state of the art of forest machine ergonomics. This was done in a publication covering all the issues to be discussed in the final list (WINKEL & ATTEBRANT 1996). The first draft of the list was discussed in national seminars in all the four countries where machine operators, contractors, forest company and machine company representatives took part. Also new drafts were discussed in a similar way,and in 1996, the list was published (GELLERSTEDT et al.1996).

It was a growing concern that the health situation changed but not improve. As it was clear that technical measures were not enough to improve the working conditions, the Swedish Work Environment Authority started to discuss if they should enforce regulations that limited the part of the working day that the machine operators could spend in the machine cabin to six hours. Only four of these hours could be continuous machine operation.

In 1994 discussions took place between the Swedish Work Environment Authority and the logging industry. It was decided that during a two-year period the logging industry should get a chance to prove that they could achieve a positive change. To study this a special project was carried out. It was called the AND-project because the aim was to "emphasise the matters of production AND work environment" (SYNWOLDT & GELLERSTEDT 2003)

The AND-project has been implemented. An evaluation of the project (SYNWOLDT & GELLERSTEDT l.c.) shows that the companies engaged themselves in the problem area, but it is difficult to demonstrate any distinct improvement. As a consequence of the study and project, no distinct regulations were enforced. However a recommendation was issued: "Work in a harvester shall be joined with other work tasks or breaks which consist of at least two hours every complete working day. These other work tasks should not consist solely of work in the forwarder."

FUTURE RESEARCH

Future co-operation in ergonomic research in forestry

The last joint Nordic ergonomic project was finalised in 1996. At that time Denmark, Finland and Sweden had joined the European Union. Only Norway and Iceland were outside the EU.

This has caused a big difference in the situation. The Nordic Council for Work Studies in Forestry still exists, but the activity level is very low. The development of the European Union has also influenced the Nordic co-operation, and because both Iceland and Norway have made a special agreement with the European Union, we are allowed to take part in the European research programmes.

The first example of such activity is ErgoWood, a programme sponsored by the European Union as part of the programme called "Quality of Life and Management of Living Resources". The full title of the project is: "Ergoefficient mechanised logging operations".

In this project, the participants from the Nordic part of Europe are Norway and Sweden. Other participants are United Kingdom, France, Germany and Poland. The administrative staff is in Sweden.

The idea was born during discussions among Nordic research people. Both the potential for new projects supported with European Union money and the successful co-operation in connection with the new checklist contributed to the idea.

ErgoWood has as its main purpose to give the European logging industry a better competitiveness through development of the organisation of logging operations and its machinery. The project will develop, publish and initiate implementation of "European recommendations for ergoefficient mechanised logging operations".

The project started in 2003 and will be finalised during 2005. Up till now, the major activity has been a combined questionnaire and interview study in all six countries. During the autumn of 2003, 294 questionnaires were collected and 82 interviews were made with contractors and machine operators. The machine operators were for the most part employed by contractors.

The project is based on the total experience from all European countries. In this connection the Nordic experience has not been the least contribution. However, the forest operations situation in various parts of Europe differs greatly. In the Nordic countries the focus in recent years has been on machine operators' work. Still Europe has some motor manual workers, but their number is diminishing all the time. Therefore most likely, the machine operator will be the focal point for future research.

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Evaluation of Methods and Procedures for Best Management Practices Monitoring and Reporting in the Southeast United States

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ABSTRACT: Every state in the Southeast US has developed a set of Best Management Practices (BMPs) to protect water quality during silvicultural activities. These BMPs are either voluntary or quasi-regulatory in the Southeast, though water quality protection is mandatory under the Clean Water Act. Although the Southern Group of State Foresters (SGSF) has adopted a Silvicultural BMP Implementation Monitoring Protocol, each state Forestry agency has developed a particular inspection and reporting methods, that accompany their own set of BMPs, to comply with EPA requirements. Inconsistencies among the States have led to a concern about the ability to measure progress within a particular state, and to make meaningful comparisons between states. This paper evaluates the methods and procedures that each state has developed for both operational inspections as well as implementation and effectiveness inspections for EPA reporting purposes. Four of the nine state forestry agencies reviewed had the right to trespass and only one state had enforcement powers. The number of sites inspected for EPA reporting purposes varied between 200 and 400. Site selection procedures included aerial reconnaissance, timber receipts and geographical stratification. This paper concludes that the development and utilization of uniform terminology, assessment methodology and standard reporting procedures, by states, would be beneficial to address the inconsistencies identified.

INTRODUCTION

The Clean Water Act of 1972, particularly section 208, exempts timber-harvesting activities from acquiring a permit for nonpoint pollution discharge (known as Section 404 permit) as long as best management practices are used to protect water quality. The EPA has since required proof that these BMPs are being implemented (Ryder 2003). The monitoring of implementation and effectiveness of these practices will help foresters and other land managers understand the value of these techniques and help in making sound decisions to protect water quality.

Generally, the southern states have employed a voluntary non-regulatory approach to BMP implementation and monitoring. This system relies heavily on education and other incentives like cost-sharing to encourage BMPs (Ice 1985). In comparison, the Pacific Northwest states and some Northeastern have developed Forest Practices Acts, in which silvicultural activities are highly regulated. A study in Virginia showed that a non-regulatory BMP system, compared to a hypothetical regulatory system, resulted in a better costs benefits ratio (Aust et al 1996). The EPA has approved silviculture BMPs for each southern state (SGSF 2002). Each state has also developed individual monitoring and formal reporting systems.

Inspections of BMPs are undertaken to determine if technical specifications are being met, also called compliance monitoring, and to reveal if the implementation actually protects site and water quality, also knows as effectiveness monitoring (Ellefson 2001). Another goal of inspecting is for enforcement of water quality infringements. Other objectives include education, environmental and site quality protection and detection of any adjustments that may need to be made to the technical requirements of BMP implementation.

Monitoring inspections occur either during or after closure of routine operations or formal reporting of BMP implementation. Figure 1 illustrates how these two levels reveal information about BMP compliance and water quality protection.

Due to the importance of protecting and evaluating impacts of silviculture on water quality, the recommended protocol of the SGSF provides a recommended set of standards and inspecting procedures to promote better management and understanding of the rates of BMP implementation throughout a state.
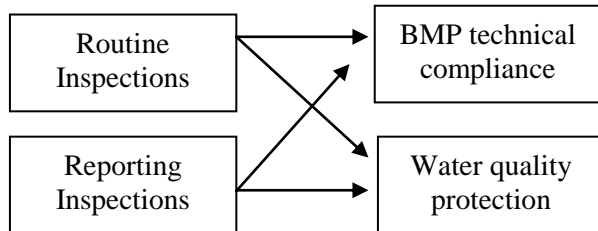

Figure 1. Flow chart demonstrating how routine monitoring inspections and formal reporting inspections relate to BMP compliance and water quality protection.

Continuity among the states would encourage understanding of the progress, effectiveness and compliance of BMPs within the states as well as promote meaningful comparisons between the states.

METHODS

Information regarding BMP inspecting and reporting procedures, on all southern states with a coastline, was collected. Phone interviews were held with most state BMP coordinators or their equivalents. BMP manuals and reporting surveys were obtained online and through the state forestry offices where possible. Additional information was collected through journal articles and conference proceedings, including the Southern Group of State Foresters (SGSF) Silviculture BMP Implementation Monitoring Protocol (SGSF 2002).

TERMINOLOGY

Some confusion exists regarding how to refer to the types of inspections and or visits that are carried out by the state agency. 'Monitoring' and 'Auditing' are terms often used to describe these inspections. The terms courtesy exam, courtesy audits and self-audits are used in the South. The

Oxford American Dictionary (1980) defines the terms as follows:

- Monitor: to watch over, to record or test or control the working of.
- Audit: an official examination of accounts to see that they are in order.
- Inspect: to examine officially, to visit in order to make sure that certain rules and standards are being observed.

In this paper, we will use the term inspection for active site visits by the state agency – regardless of the purpose of their visit. Each state may refer to these visits using its own terminology.

KEY RESULTS

A summary of the BMP inspecting protocols from the selected Southern states is broken down in Table 1. Notification of harvest operations to the state forestry agency is categorized as not required, voluntary or mandatory. Active harvest and closeout inspections are addressed through a courtesy exam or audit, performed upon request from the landowner or logger, mandatory or as response from citizen complaint. Both notification and active/closeout inspections are performed for routine harvest activities. State forestry agencies are responsible for developing and implementing BMPs, though Virginia is the only state responsible for enforcing water quality infringements. Four of the nine states examined have the right to trespass to inspect for BMP implementation and compliance. The number of sites inspected for formal reporting is listed along with whether the state monitors for water quality, BMP compliance or both.

The following is a brief summary from each of the states:

Alabama: Alabama has voluntary BMPs. They do not routinely visit individual logging sites unless they are invited by the landowner for a preharvest consultation, or are responding to a complaint. They do pursue an invitation upon the discovery of an operation. The Alabama Forestry Commission does not have the right to trespass. Six random sites per county per year in half the

state (total of 34 counties per year) are selected for 'aerial monitoring' of BMP implementation. The site is evaluated on implementation for each BMP category on a yes/no basis and also reports overall implementation (Greis *pers. com.* 2003; Hyland *pers. com.* 2003). The Commission follows most of the protocols set forth in the SGSF protocol. The Alabama Department of Environmental Management handles the enforcement of water quality impairment and penalties (Hyland *pers. com.* 2003). To date there are no published reports on BMP implementation (Prud'homme and Greis 2002).

Table 1. Summary of information gathered by state.

States	Routine operations				EPA Reporting	
	Notification	Active Harvest / Closeout Inspection	Enforcement Agency	Right to Trespass	Number of Sites Inspected	Inspect for Water Quality or BMP Implementation
Alabama	N	CE	N	N	200	BMP
Florida	V	CA	N	N	>200	Both
Georgia	V	CE	N	Y	>400	Both
Louisiana	N	~	N	Y	>250	BMP
Mississippi	N	~	N	Y	>250	BMP
North Carolina	V	SA	N	Y	>200	Both
South Carolina	N	CE	N	N	>200	Both
Texas	N	~	N	N	150	Both
Virginia	Y	Y	Y	Y	>50	Both

N = no, Y = yes/always, V = voluntary
CE = courtesy exam, SA = self audit, CA = courtesy audit
~ = depends on invitation from appropriate party

Florida: Florida has a quasi-regulatory system of BMP enforcement and has recently initiated a 'notification rule' (Vowell *pers. com.* 2003). Upon request from loggers, landowners, foresters or timber buyers, a BMP forester will perform a courtesy audit. These can take place before, during or after a harvesting operation. Usually those sites that have a courtesy audit before or during harvest have another after closeout. Since 1981 and every other year, Florida conducts a statewide implementation survey to determine BMP compliance (Vowell *pers. com.* 2003). These surveys comply with the SGSF framework for

Silviculture BMP Implementation Monitoring. Over 200 sites are randomly selected for reporting by aircraft or on the ground and distributed by timber receipts (Prud'homme Greis 2002). They examine 14 BMP categories and record yes/no answers then report compliance as a percentage (Prud'homme

Greis 2002). The Department of Environmental Regulation is responsible for handling water quality violations. Vowell also stated, "Florida also evaluates potential water quality impacts by assessing significant risk, and with follow-up actions – both of which area also required for compliance with the SGSF Framework" (Vowell *pers. com.* 2003).

Georgia: Georgia has voluntary BMPs except in certain sensitive areas like public water supply watersheds, waterways that flow over 400 cfs and mountaintops that exceed 2,200 feet in elevation (Green *pers. com.* 2003). Stream crossings and wetlands are regulated under the CWA and must meet baseline standards to be exempt from Section 404 permitting (Green *pers. com.* 2003). Some counties in Georgia that have logging ordinances require written notification of a harvesting operation (Green *pers. com.* 2003). Routine inspections are made monthly and reporting inspections are conducted biennially. Routine BMP implementation inspections are performed on a sample of active harvest or site preparation operations through a courtesy exam program similar to South Carolina. This program utilizes a series of questions answered by either yes/no/ or not applicable. After a harvest is examined and closed out, a follow-up inspection is performed. During the biennial reporting inspections random site selection for reporting is determined using a stratified sample based on timber harvesting across ownership classes in each county resulting in 420 sites for 2002. Implementation in various BMP categories is reported as percent compliance based on the yes/no/na questions (Prud'homme Greis 2002). The information can be classified be ownership classes, physiographic region and river basin (Green *pers. com.* 2003). They attempt to perform the statewide reporting survey every 2 years and follow the SGSF protocol for implementation monitoring of BMPs. The Georgia Environmental Protection Division is responsible for enforcing water quality violations (Green *pers. com.* 2003).

Louisiana: Louisiana Department of Agriculture and Forestry has voluntary BMPs except in wetland and other sensitive areas. They do not routinely inspect active or closed logging operations but will

do an inspection upon invitation by landowner or responding to a complaint. Every three years they select at least 250 sites (or amount needed to achieve 95% confidence of BMP implementation) using aerial reconnaissance and inspect for BMP compliance using the SGSF protocol for Silviculture BMP Implementation Monitoring (Heaton *pers. com.* 2003; Thomas *pers. com.* 2003). Reporting is performed across 5 BMP categories and is listed as exceeding guidelines, full implementation, minor departure of BMP (still considered in compliance), needed but not applied or not applicable (Prud'homme and Greis 2002). BMP compliance is reported as percentage of implementation. All enforcement issues and fines are handled through the Louisiana Department of Environmental Quality.

Mississippi: The Mississippi Forestry Commission has voluntary, nonregualtory BMPs but they will offer advice upon invitation. Routine inspections are performed on a discovery basis. Mississippi forest rangers do have the right to trespass for water quality monitoring. Attempts are made to mitigate water quality violations but penalties are handled through the Mississippi Department of Environmental Quality. Mississippi Forestry Commission has adopted SGSF recommended framework for BMP implementation inspecting (Sampson *pers. com.* 2003). To date there is no published formal report on BMP implementation though the state is undergoing changes in their BMP monitoring procedures (Prud'homme and Greis 2002).

North Carolina: North Carolina, like Florida and Virginia, has quasi-regulatory system that involves a mandatory water quality program though BMPs are voluntary. They have a set of 'forest practice guidelines' (FPGs) pertaining to the protection of water quality that contain nine performance standards pertaining to all site disturbing silvicultural activities. BMPs are recommended by the FPGs for protecting water quality. (Gerow *pers. com.* 2003; Gueth *pers. com.* 2003). Rangers and foresters will perform routine water quality inspections in response to complaints or upon request. If a problem is noted then the Division of Forest Resources will try to mitigate the problem. The NC Division of Water Quality and Division of

Land Resources both handle the enforcement of water quality impairments, depending on the type of impairment (Gerow *pers. com.* 2003). Loggers, landowners, timber buyers or consultants can perform their own water quality evaluation through the self-audit program (Gerow *pers. com.* 2003; Gueth *pers. com.* 2003). For SGSF compliance reporting, a minimum of 200 randomly selected that fit the selection criteria are located aerially or on the ground, and then an on-the-ground survey is completed. The sites are evaluated and yes/no implementation questions are answered as well as an assessment threat to water quality.

South Carolina: Routine BMP inspection is performed in South Carolina through the Forestry Commission's courtesy BMP exam program that attempts to identify potential water quality impacts. They make regular flights over drainage basins to locate harvest and site preparation operations. Then they will approach the landowner and ask permission to do a courtesy BMP exam. On the sites these examinations are performed, they typically visit again after closure. They will also give an exam upon request or to respond to a citizen complaint. Over 200 sites are selected by aircraft and inspected on the ground for reporting purposes. These sites are stratified in a random manner by timber receipts followed by 3 on the ground inspections; one after harvest, one after site preparation and one two years after closure (Greis 2002). All water quality infringements are reported to the South Carolina Department of Health and Environmental Control (Jones *pers. com.* 2003).

Texas: Routine inspecting occurs by landowner/logger request. Currently, Texas is relying on education to promote BMP implementation and protect water quality (Carraway *pers. com.* 2003). Texas has redesigned their monitoring and reporting protocol to follow the recommendations of the SGSF. Approximately 150 sites are selected via aerial reconnaissance and distributed regionally by ownership category and also by amount of timber harvested from each county (Simpson *pers. com.* 2003). The BMP categories are assessed using yes/no/NA questions and are then tallied for a rating of compliance (Greis 2002).

Virginia: Virginia has a mandatory 3-day notification system (before or after harvest begins). They attempt to visit every logging job and are obligated to visit the harvest site at least 15 days after notification and at least 15 days after closure (Poirot *pers. com.* 2003). The VA Department of Forestry is the only state examined that is responsible for enforcement of water quality infringements. They strategically and randomly select 30 sites from the notification list biannually for auditing. An on the ground inspection determines compliance. To be in compliance the site must use all relevant BMPs 100% of the time and meet 100% technical specifications (Poirot *pers. com.* 2003). This method of reporting gives low compliance though 90% of sites showed effort to implement BMPs (Greis *pers. com.* 2002).

DISCUSSION

The Southeastern states reviewed in this paper use many different methods for routine inspections and formal EPA reporting inspections. Florida has a voluntary notification system and Georgia loggers are required to notify only when working in those counties with an ordinance that regulates forestry activities (Green *pers. com* 2003). Virginia is unique in that it is the only state where notification is mandatory and the state is obligated to visit every harvest operation with a $1000 fine for failing to do so (Poirot *pers. com.* 2003). A notification system does ensure that the state forestry agency is aware of harvesting operations and can inspect routine operations accordingly. Inspections on randomly sampled sites, attempt to accurately represent BMP implementation for reporting purposes.

All of the examined states will give advice on BMPs upon invitations from landowners, loggers, timber buyers or respond to citizen complaints. They are called either courtesy exams or audits and are routine in Alabama, Florida, Georgia, and South Carolina. North Carolina has a similar program called the NC Self-Audit Program. If an agency is invited to perform courtesy exam/audit, it will usually come back after closure to make sure the BMPs are working and there is no threat of sediment

entering a waterway. There is much variation in the language used to describe these routine inspections.

Georgia, Louisiana, Mississippi, North Carolina and Virginia and have the right to trespass in order to inspect water quality infringements. Without this inherent right, a state forestry agency may be unable to inspect a questionable operation and offer advice on water quality protection. Generally, state forestry agencies do not feel the lack of the right to trespass is prohibiting amelioration efforts on harvest sites. Instead, they prefer to rely on education and not appear as a 'regulator' to the general public. Virginia is the only state with the responsibility of enforcement and penalizing water quality infringements. In the eight other states reviewed, the responsibility has remained with another state department of environmental health or environmental quality.

For formal reporting purposes for the EPA, most states attempt to follow the SGSF recommended framework for implementation of silviculture BMP monitoring (SGSF 2002). Some of the recommended guidelines address frequency of reporting, the attributes a monitoring site should have, which practices should be evaluated, how the sites should be 'graded' and how potential threat to water quality is evaluated (SGSF 2002). While these recommendations from the SGSF attempt to provide some continuity between the states, the guidelines remain broad, leaving room for each state to tailor the framework to its needs. One of the guidelines include, statewide monitoring to be undertaken at least every three years.

For site selection in the SGSF Protocol, there is no minimum size, no water has to be present on the property, operation must be closed for no longer than two years and sites may be selected by, "aerial reconnaissance, severance tax records, notification logs…it is essential to achieve random, stratified random or randomized cluster statistical design to obtain an unbiased sample" (SGSF 2002). Sites that are considered ineligible are those that are using timber harvesting to undergo a change in land use. Some evaluation categories include the harvesting, site preparation, roads, stream crossings and streamside management zones.

Site selection methods for EPA reporting vary throughout the states, although states attempt to obtain a set of random and unbiased sites to inspect for reporting. Some sites are chosen completely randomly with no stratification while others like Georgia and Texas sort by timber receipts while still others like North Carolina and Virginia sort by region. States that select sites by aerial reconnaissance include Alabama, Florida, Louisiana, North and South Carolina and Texas. The number of sites that each state ultimately chooses varies widely with Virginia having the fewest and Georgia having the most.

Alabama performs their BMP 'implementation monitoring' inspections from the air. Aerial surveying could fall short of accurately measuring the implementation and effectiveness of BMPs. Often BMPs can only be assessed by taking an up close look, for example, spacing between water bars, suitable stream crossings and stream side management zone widths.

In terms of scoring, the SGSF recommend to report a percentage of applicable practices and record BMPs on a yes/no/not applicable basis. The number of sites to monitor must be enough to "achieve an estimate of implementation that is $\pm$ 5% within the 95% confidence interval" (SGSF 2002). These recommendations, while valuable, do not specify exactly how the monitoring should be performed; aerial survey (Alabama), on the ground (Virginia and North Carolina) or combinations, therefore making comparisons between the states difficult even though the reporting methods are consistent.

All the states are inspect for BMP implementation but North and South Carolina, Florida, Texas and Virginia also monitor for threat to water quality, or BMP effectiveness. The SGSF Framework does recommend that an assessment of significant risk/threat to water quality be documented (SGSF 2002). Inspecting for both BMP compliance and water quality protection produces a more thorough approach because 100% implementation in all situations may still leave room for water quality degradation. Just because BMPs have been installed properly does not necessarily mean that no threat to

water quality exists though BMPs have been proven effective in protecting water quality (Swift 1988).

In spite of the effort to improve BMP monitoring and reporting processes, there is a remaining inability to compare state compliance ratings. If all states followed the SGSF recommended protocol, there would be more consistency among states. As of 2002, four states, of those discussed in this paper, follow the SGSF monitoring framework (Florida, Georgia, North Carolina, Texas) (Prud'homme Greis 2002). Some suggestions include having an explicit protocol that dictates exactly how the survey is to be conducted, how often how to select sites to survey (whether they are proportional to the amount of harvesting jobs or some other stratified manner), standard terminology and a repeatable inspection method that will produce consistent results. Ample allotment of resources and planning would ensure availability of personnel and efficiency to make reporting as easy as possible.

CONCLUSION

To be able to compare BMP programs and to measure progress, there is a need for participation among Southern states to follow the SGSF recommended protocol or some uniform procedure for collecting and reporting on BMPs. Standardizing BMP assessment methodology and terminology and reporting will provide consistency. Currently, there still is an inability to compare monitoring results among states because each state has developed its own methodology. The ability to compare results could provide evidence that technical requirements may need to be adjusted or reveal new innovative methods that are also effective in protecting water quality in a region. Future work should develop a more standardized and utilized BMP monitoring protocol that will be a valuable tool in the future for understanding BMP implementation and effectiveness amongst and between the states.

ACKNOWLEDGEMENTS

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