

Productivity and Cost Analysis of Three Small-Scale Harvest Systems for Fuel Reduction

Within the Wildland Urban Intermix of North Central Idaho

A Thesis

Presented in Partial Fulfillment of the Requirements for the

Degree of Master of Science

With a

Major in Forest Products

In the

College of Graduate Studies

University of Idaho

by

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June 2005

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AUTHORIZATION TO SUBMIT THESIS

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Abstract

This study explored the production capabilities, limitations, and practicalities of using small-scale, low impact machinery to reduce fuels around wildland urban homesites. Three systems that were evaluated include an all-terrain vehicle (ATV) with a log arch, an Iron Horse mini-skidder, and an ASV RC-30 with a radio remote controlled log winch. The study showed that these systems are easily transported, require a low capital investment, are highly maneuverable, and have a high labor component. Labor was found to be the single most influential cost for these systems. For the ATV and Iron Horse machines, which have a capital investment of <\$12,000, the labor component represents between 84 and 81% of the total scheduled hourly machine costs respectively. For the ASV, which has a capital investment of \$36,000, this labor component falls to 57%. Each system tested has an operational niche. The Iron Horse works well on snow or over slash without the need for trails; the ATV works well over longer distances where skidding downhill or over level terrain is an option, and the ASV works well winching logs to roadside locations where self-loading log trucks have access. Using production study estimates, the ATV averaged 190 ft³ of sawlog production per SMH, and had a system cost including felling of \$36/CCF. Treatment costs for the ATV which include pile and burning were \$1125 per acre. The Iron Horse sawlog production averaged 89 ft³ per SMH costing an average of \$50/CCF, and had a treatment cost of \$1350 per acre. The ASV produced 260 ft³ of sawlogs per SMH costing an average of \$35/CCF, and a treatment cost of \$1073 per acre. Though revenue was received from sawlog and firewood sales, the fuels reduction treatments would still cost the landowner \$297 and \$44 per acre for the Iron Horse and ASV treatments respectively after fully treating the area. The ATV treatment site produced enough firewood to provide \$23 per acre in revenue for the homeowner. While sawlog and firewood revenue may not completely pay for fuel reduction treatment costs, they may offset costs sufficiently to persuade homeowners to initiate fuels reduction treatments on their property in the absence of subsidies.

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Introduction

Background

Since the 1930's, fire exclusion and suppression as well as past logging practices have led to unusually dense forest conditions throughout the country. Currently, 190 million acres of federal land in the Continental United States are considered to be at high risk for fire danger (Healthy Forests 2002). Ponderosa pine forests that have historically held between 25-35 trees per acre today may have over 500 trees per acre (Healthy Forests 2002). This increase in density has resulted in fires that are increasingly difficult to control and which burn larger areas of land. During the 2002 fire season, more than 6.9 million acres burned along with 815 homes and structures (NIFC 2002, Healthy Forests 2002). This was twice the 10-year average of acres burned and a record number of homes destroyed (NIFC 2002). A fire ecologist testified before Congress, "...It is one of the great paradoxes of fire suppression that the more effective we are at fire suppression, the more fuels accumulate, and the more intense the next fire will be" (Babbitt and Glickman, 2000).

Forest productivity is in decline throughout several areas of the Interior West. This loss of productivity can be traced to dense overcrowded stands susceptible to insect epidemics, species composition changes, root rot, and water stress (O'Laughlin et al. 1993). Individual trees in these stands compete for light, water, and nutrients. The resulting forest exhibits suppressed growth, small-diameter, and increased mortality (O'Laughlin et al. 1993). Intensive forest management practices such as thinning, prescribed fire, and species composition shifts are required to return these forestlands to a productive state (Graham R.L. et al. 1999).

Fire Suppression Costs

Wildland firefighting costs in the United States are currently at an all time high. During the 2002 fire season, 1.6 billion dollars were spent fighting these fires (NIFC 2003). These high suppression costs are a trend rather than an isolated incident. Figure 1 shows the number of acres burned and federal suppression costs of these fires during the last 10 years (NIFC 2003).

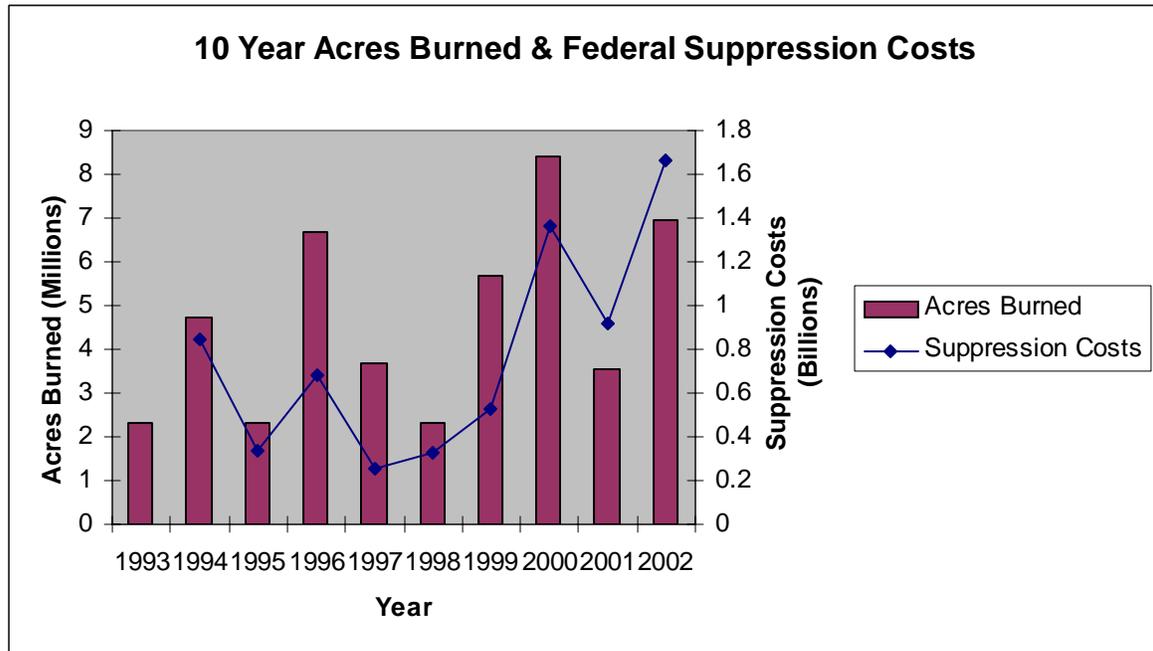


Figure 1. Number of federal acres burned and suppression costs to fight these fires

Concerns over rising suppression costs have initiated many studies exploring the reasons for these increased costs. Factors that have had the largest influence on costs include (NAPA 2002, USDA Forest Service 2000):

- Increased fuel accumulation
- Years of fire suppression
- Changes in species composition
- Several years of drought in the western United States
- Increased human population located adjacent to and within forested areas

While some of these factors cannot be changed, recommendations strongly encourage reducing fuels that surround communities and homes in forested areas.

The Forest Service has simulated fires using the National Fire Management Analysis System which performs a cost-benefit analysis weighing the costs used to prevent fires versus costs due to fires and the natural resources lost in the fire. Using this system, the Forest Service

estimates that for every dollar spent on pre-suppression activities, five to seven dollars are reduced during fire suppression and rehabilitation (USDA Forest Service 2000).

Community Costs of Fire

There are major costs involved with wildland fire that go beyond suppression costs. Costs to the community may include lost business from recreation, resources, decreased property tax, impacts on resident health, and degradation of aesthetics, watersheds, and wildlife habitat just to name a few.

An economic study concluded that the wildfires in Florida during the 1988 wildfires season resulted in the following losses (Butry et al. 2001):

- Pine timber market: \$400 million
- Property loss (340 homes, 33 businesses, several cars and boats): \$10-\$12 million
- Tourism and trade: \$61 million in hotel revenue and \$77.2 million in other non-hotel related tourist expenditures
- Increased health care (asthma and bronchitis): \$325,000 to \$700,000

Idaho experienced severe wildfires during the 2000 fire season. As of September 26 of that season, Idaho had 1,541 fires reported with over 1,235,150 acres burned (FEMA 2000). Over 3 million acres of public land were closed due to fire danger. Encompassed within this acreage were 2000 miles of backcountry trail, 80 miles of river, and almost all public airstrips (FEMA 2000). According to the Idaho Outfitters and Guides association, 150 outfitting businesses, over 400 employees, and 2,150 guided wilderness clients were affected by the 2000 fires. Outfitter losses from this event were reported to exceed \$2.5 million (IOGA 2001).

The 2002 Hayman fire in Colorado greatly affected property values in four counties due to the destruction of homes, property, and resources. In a Forest Service Hayman fire case study report, losses included 132 residences, 1 commercial building, 466 outbuildings, and major utility infrastructures. County assessors calculated a loss of \$3.4 million in private property assessed value, which represented a revenue loss of \$238,000 per year. Insurance payouts for

private property losses and damages totaled \$38.7 million. Suppression costs alone for this fire were estimated to exceed \$39.1 million (Graham, R.T. 2003).

Urban Interface Fuels Reduction

After the 2000 fire season, in which over 8 million acres burned and 861 homes were lost, a greater focus was placed on reducing the fuels that had accumulated on forestlands across the United States (NIFC 2003). As part of the National Fireplan, funding has been established for reducing these fuels adjacent to cities (interface), and rural homesites located within forested areas (intermix). Urban interface/intermix fuels reduction, specifically defensible space, has been recommended to lower suppression costs, save lives, and protect structures. The concept of defensible space is not new. First defined in a 1980 California structure protection field guide, defensible space is a widely used concept to modify fuels around a structure (UCFPL 2001). A highly successful federal program called Firewise is currently being used to educate homeowners, fire departments, and civic leaders on the importance of fuel reduction/defensible space around forested homesites. Defensible space focuses on treating the homesite first with subsequent fuel reduction treatments radiating out from the homesite. The treatment distance varies with each homesite due to slope, aspect, home construction, and various landscaping methods.

Small-Diameter Timber

Funding for fuels reduction projects ranging from landscape level community fuelbreaks to rural homesite defensible space is currently a high priority for forest managers. These projects usually concentrate on removing many of the small understory trees leaving the larger overstory trees to remain. There are several issues associated with the removal of this small-diameter timber.

In order to investigate the issues associated with small-diameter timber (SDT), a discussion must first focus on the definition of SDT. Different regions, organizations, and beliefs have led to a wide variety of small-diameter definitions. Differences between hardwood uses and products compared to uses and products of softwoods are one source of variation. Individual perceptions, however, are a major source of debate when attempting to define small-diameter

timber. Sizes ranging from fifteen inches to less than six inches diameter at breast height (DBH) have been used to describe small diameter timber. (COPWRR 2002, Phillips 1982, Johnson 1982, Hoffman JR. 1982). For this thesis, small-diameter timber is defined as softwoods found in the Interior West having a DBH of less than 10 inches.

SDT is more expensive to harvest compared to larger timber due to size and value of the material. Several stems may need to be cut and accumulated for SDT to equate to one large stem (Keatley 2000). The cost of harvesting and transportation of SDT often exceeds its value for uses such as biomass energy, pulp chips, and small sawlogs (Han et al. 2004, Dooley 2002). Due to increasing fire danger and decreasing forest productivity, SDT stands must be treated; however, economic values are low for SDT, especially when undesirable physical characteristics are present (Spelter et al. 1996). Physical properties such as a high percentage of juvenile wood are characteristics unfavorable to dimensional lumber. While the majority of juvenile wood is found in young trees, at least some juvenile wood is found in all trees. This is crown formed wood where a tree's physiology allocates resources to growth rather than strength. Wide growth rings, spiral grain, and low specific gravity combined with high fibril angles cause longitudinal shrinkage that is 10 times greater than that of mature wood. Twisting frequently occurs with juvenile wood as it dries (Wood Handbook 1999).

Energy biomass is another use for small-diameter material, but lower cost energy sources such as natural gas, coal, and hydroelectric projects make the use of biomass unprofitable. Additionally, the small number of markets currently available combined with a high transportation cost adversely impact the economics associated with the use of biomass from forest residues for energy production (Han et al. 2003). The question arises then on covering the costs associated with fuel reduction projects. Currently, few biomass projects cover the cost to harvest SDT (Graham, R.L. et al. 1999). Intrinsic values from fuel reduction projects may help subsidize the cost of biomass projects in the future (Graham, R.L. et al. 1999).

The inclusion of value added products might increase the profitability of SDT (Dooley 2002). Value added products demand a higher price due to properties such as increased strength,

appearance, or straightness (Levan-Green 2001). An estimated 20-30% of the thinned small-diameter material may have value added potential. This increases the revenue generated thus reducing the gap between profit and loss (Levan-Green 2001).

Specialty markets may be available for:

- Appearance (curved, twisted, “character pieces”)
- Strength (highway guard rail posts, high grade lumber)
- Post and poles (fencing, furniture, log structures)

Small roundwood structural posts made from SDT may be another use for thinned material. Juvenile wood is not as large an issue for poles since there is a larger proportion of tighter growth rings on the exterior of these posts. Spiral grain however can cause problems with connectors as the timber dries (Umeme 2002). Several roundwood structures were constructed as informational kiosks during the 2002 Olympic Games. Continued research is underway for both the connectors for these structures and mobile testing machines to measure the strength of logs prior to leaving the landing (Levan-Green 2001).

Fuels Reduction Equipment

Conventional logging equipment such as cut-to-length systems, feller bunchers, and full sized skidders are often cost effective and efficient on large parcels of forestland; however, as the size of the treatment area gets smaller, the owning, operating, and transportation costs cannot be spread over a large area and the per acre costs increase substantially. As the parcel size becomes less than 10 acres, such as a small forested homesite, this per acre cost usually becomes prohibitive for conventional equipment (Cubbage 1983). Soil displacement and residual stand damage associated with conventional logging equipment may additionally prohibit this equipment operating on these small parcels where aesthetics and disturbance are a concern.

Small-scale logging systems have been used in European countries for several decades. As the benefits are realized, they are slowly being adopted for uses in the United States. These systems include animals (horses, oxen, etc), modified agricultural tractors, and all-terrain

vehicles. There are many benefits to using these small systems. One of the main benefits is that this equipment generally can be moved to new locations behind conventional pick-up trucks or even cars resulting in low transportation costs. Other benefits include low capital investment, low site impacts, and decreased residual stand damage. While there are several advantages, these small systems frequently are characterized by having low horsepower, usually resulting in decreased production capabilities. A high manual labor component is also associated with small-small logging systems, which may result in safety concerns.

Problem Statement

Problem Statement

Past wildfire suppression strategies have dramatically impacted the species composition and increased fuel loads on forestlands throughout the United States. An increase in human population located adjacent to and within these forested areas, forces fire managers to protect structures, lives and property increasing the costs to suppress wildfires. As the number of acres burned each year increases, and large numbers of homes burn every year, greater focus has been placed on reducing fuels and creating defensible space around wildland homes (Healthy Forests 2002, Beebe and Omi 1993).

Cost effective methods to reduce hazardous fuel buildup around small parcel wildland urban homesites need to be explored and evaluated. There is currently a lack of local knowledge regarding small-scale logging technology in relation to fuel reduction possibilities. Contractors are reluctant to invest in unproven technologies without assurances of production possibilities and cost estimates. Additionally, many homeowners do not have a vision of what a “Firewise” landscape looks like.

Various demonstration areas across the country are needed to address the aesthetic and financial concerns of homeowners who ultimately control the decisions to reduce hazardous fuel accumulations on private property. Demonstration areas allow contractors the ability to evaluate the financial and operational limitations of using small-scale equipment for fuel reduction around wildland homes.

Objectives

Objectives

A demonstration study area locally known as the “Dawes Project” near Viola, Idaho was developed and designed to showcase several small-scale fuels reduction and stand improvement treatments within the wildland urban intermix.

While providing the public an opportunity to view these treatments, this study specifically addressed three different small-scale logging systems used on the Dawes Project.

Objectives for this study included:

- Identify factors that effect productivity for each of the three small-scale systems
- Determine treatment costs (\$/acre, \$/CCF) for each system
- Evaluate operational limitations for each system

Site Description

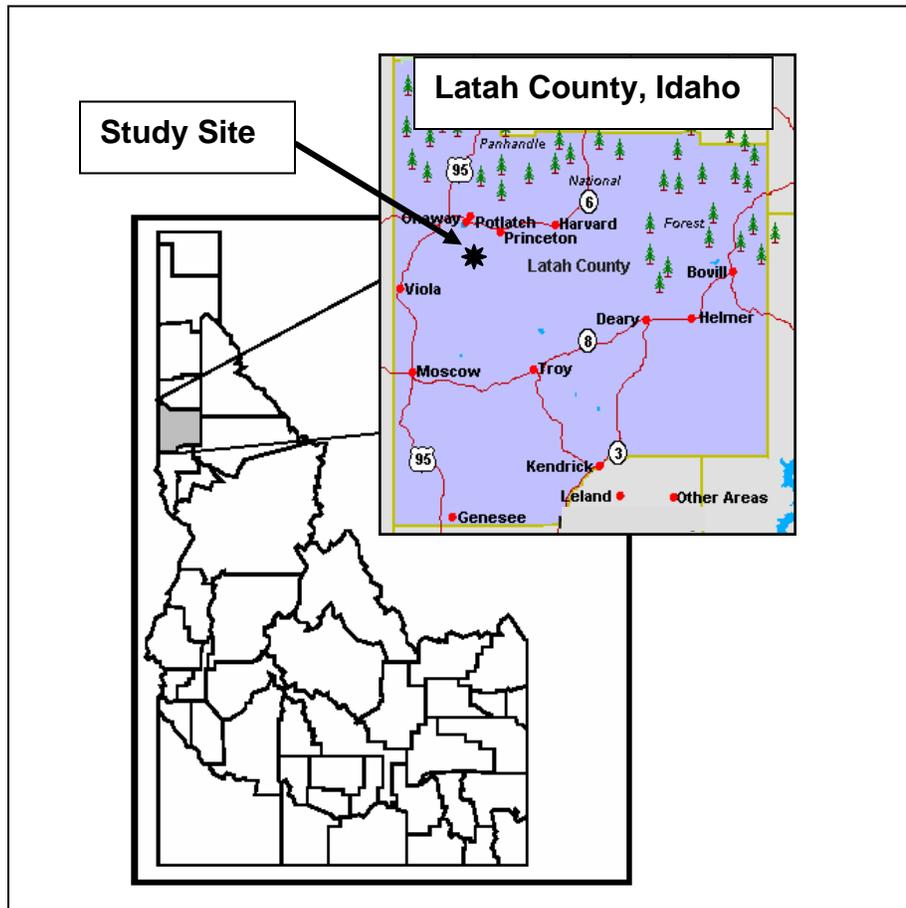


Figure 2. Dawes Project location map

The study site (Figure 2) was located approximately 15 miles northeast of Viola, Idaho. The 28 acre site was privately owned by Dana and Kathy Dawes. This study site has experienced a variety of disturbances over the last 25 years including grazing by horses, the creation of several spur roads, an above ground cleared powerline right of way, and an existing rental homesite was present. The landscaping around the homesite was natural with no wildfire defensible space present. Slopes across the property range from 10 percent to 38 percent with a mostly southwest aspect. Soils on the site are predominantly classed as Taney silt loam (soil

type 51) on slopes up to 25%, and Uvi/Spokane associations (soil type 60) on steeper more south facing slopes (Barker 1981). Harvest precautions on these soils include water erosion, soil wetness, and the hazards of plant competition on new seedling growth (Barker 1981).

Tree species on the site consisted of Douglas-fir (*Pseudotsuga menziesii*), ponderosa pine (*Pinus ponderosa*), Western larch (*Larix occidentalis*), lodgepole pine (*Pinus contorta*), and grand fir (*Abies grandis*). The shrub component included ocean spray (*Holodiscus discolor*), ninebark (*Physocarpus malvaceus*), snowberry (*Symphoricarpos albus*), and Scouler willow (*Salix scouleriana*). A well established grass layer included Pine grass (*Calamagrostis rubescens*), Idaho fescue (*Festuca idahoensis*), and non-native pasture grasses.

Stand Measurements

The study site was divided into several treatment areas. Three study units were selected for this study. For two treatment areas (ATV and Iron Horse), measurements were conducted to determine pre-treatment conditions.

- Average slope (%)
- Trees per acre
- Basal area (ft³/acre)
- Fuel load (tons/acre)

The third treatment (ASV with radio remote control winch) was experimental. No pre-treatment stand conditions were measured for this system. A summary of the stand characteristics follow in Tables 1 and 2. Figures 3 and 4 show the diameter class distribution for these stands.

Table 1. Summary of stand characteristics for ATV study site

Size (ac)	Average slope (%)	Quadratic Mean diameter (in)	Trees/Acre DF/PP (TPA)	Total TPA (TPA)	Basal Area DF/PP (ft ³)	Total BA (ft ³)	Fuel Load tons/ac
2.2	10%	15.4	73/277	350	50/72	122	5.18

Note: Trees per acre summary statistics utilized plot measurements taken by a 20 BAF prism. Small trees (2-3 inch class) included in these measurements greatly increased the TPA count. (Abbreviations: DF=Douglas-fir, PP=ponderosa pine, TPA=trees per acre, BA=basal area)

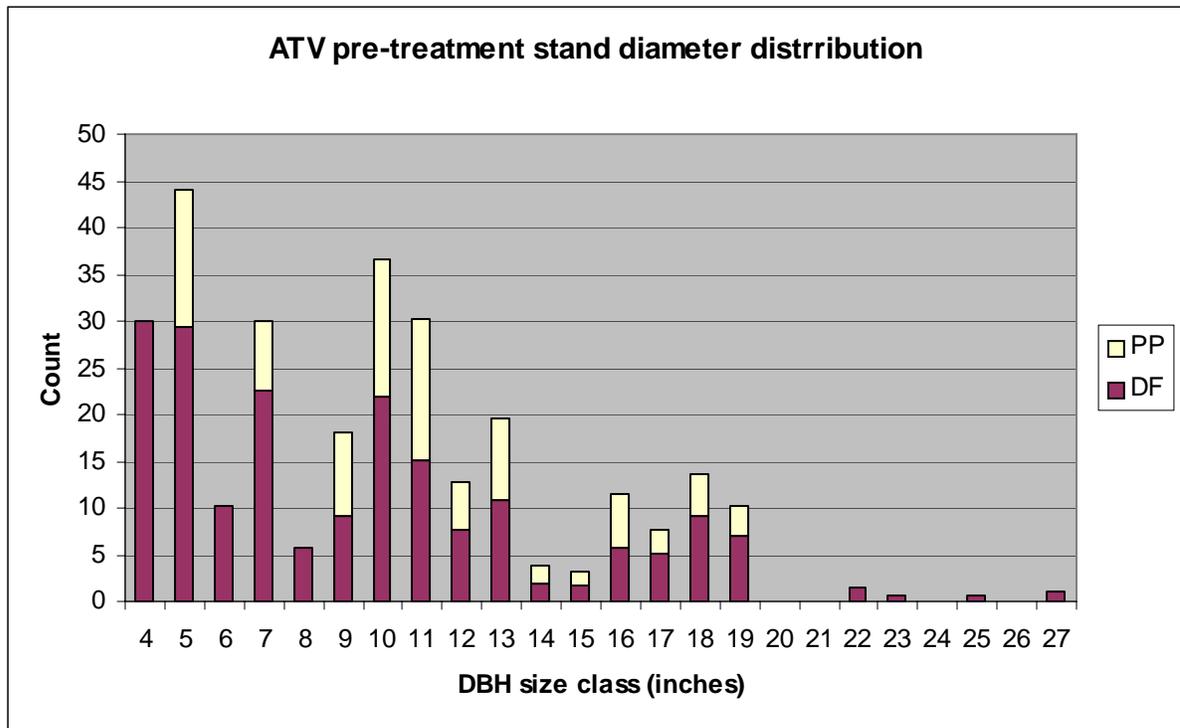


Figure 3. Chart of pre-treatment tree diameter distribution for the ATV study site.

Table 2. Summary of stand characteristics for the Iron Horse study site.

Size	Average slope	Quadratic Mean diameter	Trees/Acre DF/PP/LPP	Total TPA	Basal Area DF/PP/LPP	Total BA	Fuel Load
(ac)	(%)	(in)	(TPA)	(TPA)	(ft ³)	(ft ³)	tons/ac
1.0	11%	14.92	187/25/35	248	45/55/8	108	5.04

Note: Trees per acre summary statistics utilized plot measurements taken by a 20 BAF prism. Small trees (2-3 inch class) included in these measurements greatly increased the TPA count. (Abbreviations: DF=Douglas-fir, PP=ponderosa pine, LPP=lodgepole pine, TPA=trees per acre, BA=basal area)

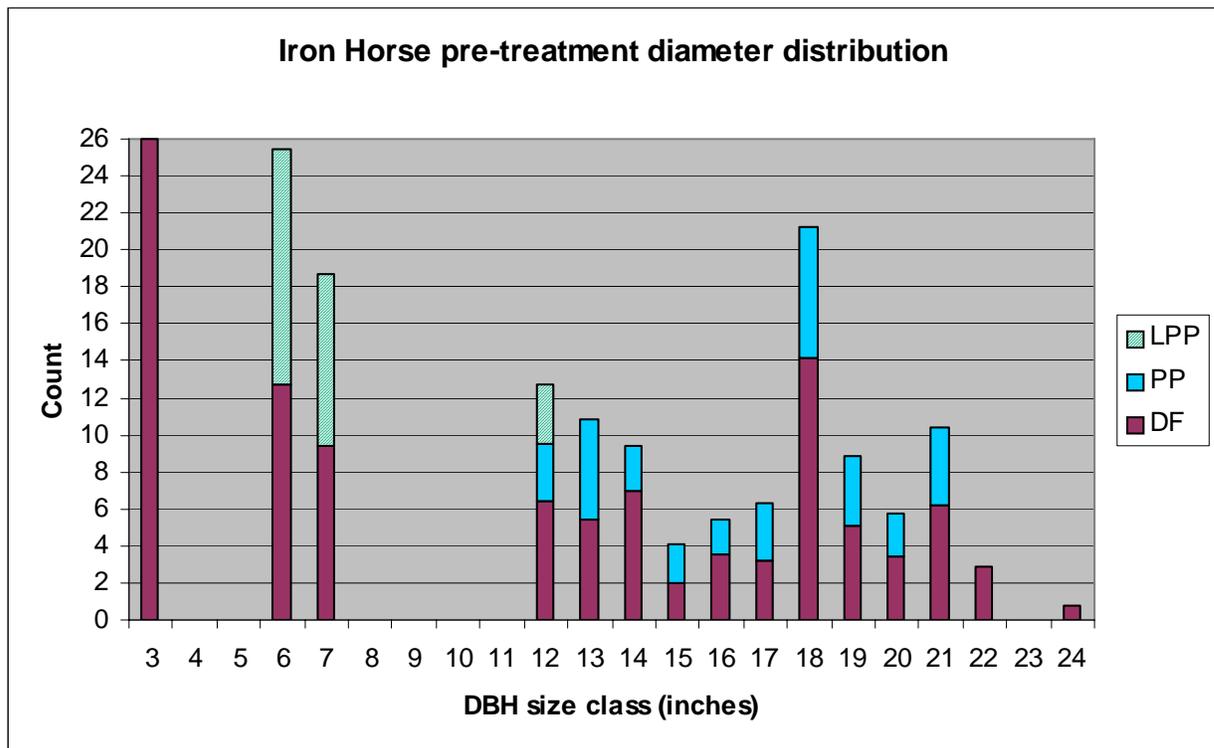


Figure 4. Chart of pre-treatment tree diameter distribution for the Iron Horse study site.

Pre-treatment Measurements

Transect lines were established to quantify pre and post treatment stand conditions. Utilizing an initial point defined by a north/south and east/west fenceline on the northeast corner of the property. Transect lines running north and south were spaced 60-ft apart along the east/west fenceline. To alleviate an edge effect, the first transect line was started 70-ft east of the initial point. Plot centers were established along the transect lines at 60-ft intervals.

At each plot center, a 50-ft fuel transect was measured utilizing protocols from the Handbook for Inventorying Downed Woody Debris (Brown 1974). The slope along the fuel transect was measured using a clinometer. Each plot center was then permanently marked with an iron spike driven flush with the ground with orange ribbon tied to it. Orange marking paint was then sprayed on the ground making an “X” approximately 2-ft wide over the plot center.

Variable plot measurement procedures using a 20 basal area factor prism occurred at each plot center to determine which trees would be selected for measurement. A diameter tape was used to measure the diameter of each tree selected. The heights of each tree, as well as dead and live branch heights were measured using a clinometer.

Treatment Prescription

The treatment prescription for this study was similar for all three units. The overall objective of the treatment was to increase the fire resistance by modifying stand density, stand structure, and stand composition. There is not a “set” treatment prescription for fire resistance. Fire resistance is mainly a compilation of species, diameter and height of tree, crown closure, height to lower branches, fuel loading, and slope. The guidelines used for marking addressed these resistance factors for all trees marked for removal across each treatment study area.

Residual trees were marked with ribbon rather than marking paint for a more natural appearance after treatment. Fire resistant ponderosa pine and western larch were favored over Douglas-fir and lodgepole pine. Larger trees were favored as leave trees over smaller trees; however, several smaller recruitment trees were left for future replacement trees. Ladder fuels

were targeted for removal, the average dead branch height on residual trees was heightened by pruning, and residual canopies were separated.

For this study, logs were decked near their respective treatment sites where they were loaded and hauled using a self loading log truck. The preferred log length was 16'6" including trim. The minimum top diameter sent to the log deck differed with each treatment; however the merchantable small end diameter was 5.6 inches. Non-merchantable logs brought to the deck were sold as firewood to pay as cut woodcutters working the roadside decks.

Post-treatment measurements were conducted after each of the three treatments. These measurements included:

- Trees per acre
- Basal area (ft³/acre)
- Fuel load (tons/acre)
- Residual stand damage evaluations
- Soil disturbance observations

System Descriptions and Study Methods

All-Terrain Vehicle with Skidding Arch

The skidding arch concept has been effectively used to remove logs from forests for centuries. Oxen and horses have historically been used to pull the arch. Today, tractor power has largely replaced animal power for this task. All-terrain vehicles (ATV) with arches (Figure 5) have been used by arborists and fire departments to remove logs from urban homesites. The arch allows one end of the log to be suspended above the ground thus reducing soil disturbance and providing reduced skidding resistance.



Figure 5. Positioning the ATV arch over log

Safety is a concern when logging with an ATV. Dragging a log behind the ATV without an arch for suspension has been attempted. This generally works, however the load may snag suddenly, and the operator may be thrown from the vehicle due to the sudden stop.

Suspending one end of the log with an arch reduces this problem, but introduces another problem. With one end suspended, stopping may be a problem when traveling downhill. The

lack of an Operator Protective Structure (OPS) and Falling Object Protective Structure (FOPS) may preclude this equipment from being operated by employees due to Occupational Safety and Health Administration rules.

Mark Havel, designer of the Future Forestry Products ATV Forwarding Arch (Table 4), operated an ATV (Table 3) for this study. Mr. Havel has demonstrated this equipment at several fuels reduction demonstration sites across the country. For this study, Mr. Havel fell, bucked, bunched, and skidded all trees in the ATV study area.

Table 3. All-terrain vehicle (ATV) specifications

1998 Honda Foreman All-Terrain Vehicle	
Model:	TRX300FW
Year:	1998
Engine type:	Single cylinder 4 stroke
Displacement:	282 cc
Cooling:	Air cooled
Transmission:	5 speed manual
Fuel capacity:	3.3 gallons
Wheel base:	48.6 inches
Ground clearance:	6.8 inches
Weight:	487 lbs

Table 4. ATV arch specifications

<p style="text-align: center;">Future Forestry Products ATV Forwarding Arch</p> <ul style="list-style-type: none"> • 219 lbs • 58 inches wide • 109 inches long • 24 inch diameter log capacity • 2000 lb load capacity (with high load tires) <p style="text-align: center;">Future Forestry Products Jr. Arch (for bunching logs)</p> <ul style="list-style-type: none"> • 57 lbs • Used to bunch 4-12 inch logs

A looped trail was cleared of shrubs and downed timber for this system. The loop trail ran from the landing to the study unit and from the unit back to the roadside landing. Once inside the study unit, the ATV could travel anywhere without a trail. The ATV system log deck was located on the downhill side of the study unit.

During this study, two to three trees were directionally felled, limbed and bucked prior to forwarding. The butt log of a large tree (>11 inches) generally made a single load. The other logs from a tree were usually hand bunched with a small “Jr. Arch” to create a three-log load on the average. Once several loads were pre-bunched, the ATV and arch was used to forward logs to the landing. Since the ATV did not have the ability to mechanically deck logs, deck maintenance was an important phase of the operation. Extra care was therefore taken to roll logs onto the deck to allow for future decking space. After all the pre-bunched logs were brought down to the landing, the felling operation would be repeated. With a single operator working this system, the work technique dictated that the ATV arch sat idle while felling, limbing, and bucking activities occurred.

Time and Production Data

Detailed time and production data were recorded for each element of the ATV study.

Elemental times were recorded using a stopwatch to the nearest hundredth of a second. The ATV study was divided into two phases. The first phase was the felling, limbing, bucking and pre-bunching of the logs. The second phase involved the forwarding of the logs by the ATV and arch. For this system, the following elements typically were recorded:

Phase 1 (Felling, limbing, bucking, pre-bunching)

- *Felling*: Begins as the sawyer travels to a tree, and includes starting the saw. Felling ends when the sawyer begins to cut the stump shot off the butt log.
- *Limbing & Bucking*: Begins as the stump shot is cut, continues as the tree is limbed and bucked, ending when the saw is placed on the ground or the sawyer begins to travel towards another tree to fell.
- *Pre-bunching*: Begins when either the worker picks up the Jr. Arch or takes out hand tongs to move logs. This process ends when the worker lets go of the arch and moves away from it.
- *Cutting Brush/Slash*: Time spent cutting non-merchantable material
- *Chain Saw Related Delays*: Fueling and oiling saw, tightening chain, replacing chain
- *Personal Delays*: Breaks or other delays directly associated with the operator
- *Mechanical Delays*: Breakdowns or delays due to machinery
- *Clearing Trail*: Time spent moving brush and slash out of the way of the operator

Independent Variables Measured: Butt diameter
Number of logs bucked or bunched
Species

Phase 2 (Forwarding with the ATV)

- *Unloaded Travel:* Starts when the operator boards the ATV at the landing and ends when forward motion stops near the log to be forwarded.
- *Positioning ATV:* Starts when the ATV begins to move again, or the operator exits the ATV to position the arch. This process ends when the operator releases the winch cable.
- *Hooking:* Begins as the operator pulls the choker cable out to hook onto log(s), and ends when the operator grabs the winch handle.
- *Winching:* Starts as the operator turns the winch handle and ends when the operator boards the ATV.
- *Rehooking:* Begins when the choker cable is released and ends when the operator is finished with the winching process.
- *Re-positioning ATV:* Any time the ATV is moved between the initial positioning of the machine until the ATV leaves for the landing.
- *Loaded Travel:* Begins when the operator starts the ATV and ends when the ATV arrives at the landing and the operator leaves the machine.
- *Unloading:* Time spent releasing the choker cable, and moving the arch away from the logs.

Iron Horse Pro Mini-Skidder

Mini-skidders like the Iron Horse have been used for many years in Scandinavian countries. While these skidders have a high labor component, they are simple to operate, easily transportable, and require a low capital investment. Mini-skidders can be wheeled or track driven.



Figure 6. Typical Iron Horse log load

The Iron Horse system used during this study (Table 5) was operated by Harold Osborne. Mr. Osborne has operated this machine at several demonstrations across the western United States prior to this study including the mechanical fuels treatment trials in John Day Oregon, and a snow season operability study during winter of 2001.

Table 5. Jonsered Iron Horse Pro mini-skidder specifications

Johnsered Iron Horse Pro mini-skidder	
Engine:	Honda 9 horsepower
Weight:	926 lbs
Width:	42.5 inches
Length:	110.25 inches
Ground pressure:	2.56 lbs/in ² (With 1102 lb load)
Winch:	50 feet of line (2500 lbs capacity)
Traction:	Differential lock
Track width:	15 inches

The work technique for this system involved felling, limbing, and bucking several trees. The operator then walked in front of the mini-skidder controlling the speed and direction with the mini-skidder's control arm. Since the Iron Horse is a tracked skidder, it was able to negotiate over a variety of terrain including slash. This allowed the machine to operate without a trail system. When the operator reached the logs to be removed, cable was pulled from the onboard belt driven winch and connected to the log. The operator then returned to the skidder to winch the log onto a set of bunks attached to the skidder. A turn ranging from one large log to several smaller logs was built during this process. A ratchet strap held the logs in place as the operator walked the machine to the log deck. Once at the landing, the strap was removed and a lever released the bunks. The operator then walked the skidder out from beneath the logs. Logs were hand decked.

Time and Production Data

Detailed time and production data were recorded for each element of the Iron Horse study. Elemental times were recorded using a stopwatch to the nearest hundredth of a second. Similar to the ATV study, the Iron Horse study was divided into two phases. The first phase was to

fell, limb, and buck trees into logs. The second phase involved the loading and forwarding of the logs with the Iron Horse. For this system, the following elements typically were recorded:

Phase 1 (Felling, limbing, bucking)

- *Felling*: Begins as the sawyer travels to a tree, and includes starting the saw. Felling ends when the sawyer begins to cut the stump shot off the butt log.
- *Limbing & Bucking*: Begins as the stump shot is cut, continues as the tree is limbed and bucked, ending when the saw is placed on the ground or the sawyer begins to travel towards another tree to fell.
- *Cutting Brush/Slash*: Time spent cutting non-merchantable material
- *Chain Saw Related Delays*: Fueling and oiling saw, tightening chain, replacing chain
- *Personal Delays*: Breaks or other delays directly associated with the operator
- *Mechanical Delays*: Breakdowns or delays due to machinery
- *Clearing Trail*: Time spent moving brush and slash out of the way of the operator

Independent Variables Measured: Butt diameter
 Number of logs bucked
 Species

Phase 2 (Forwarding with the Iron Horse)

- *Unloaded Travel:* Begins when the operator touches the Iron Horse at the landing and ends when forward motion slows or stops near the log to be forwarded.
- *Positioning:* Manuvering the Iron Horse prior to pulling cable
- *Cable Out:* Begins as the operator pulls the winch cable out to a log and ends when operator touches the log.
- *Hooking:* Operator begins to hook log and ends when cable is hooked.
- *Walk Back To Machine:* Time taken to walk back to Iron Horse
- *Winching:* Begins when operator engages winch and ends when cable tension is released.
- *Rehooking/Winching:* Time spent releasing cable, rehooking cable to previously winched log, and rewinching log. Ends when cable tension is released.
- *Unhooking:* Time spent unhooking cable from logs, including time spent securing cable for transport. Ends when operator releases cable or starts pulling cable out.
- *Re-positioning:* Any time the Iron Horse is moved between the initial positioning of the machine until the Iron Horse leaves for the landing.
- *Securing the load:* Time spent securing logs to the Iron Horse with ratchet strap for transport to landing.

All Season Vehicle (ASV) with Radio Remote Control Winch

An All Season Vehicle (ASV) RC 30 was evaluated and tested on unit #3 (Table 6). This machine had been modified and machine protection installed by the Department of Forest Products and the Microelectronic Research and Communications Institute at the University of Idaho. Funding for the modifications and testing was provided by the National Research Initiative Competitive Grants Program and from the United States Forest Service Southern Research Station. The ASV RC 30 is the smallest, tracked skid steer model produced by the ASV Company. This machine is designed primarily for landscaping and construction applications.



Figure 7. ASV RC30 with radio remote control log winch

Table 6. ASV RC-30 specifications

ASV RC-30	
Engine:	1.5 liter 3-cylinder diesel (Caterpillar 3013)
Horsepower:	31.5 hp (@ 2800 rpm)
Auxiliary hydraulics	10 gpm @ 3200 psi
Weight:	3235 lbs
Advertised ground pressure:	2.5 psi (pre-modification)
Height to top of ROPS/FOPS:	71 inches
Ground clearance:	10 inches
Machine length with bucket:	112 inches
Machine width:	46.5 inches
Track width:	10.75 inches

Because the modified ASV operates in a forested environment, improvements had to be made for operator protection and protection for machine. The modifications for operator safety consisted of adding front and rear doors manufactured out of 5/16-inch metal crusher screen with a one-inch box tubing framework. The added protection for the machine included the replacement of the fiberglass engine cover and the addition of a skidpan. These modifications increased the operating weight of the machine by approximately 300 pounds. A spark arrestor device was added to the machine to comply with state and federal fire regulations.

A PTO powered tractor winch (Table 7) was modified and mounted onto the ASV utilizing the quick disconnect system inherent to skid steer loaders. The winch was modified to be powered by the ASV's auxiliary hydraulic system. The winch was originally operated via a rope activated clutch mechanism. Safety concerns, residual damage, and a loss of productivity prompted the design of a radio remote control to replace the rope activation. A "deadman" switch was installed for safety. If the operator released the remote control button, the winch would stop. Once the remote control was installed, the operator no longer had to walk back to

the machine to power the winch. The operator could now observe the load as it was winched, stopping the load before it became stuck against stumps or damaged residual tree boles.

Table 7. Modified tractor winch specifications

Star Winch	
Manufacturer:	Sonnys Maskiner Ab
Model:	Starkranen Typ 45
Pulling Capacity:	4400 lbs
Line Capacity:	130 feet (3/8 in line)
Remote Control:	University of Idaho/Tele Radio

Jeff Halbrook, a research assistant from the Department of Forest Products, operated the ASV and has experience using various tractor mounted winch systems. Halbrook was involved with the ASV’s modifications, and operated the ASV during a winter production study, as well as several demonstrations across the western United States. Prior to this study, the ASV had undergone extensive hydraulic modifications. Study unit #3 was used to test these new hydraulic modifications; no pre-treatment measurements were conducted on this site. Trees were directionally felled, limbed, and bucked by 2 fallers contracted from C&M Logging, Inc.

The work technique for this system involved the downhill winching of logs to several log deck locations at the roadside. No forwarding was necessary since a self loading log truck could reach all log decks for this unit. The ASV was parked on the road surface and faced the unit. Winch cable was pulled uphill and attached to individual logs. The log was pulled to the roadside using the remote control winch. When a log deck became full or when all logs were winched from the area, the ASV was moved down the road to the next area to be winched. This process repeated until the unit was completed.

Time and Production Data

Detailed time and production data were recorded for each element of the winching processes involved in the ASV study. Elemental times were recorded using a stopwatch to the nearest tenth of a minute. Unlike the previous data collection procedures in this study, no data were collected during the felling, limbing, or bucking of this unit. This was only an analysis of the winching productivity of the modified ASV. For this system, the following elements typically were recorded:

(ASV Winching Elements)

- *Cable Out:* Begins as the operator pulls the winch cable out to a log and ends when operator touches the log.
- *Hooking:* Operator begins to hook log and ends when chain is hooked.
- *Winching:* Time spent between the hooking element and when the operator touches the choker chain at the log deck after winching the log.
- *Unhooking:* Time spent releasing the choker chain. Ends when the cable begins to pull out for next turn, or when cable is secured to ASV.
- *Operational Delays:* Delays caused while contributing to the productivity of the system (limbing, clearing slash, positioning ASV, deck management, hang-ups).
- *Personal Delays:* Breaks or other delays directly associated with the operator.
- *Mechanical Delays:* Breakdowns or delays due to machinery.

Independent Variables Measured: Winching distance
Species
Volume of the turn

Results

Production, cost results, and statistical analysis from this study are presented for each of the three small-scale systems. Detailed information about each of the systems is included in the Appendix. This study did not involve replications, and involved only short study periods for each system; therefore, it is important to keep in mind that comparisons between systems can not be made. The short study periods may not sufficiently incorporate all the variables inherent to working with small-scale systems. The operator may increase or decrease production over time due to different circumstances.

All-Terrain Vehicle with Skidding Arch

The ATV system was divided into two phases, a felling/limbing/bucking/bunching phase, and a skidding phase. During this study 96 skidding turns were recorded, totaling 223 logs with a total volume of 1592 cubic feet.

Phase 1 (Felling/Limbing/Bunching)

During phase 1, the mean total cycle time (including delays) was 11.02 minutes (Table 8).

On average, 2.40 logs (16'6" in length) were produced and bunched per cycle.

The average log contained 7.15 cubic feet with an average large end diameter of 9.87 inches.

Douglas-fir trees took 1.6 minutes longer on average to process than ponderosa pine species.

This is due to the numerous limbs encountered on Douglas-fir, which resulted in increased processing time.

Delays accounted for 25.1% of the total cycle time (Figure8). Of these delays, 25% were mechanical, 68% operational, and 7% personal. Clearing trails, slashing brush, and cutting small (< 2 inch) trees accounted for 80% of all operational delays.

Table 8. ATV Phase 1 production statistics

Felling/Limbing/Bucking/Bunching Statistics					
Element	Average	95% CI	Std Dev	Minimum	Maximum
Total cycle time (min)	11.02	+/- 1.33	6.42	1.00	31.62
# Logs/cycle	2.4	+/- 0.304	1.06	1	5
Volume/log (ft ³)	7.15	+/- 0.77	5.93	1.09	38.01

Detail of Phase 1 ATV System Delays By Type

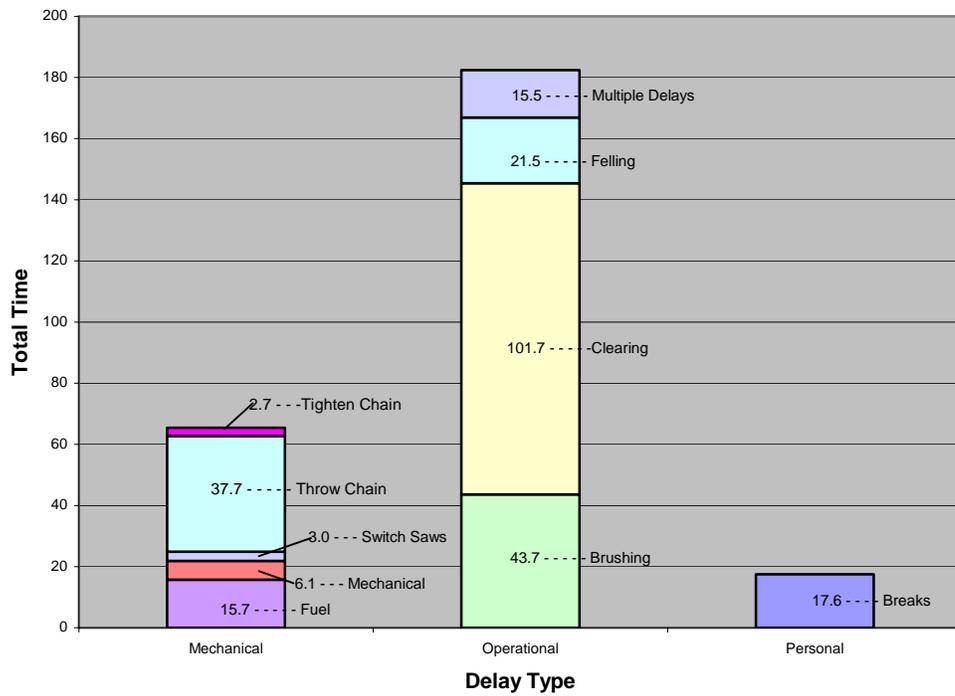


Figure 8. Graph of delays by type for ATV phase 1

Utilizing the data observed during the ATV operation, SPSS statistical software was used to develop regression models predicting the delay free felling/bucking and bunching cycle times

(in minutes) for the system. Stepwise regression was used to determine significant predictive variables at the 95% confidence level. The results are illustrated in Table 9.

Table 9. Descriptive regression statistics for ATV phase 1

Felling/Limbing/Bucking Regression Descriptive Statistics			
Independent Variable	Coefficient	Std. Error	P-value
Constant	-2.909	0.607	<.0001
Butt diameter	0.933	0.045	<.0001
Species	-1.554	0.422	<.0001
Excluded Variables			P-value
# Logs per tree			0.089

Bunching Regression Statistics			
Independent Variable	Coefficient	Std. Error	P-value
Constant	0.706	0.34	0.041
Number of logs	0.632	0.131	<.0001

The predictive regression equations are expressed as:

$$\text{Fell/limb/buck (min)} = -2.909 + .903 (\text{butt diameter}) - 1.554 (\text{species}^{**})$$

**Species = (0) for Douglas-fir & (1) for ponderosa pine

$$\text{Adjusted } R^2 = 0.839$$

$$\text{Standard error} = 1.98$$

$$\text{Sample size} = 88$$

$$\text{Bunch (min)} = 0.706 + 0.632 (\# \text{ of logs bunched})$$

$$\text{Adjusted } R^2 = 0.195$$

$$\text{Standard error} = 1.33$$

$$\text{Sample size} = 92 \text{ cycles}$$

The predictive variables for felling, limbing and bucking appear to explain about 84% of the model. Larger trees took more time to fell and limb than smaller trees. Additionally, species was found to be significant. Douglas-fir did indeed take longer to process compared to ponderosa pine. The number of logs bucked per tree however was not found to be significant at the 95% confidence level. The bunching predictive regression model has an adjusted R^2 of 0.195. This is rather low, and suggests that other important variables are not included in the model. Indeed, the distance that each log traveled during the bunching cycle was not recorded. The model does not differentiate a log that was moved 10 feet from one that was moved 40 feet. This regression model would be expected to improve with the addition of distance information.

Phase 2 (ATV Skidding)

Phase two of the ATV study involved the skidding of logs to a landing. During this phase, the mean total cycle time (including delays) was 5.23 minutes (Table 10). On average, 2.32 logs (16'6" in length) were skidded per cycle. The average load volume was 16.59 cubic feet.

Table 10. ATV phase 2 production statistics

ATV Skidding Statistics					
Element	Average	95% CI	Std Dev	Minimum	Maximum
Total cycle time (min)	5.23	+/- 0.37	1.83	2.46	12.47
Travel distance (ft) (empty)	312	+/- 13.52	67.58	150	480
Travel distance (ft) (loaded)	406	+/- 20.53	102.62	150	600
# Logs/load	2.32	+/- 0.24	1.19	1	5
Load volume (ft ³)	16.59	+/- 1.24	6.22	2.07	38.01

Travel empty distance (from landing to woods) averaged 312 feet while loaded travel distance (from woods to landing area) averaged 406 feet. There are two plausible explanations for the difference between these distances. The main reason is because the travel path was a looped trail. There were more loads prior to the halfway mark that resulted in a skewed shorter travel

unloaded distance and a longer loaded travel distance. Another reason for the difference in travel distances is due to in the woods positioning. Occasionally there was a substantial positioning distance associated with a load. This additional positioning distance affected the subsequent travel loaded distance.

SPSS Statistical software was again used to develop a regression model predicting the delay free skidding cycle time (in minutes) for the ATV System. Stepwise regression was used to determine significant predictive variables at the 95% confidence level. The regression descriptive statistics are shown in Table 11.

Table 11. Descriptive regression statistics for ATV phase 2

ATV Skidding Regression Statistics			
Independent Variable	Coefficient	Std. Error	P-value
Constant	1.681	0.437	<.0001
Load volume	0.0454	0.013	<.0001
Unloaded travel	0.0039	0.001	0.001
Excluded Variables			P-value
Loaded travel			0.290
# Logs per load			0.614

The predictive regression equation is expressed as:

$$\text{Skidding (min)} = 1.6814 + 0.0454(\text{load volume}) + 0.0039(\text{unloaded travel dist.})$$

$$\text{Adjusted } R^2 = 0.179$$

$$\text{Standard error} = 0.757$$

$$\text{Sample size} = 96$$

The skidding predictive regression equation for this system has an R^2 of 0.179 suggesting additional variables may need to be considered. One variable not recorded during this study was in the woods positioning distance. A longer positioning distance expended more time than

shorter distances, which was not included in the model. Another variable difficult to record was the operator’s future load planning time. This occurred during unloaded travel from the landing to the intended load. The operator planned one or more loads in advance. This variable is difficult to measure, but may be visible in the regression equation’s use of unloaded travel rather than loaded travel as a predictive variable. In addition to loaded travel, the model excluded the number of logs per load from the equation. Looking at the system, load volume does have more significance than does the number of logs per load. With the addition of positioning distance to the model, there should be an increase in the R² value.

Delays, which included deck management, attributed 30% to the total cycle time (Figure 9). Delays included mechanical (5%), operational (83%), and personal (12%). Deck management was attributed to 80% of the operational delays and was essential to continued use of the landing area.

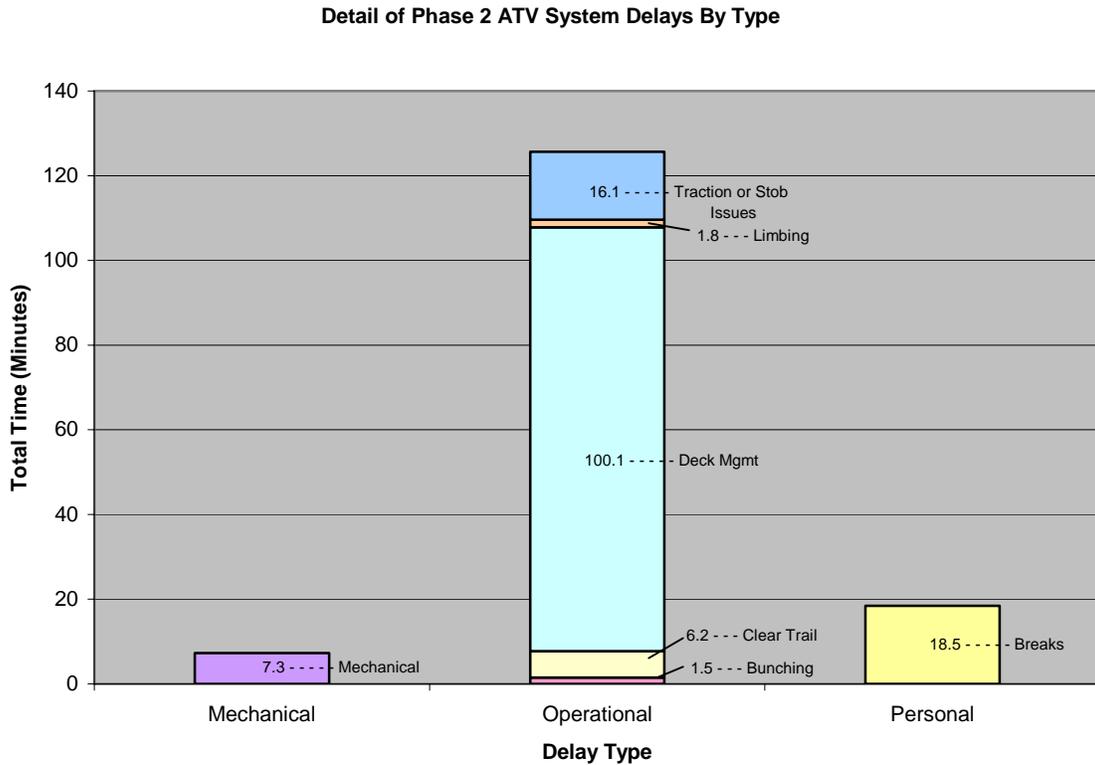


Figure 9. Graph of delays by type for ATV phase 2

During this study, phase 1 (felling/limbing/bucking/bunching) production averaged 13 logs (+/- 1.8 logs) per hour with a total cubic foot volume of 93 ft³/hr (+/- 12.8 ft³) (Table 12). Phase 2 (skidding) production averaged 26.6 logs/hr (+/- 2 logs/hr) with a total cubic foot volume of 190 ft³/hr (+/- 14.5 ft³). Fixed, operating, and labor costs were calculated for the ATV system on a per scheduled machine hour (SMH) basis (Miyata 1980). The hourly operating costs for the ATV were calculated at \$25/SMH. Included in the operating cost was a labor component of \$21/SMH (\$15/hr + 40% benefits) that comprised 84% of the overall operating cost. Utilizing the average total cycle times (including delays) for the felling and skidding phases, and their associated 95% confidence intervals, the costs per CCF ranged from \$35 to \$45 with an average of \$39/CCF. Though a single operator worked both phases of the ATV system, the production rates suggest that two phase 1 workers could fell, limb, buck, and bunch enough material to keep one ATV operator busy skidding. Detailed production, cost estimates, and assumptions for the ATV system are further detailed in Appendix 1.

Table 12. ATV system production statistics

	Avg cycle Time	95% CI	Std Dev	# Logs/Cycle	Cycles/hr	Logs/hr
Fell/limb/bunch	11.02 min	1.33	6.42	2.40	5.44	13.07
ATV	5.23 min	0.37	1.83	2.32	11.47	26.62

Treatment cost estimates (Table 13) were determined using calculated machine rates, log mill receipts, trucking costs, and contractor estimates for piling and burning slash (Corrao 2005, Davis 2005). Unmerchantable logs brought to the landing were later sold to firewood cutters, which added an additional \$105 in revenue. When firewood sales were included, the overall treatment provided a net income of \$23 per acre to the homeowner.

Table 13. ATV treatment cost estimates

Sawlog	Firewood		Pile				Net		
revenue	Sales	Trucking	Felling	Skidding	slash	Burning	revenue	Acres	\$/acre
\$1,351.00	\$105.00	(\$193.00)	(\$369.00)	(\$374.00)	(\$220.00)	(\$275.00)	\$25.00	1.1	\$23.00

Observations

Throughout the ATV study, observations were noted on the abilities and limitations of the system. The operator preferred operating smaller ATV's (300cc range) as compared to larger machines, which have up to 700cc engines because the smaller machines are easier to maneuver through tight forest conditions.

Directional felling was used to facilitate skidding by orienting the butt end of logs toward the direction of the skid. Placing a small roundwood stick cut from unmerchantable top material or small diameter tree under the logs to be skidded provided a choker hole allowing easier hooking later in the skidding cycle. The ATV system requires careful limbing of the logs prior to skidding. Branches or limbs not cut flush with the log act as anchors, which significantly increase the skidding resistance. It was observed that skidding with the large ends of the logs suspended rather than the small ends reduced the skidding resistance as well. Uphill skidding often resulted in a loss of traction during the initial breakout period. Uphill skidding should be avoided in favor of downhill or level skidding.

Deck management is also an important factor for the ATV system requiring additional time at the landing. The system observed did not have a way to mechanically move logs at the deck. Smaller logs were hand rolled over the top of larger logs in the log deck to allow room for additional skids.

Iron Horse Pro Mini-Skidder

The Iron Horse system study design, similar to the ATV study design, is divided into two segments, a felling/limbing/bucking phase, and a skidding phase. During this study 45 skidding turns were recorded, totaling 130 logs with a total volume of 956 cubic feet.

During the felling/limbing/bucking phase, the mean total cycle time (including delays) was 8.99 minutes (Table 14). On average, 3.31 logs were produced ranging from 9 feet to 25 feet in length with an average of 15 feet 6 inches. The average log contained 7.35 cubic feet with a large end diameter of 9.95 inches.

Table 14. Iron Horse phase 1 production statistics

Felling/Limbing Statistics					
Element	Average	95% CI	Std Dev	Minimum	Maximum
Total cycle time (min)	8.99	+/- 1.03	3.99	3.93	21.48
# Logs/cycle	2.31	+/- 0.22	0.86	1	4
Volume/log (ft ³)	7.35	+/- 1.10	6.38	0.48	34.63

Delays accounted for 43% of the total cycle time (Figure 10). Of these delays, 9% were mechanical, 38% operational, and 53% personal. Clearing trails, slashing brush, and cutting small (< 2 inch) trees accounted for 92% of all operational delays.

Utilizing the data observed during the Iron Horse operation, SPSS statistical software was used to develop regression models predicting the delay free felling, limbing, and bucking cycle time (in minutes) for the system. Stepwise regression was used to determine significant predictive variables at the 95% confidence level. The results are illustrated in Table 15.

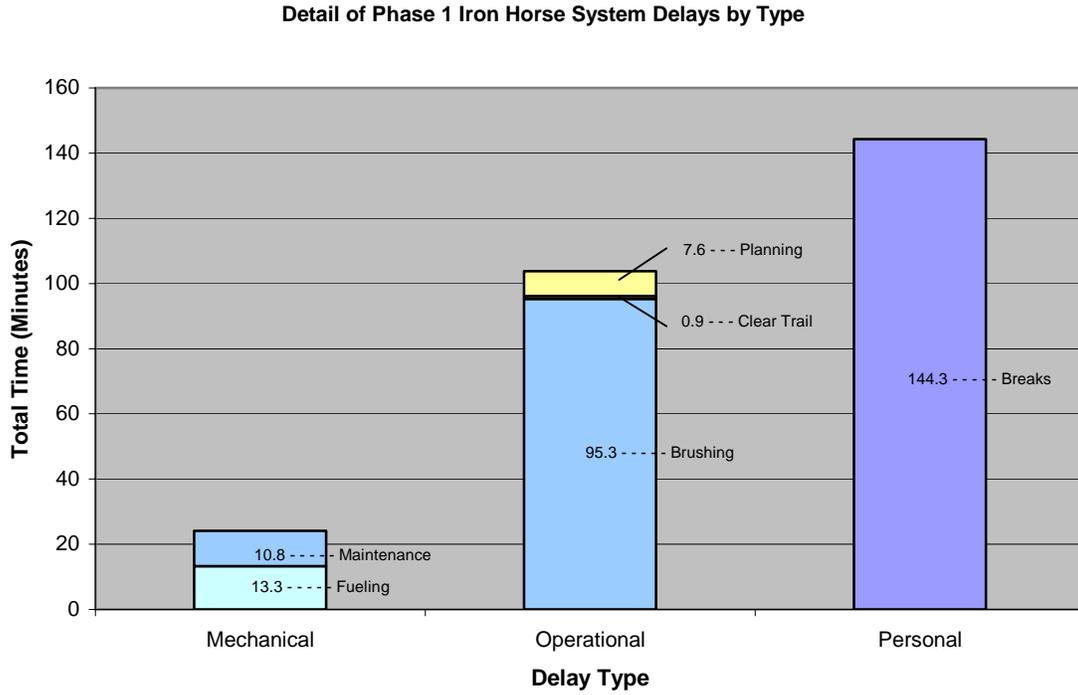


Figure 10. Graph of delays by type for Iron Horse phase 1

Table 15. Descriptive regression statistics for Iron Horse phase 1

Felling/Limbing/Bucking Regression Descriptive Statistics			
Independent Variable	Coefficient	Std. Error	P-value
Constant	-2.482	0.762	0.002
Butt diameter	0.837	0.068	<.0001
Excluded Variables			P-value
Species			0.127
# of Logs bucked			0.896

The predictive regression equation is expressed as:

$$\text{Fell/limb/buck (min)} = -2.482 + 8.37 (\text{butt diameter})$$

$$\text{Adjusted } R^2 = 0.727$$

$$\text{Standard error} = 2.09$$

$$\text{Sample size} = 57$$

Analysis results suggest that butt diameter is the only statistically significant predictive variable for the observed Iron Horse felling, limbing, and bucking phase. The average DBH for the Iron Horse study was 9.95 inches. Species and number of logs bucked per tree were excluded at the 95% confidence level. Species did however show a slight trend in predictive abilities. Additional observations may have increased the significance for species and allowed it to be used as a predictive variable. The number of logs bucked per tree significantly lacked predictive abilities and would appear not to benefit from increased observations.

Phase two of the Iron Horse study involved the skidding of logs to a landing. During this phase, the mean total cycle time (including delays) was 13.68 minutes (Table 16). On average, 2.89 logs (15'6" in length) were skidded per cycle. The average load volume was 21.24 cubic feet.

Table 16. Iron Horse phase 2 production statistics

Iron Horse Skidding Statistics					
Element	Average	95% CI	Std Dev	Minimum	Maximum
Total cycle time (min)	13.68	+/- 0.78	4.51	6.48	25.66
Travel distance (ft) (empty)	167	+/- 19.35	66.24	75	280
Travel distance (ft) (loaded)	173	+/- 19.99	68.41	90	280
Winching distance (ft)	20.27	+/- 2.80	9.57	4	50
# Logs/load	2.89	+/- 0.48	1.66	1	7
Load volume (ft ³)	20.27	+/- 1.84	6.31	8.10	34.63

Delays attributed 28% to the total cycle time (Figure 11). Delays included mechanical (0.1%), operational (28.8%), and personal (71.1%). Personal delays were operator rest periods, which reflect the intensive manual labor component of the Iron Horse system.

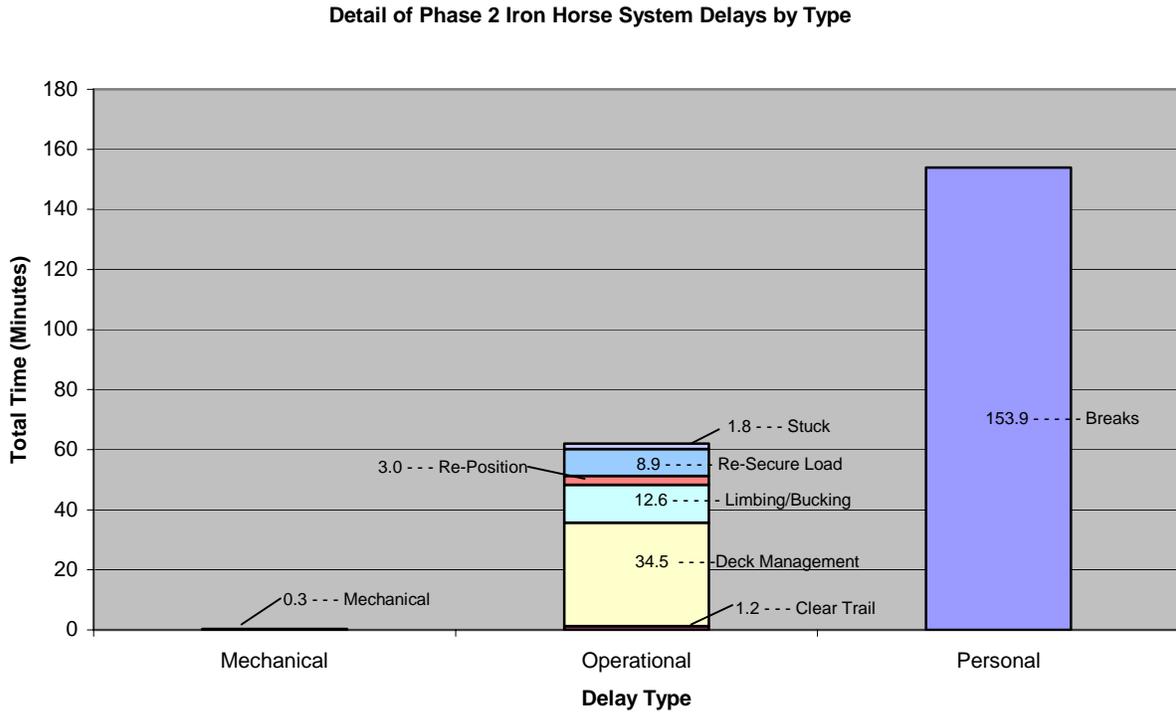


Figure 11. Graph of delays by type for Iron Horse phase 2

SPSS Statistical software was again used to develop a regression model predicting the delay free skidding cycle time (in minutes) for the Iron Horse System. Stepwise regression was used to determine significant predictive variables at the 95% confidence level. The regression descriptive statistics are shown in Table 17.

Table 17. Descriptive regression statistics for the Iron Horse phase 2

Iron Horse Skidding Regression Statistics			
Independent Variable	Coefficient	Std. Error	P-value
Constant	3.405	1.113	0.004
# Logs per load	1.828	0.178	<.0001
Load volume (ft ³)	0.169	0.046	0.001
Excluded Variables			P-value
Winching distance			0.225
Loaded travel			0.542
Unloaded travel			0.739

The predictive regression equation is expressed as:

$$\text{Skidding (min)} = 3.405 + 1.828 (\# \text{ logs}) + 0.169 (\text{load volume})$$

$$\text{Adjusted } R^2 = 0.736$$

$$\text{Standard error} = 1.95$$

$$\text{Sample size} = 45$$

The predictive model for the Iron Horse skidding phase suggests that the number of logs and the overall load volume have a significant influence on the delay free cycle time. Winching distance, loaded and unloaded travel however do not have significance at the 95% confidence level. The majority of the observed winching distances were approximately 20 feet. Additional observations with winching distances ranging throughout the line capacity (50 feet) may allow winching distance to significantly affect the model. Intuitively, travel distance should have an affect on model. Longer travel distances may indeed have this influence, however within the observed cycles, building a load had the most significance.

During this study, phase 1 (felling/limbing//bucking) production averaged 15.4 logs (+/- 2 logs) per hour with a total cubic foot volume of 113 ft³/hr (+/- 14.8 ft³) (Table 18). Phase 2 (skidding) production averaged 12.7 logs/hr (+/- 0.7 logs/hr) with a total cubic foot volume of 89 ft³/hr (+/- 5.2 ft³). Fixed, operating, and labor costs were calculated for the Iron Horse

system on a per scheduled machine hour (SMH) basis (Miyata 1980). The hourly operating costs for the Iron Horse mini-skidder were calculated at \$26/SMH. Included in the operating cost was a labor component of \$21/SMH (\$15/hr + 40% benefits) that comprised 81% of the overall operating cost. Utilizing the average total cycle times (including delays) for the felling and skidding phases, and their associated 95% confidence intervals, the costs per CCF ranged from \$46 to \$55 with an average of \$50/CCF. The production rates obtained during this study suggest that a single phase 1 worker could fell, limb, and buck enough material to keep one Iron Horse operator busy skidding. Detailed production, cost estimates, and assumptions for the Iron Horse system are further detailed in Appendix 2.

Table 18. Iron Horse system production statistics

	Avg cycle Time	95% CI	Std Dev	# Logs/Cycle	Cycles/hr	Logs/hr
Fell/limb/buck	8.99 Min	1.03	3.99	2.31	6.67	15.41
Iron Horse skidding	13.68 Min	0.78	4.51	2.89	4.39	12.69

Treatment cost estimates (Table 19) were determined using calculated machine rates, log mill receipts, trucking costs, and contractor estimates for piling and burning slash (Corrao 2005, Davis 2005). Unmerchantable logs brought to the landing were later sold to firewood cutters, which added an additional \$87 in revenue. Including these firewood sales, the overall treatment still had a net cost to the homeowner of \$297 per acre.

Table 19. Iron Horse treatment cost estimates

Sawlog revenue	Firewood Sales	Trucking	Felling	Skidding	Pile slash	Burning	Net revenue	Acres	\$/acre
\$1,126.00	\$87.00	(\$160.00)	(\$432.00)	(\$468.00)	(\$200.00)	(\$250.00)	(\$297.00)	1.0	(\$297.00)

Observations

During this study, observations were noted on the abilities and limitations of the Iron Horse system. Similar to the ATV study, directional felling was used to facilitate skidding by orienting the butt end of logs toward the direction of the skid. The operator frequently placed a small unmerchantable piece of wood under the logs during felling and bucking activities providing a choker hole allowing easier hooking later in the winching cycle.

Though highly infrequent, occasionally large logs had enough skidding resistance that during winching, the Iron Horse could be pulled completely over possibly damaging the machine. A small winch located at the front of the Iron Horse can be used to tether the machine to a tree solving this tip-over problem. Prior to securing the load, logs should be aligned parallel to the direction of intended travel (Figure 12). Logs winched from the sides of the machine which result in fan pattern often result in a re-securing delay as the trailing log ends align with one another during skidding.

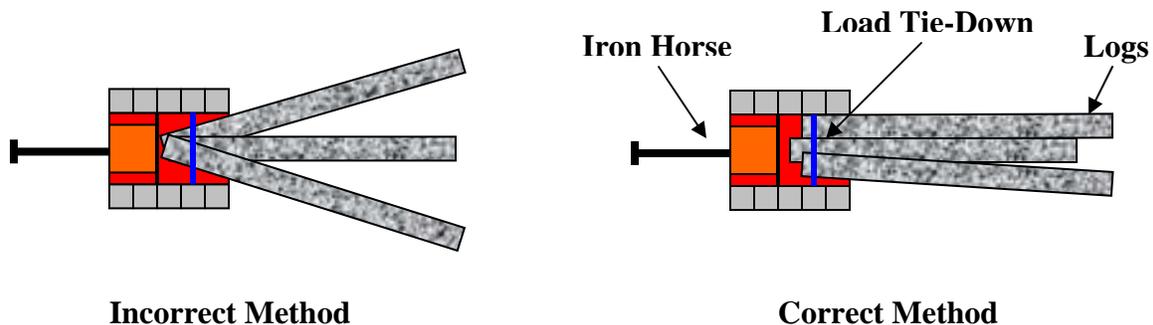


Figure 12. Illustration showing the correct alignment of load prior to skidding

It was observed that skidding with the large ends of the logs secured to the Iron Horse bunk rather than the small ends reduced the skidding resistance. Logs winched too far forward on the rotating log bunk however result in a loss of turning capability as the logs bump up against the stationary protective rack on the Iron Horse.

The Iron Horse does not need a trail system to operate. The machine can travel over light logging slash, and is highly maneuverable in tight forest conditions. The Iron Horse is

particularly adept at operating during snow season conditions. In a separate study, the Iron Horse operated on dense powder snow ranging in depth between 10 and 20 inches without a loss in traction or performance.

Deck management is an important task where landing size is small due to a lack of mechanical decking abilities. Decks located such that logs can be rolled downslope below the road often facilitate deck management.

All Season Vehicle (ASV) with Radio Remote Control Winch

As mentioned previously, the ASV system used in this study was still in the experimental stages; therefore, only two days were scheduled for time studies on this system. Felling and limbing for this system was similar to those of the other two studies, however no detailed times were obtained. The ASV study site was located next to the Iron Horse study area with similar stand conditions. During this two-day study, 146 winching turns were recorded, totaling 146 logs with a volume of 1474 cubic feet.

During the ASV study, the mean total cycle time (including delays) was 2.28 minutes (Table 20). For this study, only one log at a time was winched. The average load volume was 9.89 ft³ with an average large end diameter of 11.08 inches.

Table 20. ASV statistics

ASV Winching Statistics					
Element	Average	95% CI	Std Dev	Minimum	Maximum
Total cycle time (min)	2.28	+/- 0.26	1.61	0.62	8.11
Winching distance (ft)	61.1	+/- 4.90	30.26	12	130
Load volume (ft ³)	9.89	+/- 0.87	5.37	0.95	30.00
Large end diameter (in)	11.08	+/- 0.47	2.89	2	20
# Logs/load	1.00	--	--	1.00	1.00

Delays attributed 35% to the total cycle time (Figure 13). Delays included mechanical (11%), operational (85%), and personal (4%). Of the operational delays, positioning the machine or adjusting the log deck with the machine contributed 34% to the overall operational delays. Extra limbing and bucking, as well as winching hang-ups contributed an additional 16% and 13% respectively to the operational delays. Mechanical and personal delays consisted of winch tension adjustments and operator rest periods.

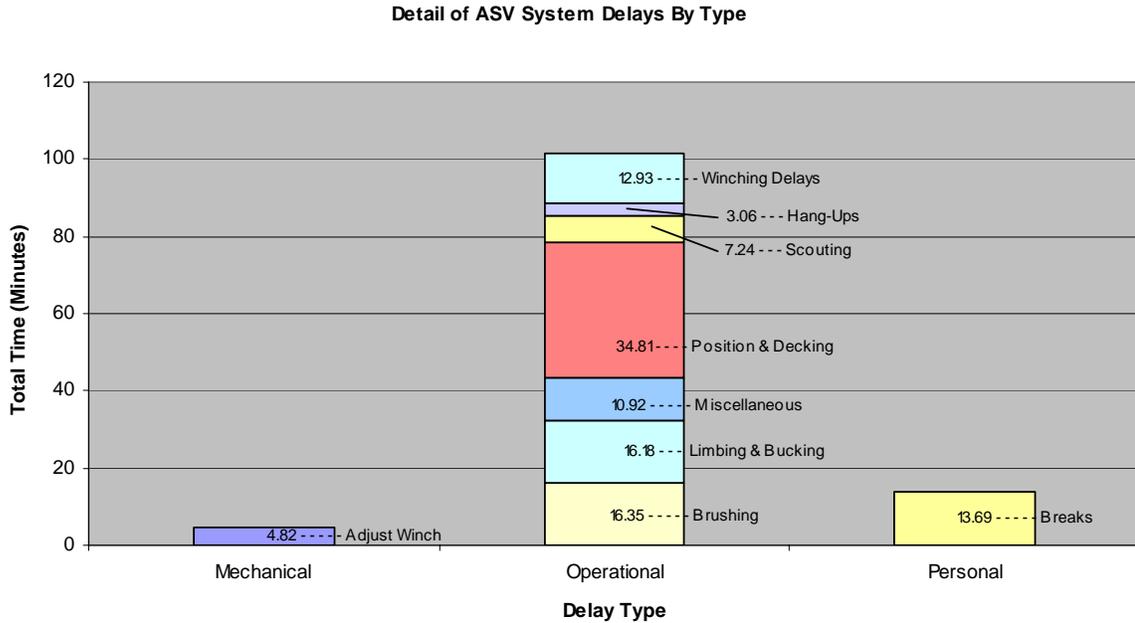


Figure 13. Graph of delays by type for ASV

SPSS Statistical software was used to develop a regression model predicting the delay free winching cycle time (in minutes) for the ASV System. Stepwise regression was used to determine significant predictive variables at the 95% confidence level. The regression descriptive statistics are shown in Table 21.

Table 21. Descriptive regression statistics for ASV system

ASV Winching Regression Statistics			
Independent Variable	Coefficient	Std. Error	P-value
Constant	0.294	0.130	0.026
Winching distance	0.016	0.001	<.0001
Log volume	0.019	0.008	0.025
Excluded Variables			P-value
Species			0.825

The predictive regression equation is expressed as:

$$\text{Winching (min)} = 0.294 + 0.016 (\text{winching distance}) + 0.019 (\text{log volume})$$

$$\text{Adjusted } R^2 = 45.9\%$$

$$\text{Standard error} = 0.54$$

$$\text{Sample size} = 146$$

The predictive winching model for the ASV suggests that the log volume and winching distance have a significant influence on the delay free cycle time. Species did not have significance at the 95% confidence level. The model has a residual value of 0.459 suggesting a possible missing element or variable. Though not recorded, time of day may have an influence on the turn time as operator fatigue occurs. Additional delays were noted towards the end of the work period due to breaks.

During this study, felling, limbing, and bucking production data was extrapolated from the Iron Horse study which averaged 15.4 logs (+/- 2 logs) per hour with a total cubic foot volume of 113 ft³/hr (+/- 14.8 ft³) (Table 22). The ASV winch production averaged 26.3 logs/hr (+/- 3.4 logs/hr) with a total cubic foot volume of 260 ft³/hr (+/- 33 ft³). Fixed, operating, and labor costs were calculated for the ASV system on a per scheduled machine hour (SMH) basis (Miyata 1980). The hourly operating costs for the ASV were calculated at \$37/SMH. Included in the operating cost was a labor component of \$21/SMH (\$15/hr + 40% benefits) that comprised 57% of the overall operating cost. Utilizing the average total cycle times (including delays) for the felling and skidding phases, and their associated 95% confidence intervals, the costs per CCF ranged from \$32 to \$40 with an average of \$35/CCF. The production rates obtained during this study may not fully reflect the variability of the ASV system since only two days were spent studying this system. Detailed production, cost estimates, and assumptions for the ASV system are further detailed in Appendix 3.

Table 22. ASV system production statistics

	Avg cycle			# Logs/Cycle	Cycles/hr	Logs/hr
	Time	95% CI	Std Dev			
<i>(From Iron Horse System)</i>						
Fell/limb/buck	8.99 Min	1.03	3.99	2.31	6.67	15.41
ASV winching	2.28 Min	0.26	1.61	1.00	26.31	26.31

Treatment cost estimates (Table 23) were determined using calculated machine rates, log mill receipts, trucking costs, and contractor estimates for piling and burning slash (Corrao 2005, Davis 2005). Unmerchantable logs brought to the landing were later sold to firewood cutters, which added an additional \$87 in revenue. Including these firewood sales, the overall treatment still had a net cost to the homeowner of \$44 per acre.

Table 23. ASV RC-30 treatment cost estimates

Sawlog revenue	Firewood Sales	Trucking	Felling	Skidding	Pile slash	Burning	Net revenue	Acres	\$/acre
\$1,577.00	\$87.00	(\$224.00)	(\$432.00)	(\$440.00)	(\$280.00)	(\$350.00)	(\$62.00)	1.4	(\$44.00)

Observations

Observations were noted on the abilities and limitations of the ASV system.

Orienting the butt end of logs toward the direction of the skid is helpful but not necessary for this system. Short (16 foot) logs were winched which allowed easier maneuvering through the residual stand. The Mechanical Engineering Department at the University of Idaho installed a radio remote control that allowed the operator to follow the logs in to the landing and stop the load prior to hang-up situations such as trees, stumps, rocks, or other obstacles.

Prior trials found that the ASV winch, which had a 4600 lb capacity, lacked breakout power needed for multiple log skids. Multiple logs that were skidded easily became hung-up on obstacles in the skid path; however, the winch had enough power to overcome these obstacles winching single logs. This study therefore only winched one log at a time though multiple logs may have been possible. Although uphill skidding was studied with this machine in subsequent trials, this study concentrated on downhill skidding only.

There was not a forwarding phase to this system. Once a log was winched into a deck, it would remain there until a self-loading log truck picked it up for transport to a mill. As the log deck grew in height, logs would hang-up on the log deck resulting in increased turn times. When this occurred, the ASV would be moved to a new location to start a new deck.

Prior to moving to a new location, the ASV was used to arrange and straighten the log deck by pushing logs into place to consolidating the pile. Log deck locations must be planned to facilitate loading by the log truck. Power lines and logs placed within tightly spaced residual trees must be avoided.

The ASV's track system allows the machine to operate in snow conditions, and traction issues have not been a problem. When winching in snow and ice conditions, the ASV did not slide while winching heavy loads.

Fuel Transect and Stand Damage Observations

Data from post harvest stand and fuel transects were collected and analyzed. A reminder is given not to compare the systems since different treatment methods, operators, and conditions were present for each system. The ASV system did not have pre-study conditions measured and is not included.

The fuels reduction prescription used for this study decreased Douglas-fir and lodgepole pine composition within the Iron Horse study area (Figure 15), and reduced both Douglas-fir and ponderosa pine in the ATV area (Figure 14). The prescription resulted in a significant reduction in overall trees per acre calculations on both sites (Tables 21 and 22). Basal area was significantly reduced for Douglas-fir, and slightly to moderately for ponderosa pine resulting in considerable overall basal area reductions. After treatment, the residual stand has fewer trees per acre and tree spacing has increased.

The treatment significantly increased slash fuel loads (143% ATV and 369% Iron Horse). The majority of this increase was in the 10 and 100 hour fuels (0.25 to 1 inch & 1 to 3 inch size classes). After post harvest measurements were complete, all three study areas received extensive pruning to reduce ladder fuels. Slash was hand piled and burned during the Fall months following treatment. No further fuel measurements were recorded, however all three sites appear to have been brought back to at least pre-harvest fuel loads (reduced levels in most areas).

Table 21. Pre and post stand summary characteristics for ATV treatment

ATV	Size (ac)	Average slope (%)	Quad. Mean Diam. DF/PP (in)	Trees/Acre DF/PP (TPA)	Total TPA (TPA)	Basal Area DF/PP (ft ³)	Total BA (ft ³)	Fuel Load Tons/ Ac
Pre	1.1	10%	11.2/6.9	73/277	350	50/72	122	5.18
Post	1.1	10%	9.0/8.0	23/141	163	10/44	54	12.58

Note: Trees per acre summary statistics utilized plot measurements taken by a 20 BAF prism. Small trees (2-3 inch class) included in these measurements greatly increased the TPA count. (Abbreviations: DF=Douglas-fir, PP=ponderosa pine, LPP=lodgepole pine, TPA=trees per acre, BA=basal area)

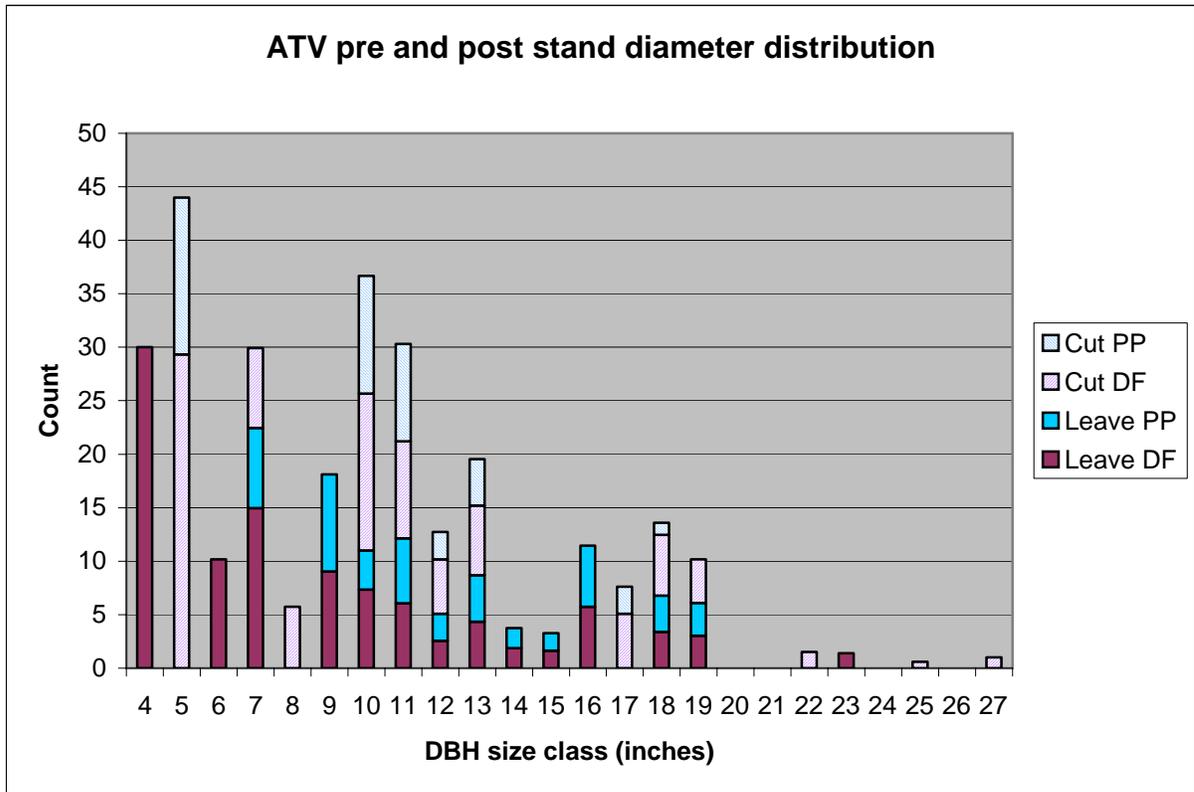


Figure 14. ATV study site residual DBH size class distribution

Table 22. Pre and post stand summary characteristics for Iron Horse treatment

Iron Horse	Size (ac)	Average slope (%)	Quad. Mean Diam. DF/PP/LPP (in)	Trees/Acre DF/PP/LPP (TPA)	Total TPA (TPA)	Basal Area DF/PP/LPP (ft ³)	Total BA (ft ³)	Fuel Load Tons/Ac
Pre	1.0	11%	6.6/16.9/7.4	187/25/35	248	45/55/8	108	5.04
Post	1.0	11%	19.4/16.7/0	16/25/0	40	33/38/0	70	23.63

Note: Trees per acre summary statistics utilized plot measurements taken by a 20 BAF prism. Small trees (2-3 inch class) included in these measurements greatly increased the TPA count. (Abbreviations: DF=Douglas-fir, PP=ponderosa pine, LPP=lodgepole pine, TPA=trees per acre, BA=basal area)

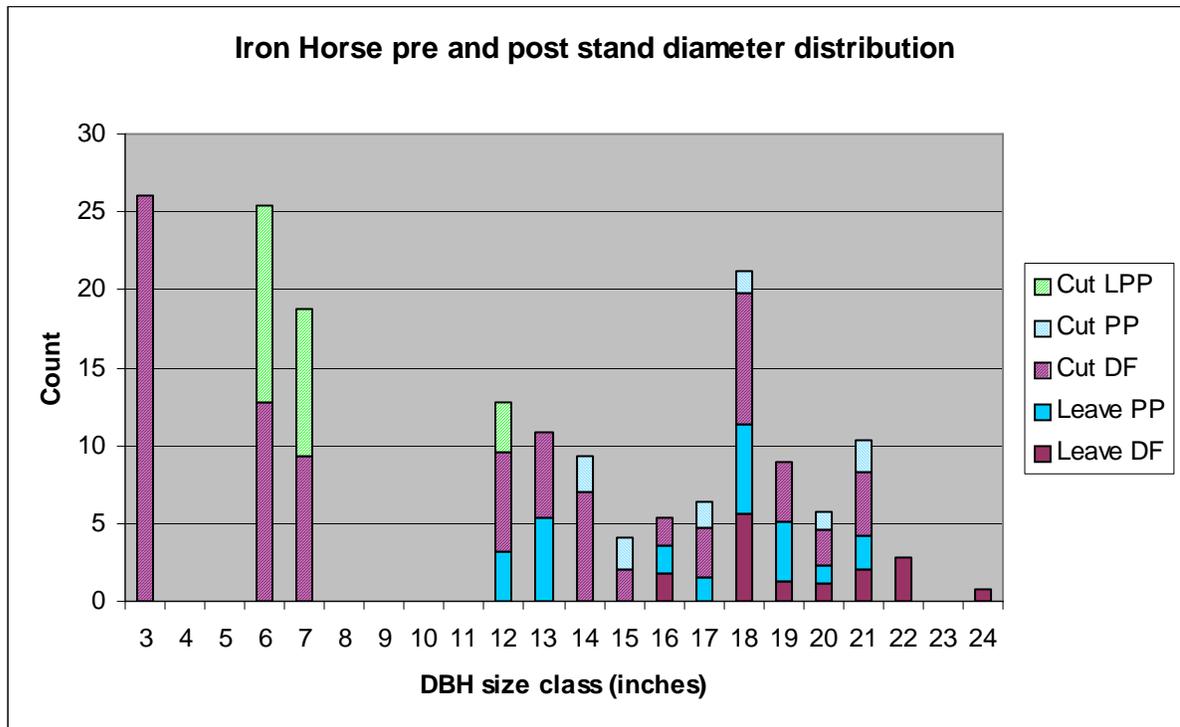


Figure 15. Iron Horse study site residual DBH size class distribution

Since the treatment sites were relatively small, a 100% survey was conducted for all trees damaged due to the fuels reduction project. Damage would be defined as any scarring that revealed cambium. The survey concluded the only “damage” was to a group of 3 saplings (<3 inches) located on the Iron Horse site. These were used as sacrificial “rub trees” to protect others next to the skid path and had not yet been removed. Slash cleanup had not occurred on this site, however the researcher intended for these trees to be removed. The researcher concluded these would be noted, however they would not be counted as damaged trees.

Homesite Defensible Space

The treatment prescription for this site reduced the likelihood that an active crownfire would occur within 200 feet of the residence. This distance follows recommended defensible space guidelines. The homesite’s power is fed by overhead powerlines. Trees located near these lines were removed to mitigate their hazard. Ladder fuels were pruned to a height of 8-10 feet. Slash was piled and burned to abate the slash hazard. These measures do not however eliminate surface fires. The ignition zone directly around the homesite was not treated. Wood decks were located adjacent to flammable grasses, vegetation was not removed around the structure, and pine needle buildup around the home was not addressed. A surface fire or blowing embers could ignite any of these items resulting in structure loss. A fire department presence would be needed still be needed to defend this home against wildfire.

Conclusions

This study focused on the production capabilities, limitations, and practicalities of using small-scale logging systems for fuel reduction around homesites in the wildland urban intermix.

Three systems were evaluated including an All-Terrain Vehicle with arch, an Iron Horse mini-skidder, and a skid steer tractor with remote control log winch. The fuels reduction prescription called for a species shift from a mixed stand of Douglas-fir, ponderosa pine, and lodgepole pine to a more open stand dominated by ponderosa pine. Utilizing the small-scale equipment in this study, the prescription was effectively met while reducing treatment costs through revenue from timber and firewood removal.

The study showed that these systems are easily transported, have a low capital investment, are highly maneuverable, but have a high labor component. Labor is the single most influential cost for these systems. For the ATV and Iron Horse machines, which have a capital investment of <\$12,000, the labor component represents 84% and 81% of total hourly machine costs respectively. The ASV, which has a capital investment of ~ \$36,000, has a labor component 57% of hourly machine costs. These labor intensive systems have high delays associated with operator rest periods but may be acceptable since the equipment does not have excessive operating costs while not working.

Each system tested has an operational niche. The Iron Horse works well on snow or over slash without the need for trails; the ATV works well over longer distances where skidding downhill or over level terrain is an option; and the ASV works well winching logs to roadside locations where self loading logs trucks have access. The ASV does however have a limited winching distance of 130 feet due to cable capacity.

Production estimates were obtained for each machine through detailed time study evaluations. The ATV averaged 190 ft³ of sawlog production per SMH with a system cost (including felling) of \$36/CCF. Overall treatment costs including felling, skidding, slashing, piling and burning for the ATV system were \$1125 per acre. On the second study site, the Iron Horse averaged 89 ft³/SMH with a system cost (including felling) of \$50/CCF. Treatment costs for

the Iron Horse were calculated at \$1350 per acre. At the third location, the ASV averaged 260 ft³/SMH with a system cost (including felling) of \$35/CCF. This system had a treatment cost of \$1073 per acre. Sawlog revenue partially offset treatment costs during this study. Revenue after hauling included \$1053, \$966, and \$966 per acre for each system respectively. Firewood sales added an additional revenue source which further helped offset some of the treatment costs. Treatment costs however exceeded revenue sources for both the Iron Horse, and the ASV resulting in a cost to the homeowner of \$297 and \$44 per acre respectively. The ATV treatment site produced enough firewood to provide \$23 per acre in revenue to the homeowner. While sawlog and firewood revenue may not completely pay for fuel reduction treatment costs, they may offset costs sufficiently to persuade homeowners to initiate fuel reduction treatments on their property. This may become an issue if federal fuel treatment subsidies diminish.

Visual aesthetics that include stand damage and soil disturbance are important factors when working around homesites. The small-scale equipment used had low pulling power. If a load or log hit the residual stand, a hang-up situation occurred requiring additional time to free the load. Work techniques were therefore used to reduce these hang-ups. As a result, residual stand damage did not occur during this study. Additionally, soil disturbance was minimal across all three studies. In most cases, grasses and forbs remained intact along the skid paths reducing the visual impacts.

It is important to note that this study's fuels treatment reduced the fuel load up to the existing homesite, but did not address the ignition zone directly adjacent to the home. While defensible, the homesite likely would not survive a wildfire without assistance from fire crews. Wood decks located alongside flammable grasses, trees, shrubs and grasses adjacent to the homesite, and dead needle buildup on and near the homesite would need to be addressed to create survivable space.

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Appendix 1: ATV

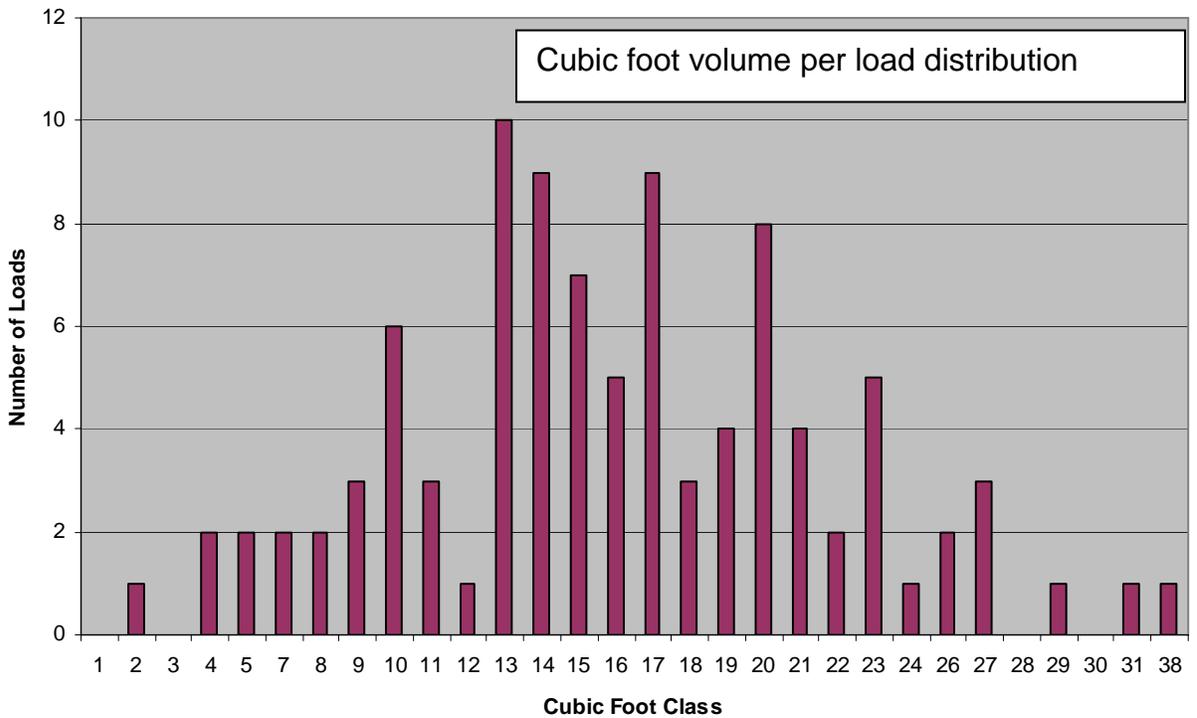
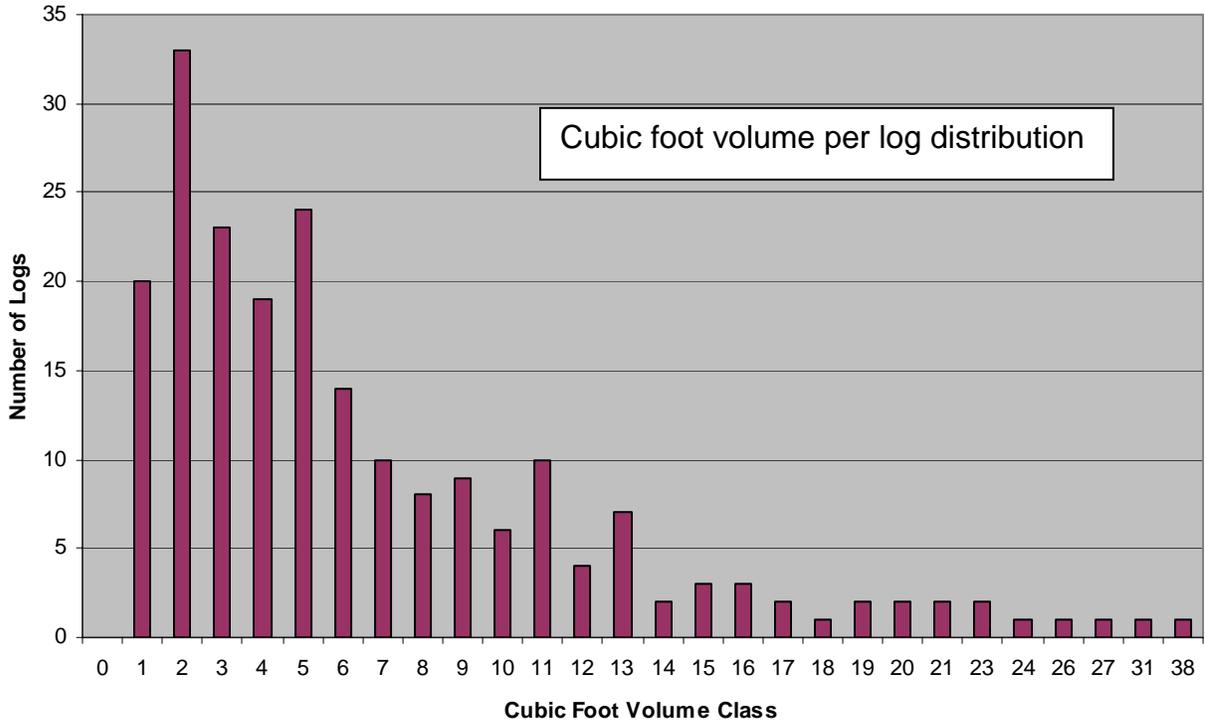
Machine rate for Jr. arch and saws

Machine Rate For: Jr. Arch + 2 Saws			
Assumptions			
Initial Cost	\$1,630.00		
Salvage Value	\$326.00		
Life of machine	2 Years		
Insurance	3%		
Interest	10%		
Taxes	2%		
Repairs	70.00% of depreciation		
# of saws	2		
Fuel Consumption Rate	0.5 gal/saw		
Fuel Costs	\$2.05		
Lubrication Costs	50.00% of fuel cost		
Benefits	40.00% of labor		
Labor	\$15.00		
Scheduled Hours / Year	1000 hrs		
Efficiency	75%		
Potential Production	93 ft ³ /SMH		
Productive hours / Year	750 hrs		
Owning (fixed) Costs			
	\$/ SMH	\$/ PMH	
Depreciation	\$0.65		\$0.87
AAI	1304.00		1,304.00
I,In,Tax	\$0.20		\$0.26
Operating (Variable) Costs			
Fuel Costs	\$2.05		\$2.05
Lubrication Costs	\$1.03		\$1.03
Repairs	\$0.46		\$0.61
Labor			
Labor + Benefits	\$21.00		\$21.00
Machine Rate			
	\$24.61		\$22.74
Scheduled Machine Hour Summary		Productive Machine Hour Summary	
Machine Rate	\$24.61 per hour	Machine Rate	\$22.74 per hour
Cost/ 8 hr day	\$196.88 per 8 hr day	Cost/ 8 hr day	\$181.91 per 8 hr day
Effective Production Rate	93 ft ³ /hr	Effective Production Rate	70 ft ³ /hr
Effective Prod/year	93000 ft ³ /yr	Effective Prod/year	52313 ft ³ /yr
Cost per cubic foot	\$0.26 \$/ft ³	Cost per cubic foot	\$0.33 \$/ft ³

Machine rate for ATV and arch

Machine Rate For: ATV & Arch			
Assumptions			
Initial Cost	\$9,375.00		
Salvage Value	\$1,875.00		
Life of machine	4 Years		
Insurance	3%		
Interest	10%		
Taxes	2%		
Repairs	50.00% of depreciation		
CC's	499 CC		
Fuel Consumption Rate	0.00011 per CC		
Fuel Costs	\$2.05		
Lubrication Costs	37.00% of fuel cost		
Benefits	40.00% of labor		
Labor	\$15.00		
Scheduled Hours / Year	1000 hrs		
Efficiency	69%		
Potential Production	190 ft ³ /SMH		
Productive hours / Year	691.2 hrs		
<hr/>			
Owning (fixed) Costs	\$/ SMH	\$/ PMH	
Depreciation	\$1.88	\$2.71	
AAI	6562.50	6,562.50	
I,In,Tax	\$0.98	\$1.42	
<hr/>			
Operating (Variable) Costs			
Fuel Costs	\$0.11	\$0.11	
Lubrication Costs	\$0.04	\$0.04	
Repairs	\$0.94	\$1.25	
<hr/>			
Labor			
Labor + Benefits	\$21.00	\$21.00	
<hr/>			
Machine Rate	\$24.90	\$26.39	
<hr/>			
Scheduled Machine Hour Summary		Productive Machine Hour Summary	
Machine Rate	\$24.90 per hour	Machine Rate	\$26.39 per hour
Cost/ 8 hr day	\$199.23 per 8 hr day	Cost/ 8 hr day	\$211.09 per 8 hr day
Effective Production Rate	190 ft ³ /hr	Effective Production Rate	131 ft ³ /hr
Effective Prod/year	190000 ft ³ /yr	Effective Prod/year	90774 ft ³ /yr
Cost per cubic foot	\$0.13 \$/ft ³	Cost per cubic foot	\$0.20 \$/ft ³

ATV skidding production charts



Appendix 2: Iron Horse

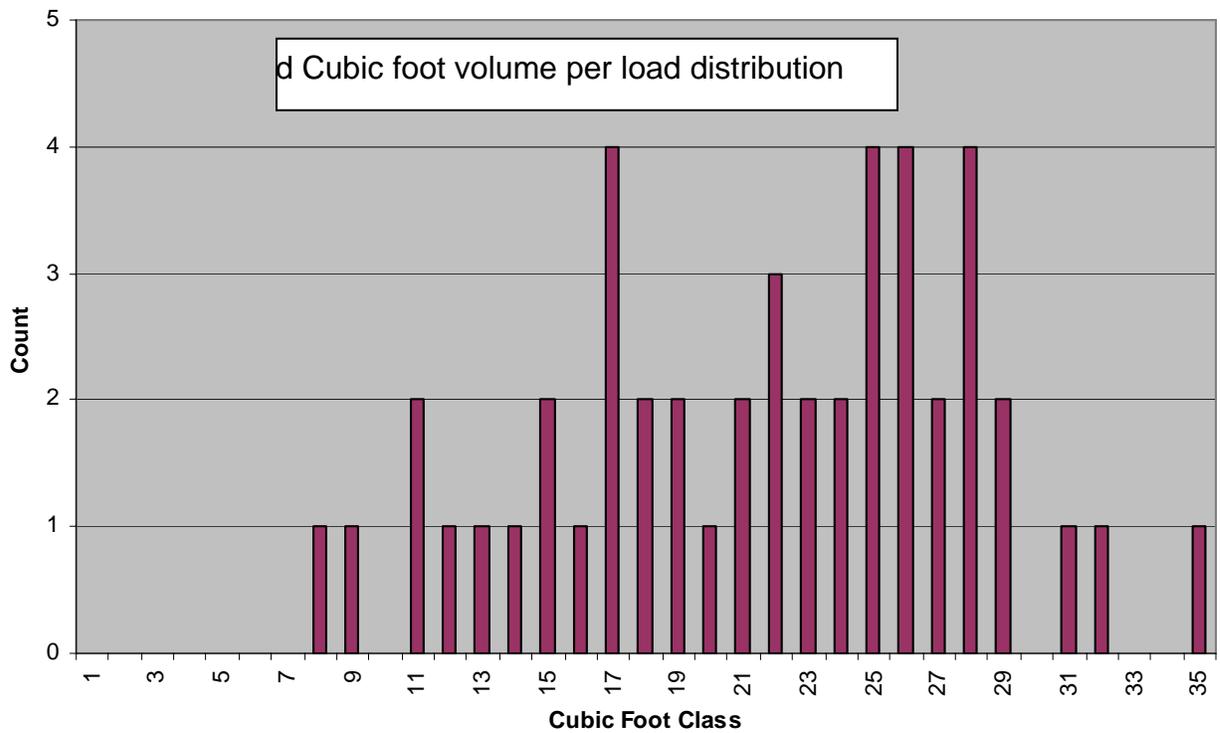
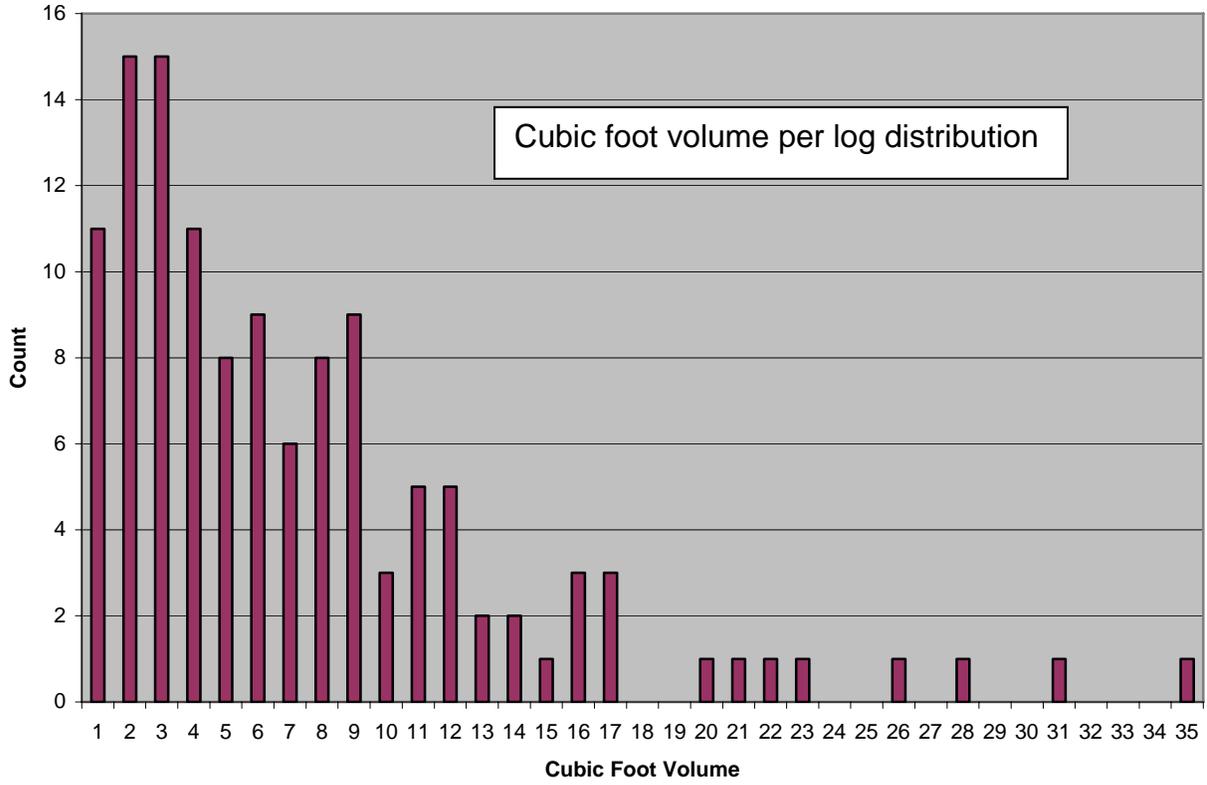
Machine rate for 2 saws

Machine Rate For: 2 Saws			
Assumptions			
Initial Cost	\$1,300.00		
Salvage Value	\$260.00		
Life of machine	2 Years		
Insurance	3%		
Interest	10%		
Taxes	2%		
Repairs	70.00% of depreciation		
# of saws	2		
Fuel Consumption Rate	0.5 gal/saw		
Fuel Costs	\$2.05		
Lubrication Costs	50.00% of fuel cost		
Benefits	40.00% of labor		
Labor	\$15.00		
Scheduled Hours / Year	1000 hrs		
Efficiency	57%		
Potential Production	113 ft ³ /SMH		
Productive hours / Year	573 hrs		
Owning (fixed) Costs			
	\$/ SMH	\$/ PMH	
Depreciation	\$0.52		\$0.91
AAI	1040.00		1,040.00
I,In,Tax	\$0.16		\$0.27
Operating (Variable) Costs			
Fuel Costs	\$2.05		\$2.05
Lubrication Costs	\$1.03		\$1.03
Repairs	\$0.36		\$0.49
Labor			
Labor + Benefits	\$21.00		\$21.00
Machine Rate			
	\$23.80		\$22.67
Scheduled Machine Hour Summary		Productive Machine Hour Summary	
Machine Rate	\$23.80 per hour	Machine Rate	\$22.67 per hour
Cost/ 8 hr day	\$190.42 per 8 hr day	Cost/ 8 hr day	\$181.32 per 8 hr day
Effective Production Rate	113 ft ³ /hr	Effective Production Rate	65 ft ³ /hr
Effective Prod/year	113000 ft ³ /yr	Effective Prod/year	37101 ft ³ /yr
Cost per cubic foot	\$0.21 \$/ft ³	Cost per cubic foot	\$0.35 \$/ft ³

Machine rate for Iron Horse Pro with loader and winch

Machine Rate For: Iron Horse Pro with loader and winch			
Assumptions			
Initial Cost	\$11,500.00		
Salvage Value	\$2,300.00		
Life of machine	5 Years		
Insurance	3%		
Interest	10%		
Taxes	2%		
Repairs	50.00% of depreciation		
Horsepower	9 hp		
Fuel Consumption Rate	0.05 gal/hp		
Fuel Costs	\$2.05		
Lubrication Costs	37.00% of fuel cost		
Benefits	40.00% of labor		
Labor	\$15.00		
Scheduled Hours / Year	1000 hrs		
Efficiency	72%		
Potential Production	89 ft ³ /SMH		
Productive hours / Year	719 hrs		
<hr/>			
Owning (fixed) Costs	\$/ SMH	\$/ PMH	
Depreciation	\$1.84	\$2.56	
AAI	7820.00	7,820.00	
I,In,Tax	\$1.17	\$1.63	
<hr/>			
Operating (Variable) Costs			
Fuel Costs	\$0.92	\$0.92	
Lubrication Costs	\$0.34	\$0.34	
Repairs	\$0.92	\$1.23	
<hr/>			
Labor			
Labor + Benefits	\$21.00	\$21.00	
<hr/>			
Machine Rate	\$25.84	\$26.42	
<hr/>			
Scheduled Machine Hour Summary		Productive Machine Hour Summary	
Machine Rate	\$25.84 per hour	Machine Rate	\$26.42 per hour
Cost/ 8 hr day	\$206.73 per 8 hr day	Cost/ 8 hr day	\$211.34 per 8 hr day
Effective Production Rate	89 ft ³ /hr	Effective Production Rate	64 ft ³ /hr
Effective Prod/year	89000 ft ³ /yr	Effective Prod/year	46010 ft ³ /yr
Cost per cubic foot	\$0.29 \$/ft ³	Cost per cubic foot	\$0.41 \$/ft ³

Iron Horse skidding production charts



Appendix 3: ASV RC-30

Machine rate for ASV RC-30 with radio remote control log winch

Machine Rate For: ASV RC-30 with radio remote control log winch			
Assumptions			
ASV RC-30	\$26,000.00		
Attachments + Guarding	\$10,000.00		
Initial Cost	\$36,000.00		
Salvage Value	\$7,200.00		
Life of machine	5 Years		
Insurance	3%		
Interest	10%		
Taxes	2%		
Repairs	80.00% of depreciation		
Horsepower	30 hp		
Fuel Consumption Rate	0.03 gal/hp		
Fuel Costs	\$2.05		
Lubrication Costs	37.00% of fuel cost		
Benefits	40.00% of labor		
Labor	\$15.00		
Scheduled Hours / Year	1000 hrs		
Efficiency	65%		
Potential Production	260 ft ³ /SMH		
Productive hours / Year	650 hrs		
Owning (fixed) Costs			
	\$/ SMH		\$/ PMH
Depreciation	\$5.76		\$8.86
AAI	24480.00		24,480.00
I,In,Tax	\$3.67		\$5.65
Operating (Variable) Costs			
Fuel Costs	\$1.85		\$1.85
Lubrication Costs	\$0.68		\$0.68
Repairs	\$4.61		\$6.14
Labor			
Labor + Benefits	\$21.00		\$21.00
Machine Rate	\$36.68		\$41.65
Scheduled Machine Hour Summary		Productive Machine Hour Summary	
Machine Rate	\$36.68 per hour	Machine Rate	\$41.65 per hour
Cost/ 8 hr day	\$293.46 per 8 hr day	Cost/ 8 hr day	\$333.24 per 8 hr day
Effective Production Rate	260 ft ³ /hr	Effective Production Rate	169 ft ³ /hr
Effective Prod/year	260000 ft ³ /yr	Effective Prod/year	109850 ft ³ /yr
Cost per cubic foot	\$0.14 \$/ft ³	Cost per cubic foot	\$0.25 \$/ft ³

ASV RC-30 winch production chart

