AN ABSTRACT OF THE PAPER OF

Derek K. Solmie for the degree of Master of Forestry in Forest Operations, presented on April 25, 2003. Title: Comparing Field Measurement Strategies for Operational Planning and Layout.

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Over the past 15 years, changes in forest-management values have led to an increase in the amount of planning requirements necessary to complete harvesting activities. The measurement of forested land areas is typically a large part of operational plans. In the two studies presented here, new measurement technologies were examined for their effectiveness in meeting those requirements. Both investigations involved area measurements and corridor layout in the Oregon Coastal mountain range.

The first study compared four survey techniques for traversing 16 1-ac patches: 1) string box, hand-held compass, and clinometer; 2) laser, digital compass, and digital data collector; 3) global positioning system (GPS); and 4) the benchmark method, as set with a total station. Defining the effectiveness of each system was based on pre-determined management objectives, including the precision and accuracy of data, time to complete the survey, and cost. Precision was highest with the total station, while the laser and digital compass method required the most time. The least expensive

technique was the string-box method. GPS proved ineffective under dense canopy conditions. Potential differences in the orientation of harvest units were revealed because of variations in the horizontal angles used for measurements.

In the second study, two surveying techniques were compared against a benchmark (i.e., total station) for profiling skyline corridors for commercial thinning. The first method employed a string box, clinometer, and hand-held compass; the second, a laser, digital compass, and digital data collector. Analysis of the profile information (slope distance and slope percent) by LoggerPC4 showed no significant differences ($p<0.57$) in lbs-per-payload results between the two surveying methods, based on t-tests. The string-box technique was most effective in terms of time (10.8 hr vs. 13.5 hr from the laser/digital method) and cost ($0.35/mbf vs. $1.00/mbf). These contrasts might be attributed to differences in: 1) the position of the critical point due to elevational changes within the mid third of the profile; 2) the elevation of the intermediate support; and 3) elevation of the tail hold.

The results of both studies demonstrate that many tools are available for completing operational planning and layout. Each has benefits and drawbacks that should be matched to the operational plan objectives.

Comparing Field Measurement Strategies for Operational Planning and Layout

by

Derek K. Solmie

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CONTRIBUTION OF AUTHORS

Dr. Loren Kellogg, Dr. Michael Wing, and Jim Kiser served as consultative members during the course of this project.

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Chapter 1

INTRODUCTION

Values for managing forestlands in the Pacific Northwest have evolved during the past fifteen years, shifting from a production-based system to one that is more environmentally conscious, ecologically safe, and socio-economically secure (Swanson and Franklin 1992, Debell and Curtis 1993, Committee of Scientists 1999). In addition to increasing the complexity of silvicultural treatments, this transition now entails greater pre-harvest planning (Whyte 1999). One of the inherent challenges is to efficiently gather accurate data while minimizing those collection costs (Becker 2001). Whereas conventional data-capture methods are effective in providing the required information, relatively new, higher-precision technologies use high-resolution data to support site-specific tactical and operational decision-making. One potential benefit is that land-use planners can complete their objectives in less time while attaining a desired accuracy in data collection (Bare 2001, Wing and Kellogg 2001).

The costs for operational layout and planning can be highly variable. In a study of four alternative thinning systems, Kellogg et al. (1998) compared the costs incurred by both U.S. Forest Service employees and contractors for various silvicultural treatments, logging systems, and site conditions. While the Forest Service employees conducted all the stand-level tasks, e.g., reconnaissance planning, marking and flagging unit boundaries, timber cruising, and logging design, the logging contractor completed the layout of skyline corridors and designated equipment trails. The former group listed per-acre costs ranging from $50.68 ($3.68/mbf) to $124.31 ($14.48/mbf), whereas the latter reported costs of $9.22 ($0.65/mbf) to $94.40 ($12.39/mbf). In addition, the wide range in time spent at work by both groups could be attributed to differing site conditions, silvicultural and harvesting systems, size of the unit, crew experience, and travel time. The most time-consuming tasks for the Forest Service were marking leave trees and flagging patch perimeters, which accounted for almost 40% of the total cost. For the contractors, the largest contributing factor to layout costs was the type of harvesting system being employed. Compared with the methods utilized in this study situation, precision forestry tools, e.g., electronic distance-measuring devices, may have been a viable option that could have decreased the effect of those site conditions.

Kellogg et al. (1996a) compared planning, felling, and skyline-yarding costs for clearcutting versus five methods of selection harvesting. They reported that planning time and costs were significantly lower within the clear-cut project than for any partial-cutting treatment, with operational planning and layout costs varying from $1.10/mbf to $5.88/mbf. Because calculations were based on the time required to lay out and traverse the unit boundaries, wildlife tree patches, and skyline corridors, this wide range in costs was attributed to the designation and flagging of skyline corridors, site characteristics, and gap-cut design.

Dunham (2001a, b) also assessed the effects of silvicultural prescriptions on operational layout and planning. In the first study, prescription costs for group selection were approximately three to four times higher than those associated with traditional clear-cut methods. This difference was due to the greater amount of time required to survey boundaries for the former treatment type. Costs incurred during the field marking of shelterwood prescriptions were then examined in the second study. Differences there were attributed to basal-area adjustments as well as variations in stand density. Dunham (2001b) hypothesized that using a digital data collector to capture and store residual basal areas would have reduced the time required and increase the accuracy of those measurements.

Boswell (2001) studied partial cutting with a cable system in coastal British Columbia, separating the tasks of operational layout and planning into either field or office work. The first category consisted of reconnaissance, road location within the block, and unit-boundary layout and traversing. The second comprised mapping, documenting road permits, and organizing the cutting permit. Costs for both aspects ranged from $0.96/mbf to $1.63/mbf, with differences arising because of block size and the level of crew experience. In this case, digital equipment could probably have streamlined the office-work component if information had been directly downloaded from the field to the mapping software.

All these studies illustrate that the cost differential for conventional layout and planning depend upon site-specific variables, factors that can significantly affect the profitability of an operation. A common goal in all this research has been to gain the required amount of accuracy while investing the least amount of capital. Therefore, accuracy or precision was not compared among various strategies but, rather, one method was used throughout to complete the many facets of layout and planning. Traditionally, these operations have consisted of locating and mapping unit boundaries, skid trails, skyline corridors, roads, and special management areas. Those tasks have typically been performed through manual survey techniques, with varying degrees of accuracy being achieved (Kellogg et al. 1998, Wing and Kellogg 2001).

In the studies presented here, the primary objective was to analyze the accuracy and precision of several techniques available for measuring unit areas and cable corridors. A secondary objective was to assess the potential benefits and drawbacks associated with each technique during operational layout and planning. The first portion of this report focuses on comparing the results from three surveying methods versus benchmark data obtained from a digital total station. These area-measuring methods included 1) a string box, hand-held compass, and clinometer; 2) a laser, digital compass, and digital data collector; and 3) a global positioning system. The second portion describes a comparison study of two traversing techniques used in 20 cable-thinning corridors versus a benchmark method, where data were again established via a total station.

Chapter 2

COMPARISON OF TECHNIQUES FOR MEASURING FORESTED AREAS

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ABSTRACT

The management objective of the southern zone of the McDonald-Dunn College Forest, Oregon State University, is to develop a mid- to late-successional Douglas-fir forest. To do so, a forest management interdisciplinary team has divided a 120-ac parcel into one, two, and four-ac harvest units, and has applied an optimization model for harvest scheduling. For the study presented here, 16 units were identified within this parcel for an evaluation of different spatial data-collection instruments as well as techniques for measuring area. These units were selected to represent various stand types, topographies, and patch locations. Areas were measured according to three surveying techniques, comprising 1) a string box, manual compass, and clinometer; 2) a laser, digital compass, and digital data collector; or 3) a global positioning system. The collected data were compared with a series of benchmarks established with a digital total station. All the techniques were statistically analyzed and error distributions were developed using regression analysis at either a unit or an individual data-point scale. Time studies were also conducted to determine the overall efficiencies of each technique. Our study results should assist forest resource managers in their decision when selecting alternate measurement tools for collecting spatial data.

INTRODUCTION

Operational planning and layout are important steps in determining the feasibility of harvesting operations. Numerous studies of the conventional methods employed in the Pacific Northwest have analyzed the use of nylon tapes, hand-held compasses, and clinometers for operational measurements. Researchers have reported that costs can vary according to the type of harvesting system (Edwards 1993), unit size and shape (Dunham 2001a), silvicultural treatments (Kellogg et al. 1991, Edwards 1993, Kellogg 1996a, Dunham 2001a, b), and level of crew experience (Kellogg et al. 1996b). However, no studies have been published concerning the more recent data-capturing technologies available to the forest industry.

Higher-precision technologies may increase measurement accuracy and efficiency while decreasing total planning costs. Although a number of trials have been completed on the *potential* implementation of some of these new technologies, few have quantified the benefits of such devices in an *operational* setting. Mixed results have been reported for the usefulness of electronic distance- and azimuth-measuring (EDM) devices. For example, Liu (1995) used the Criterion 400 EDM to traverse forest stand boundaries and concluded that this instrument was ten times more cost effective than traditional survey equipment. In contrast, Moll (1992) evaluated the use of a digital compass and laser-based EDM for low-volume road surveys. Here, the laser method resulted in a savings of approximately 60% in time and costs compared with a manual technique that consisted of a nylon measuring tape, hand-held compass, and clinometer. However, although the distance- and vertical angle-measuring capabilities of the laser met the survey requirements, the azimuth measurements with the compass did not. This was attributed to the angle at which the compass was held. Offsets in the horizontal and vertical positioning of the instrument, relative to the ground, affected the magnetic field and produced erroneous measurements. Since that study, the manufacturer of the digital compass and laser has worked to minimize the effects of those magnetic-field offsets (Joe Cronn, pers. comm., LTI, February 21, 2003).

Turcotte (1999) measured woodpile volumes in the millyards of eastern Canada with a laser rangefinder, digital compass, and data collector. The laser and compass were mounted on a staff to complete the traverse. Use of this equipment increased the accuracy of measurements. Likewise, the process of data collection, which normally required three worker days, could now be completed in less than two hours, further illustrating the potential for digital data collectors, compasses, and laser rangefinders in an operational setting.

Wing and Kellogg (2001) have also assessed the use of a laser range finder and digital compass for traversing skyline corridors and harvest boundaries. In several pilot studies, these instruments required less time overall, and showed greater accuracy than from conventional methods, apparently because of the rapid capture ability with the rangefinder. However, measurements with this highly precise technology were more difficult to obtain in thick understory brush. Therefore, further comparisons between the laser rangefinder and more conventional methods are needed to fully understand the benefits of these newer tools.

A global positioning system (GPS) has been widely used to collect spatial data in forested environments (Forgues 1998), particularly when mapping road networks and the outlines of work areas. Through more extensive trials, a number of variables have been identified that affect its usefulness, including the amount of canopy closure (Stjernberg 1997, Mancebo and Chamberlain 2001), receiver type and grade (Darche 1998), weather conditions (Forgues 2001), and topography (Liu and Brantigan 1996). Historically, one of the challenges when using GPS has been the effect of multi-path signals caused by the forested canopy (Stjernberg 1997, Forgues 2001). This phenomenon, which occurs when part of the signal from the satellite reaches the receiver after being reflected by the ground, a building, or another object (van Sickle 1996), has largely been minimized by manufacturers incorporating 'multipath' into their equipment. Signal availability is another problem (Karsky et al. 2000), primarily because of the relatively limited number of satellites circling the earth and the positions of GPS receivers in relation to constantly changing orbits. Forest cover and topography also pose significant obstacles to satellite reception.

Liu and Brantigan (1996) compared the accuracy of GPS with values obtained with chain and compass. Their study demonstrated that differential GPS (DGPS) traverses were a cost-effective technique for measuring land areas. Both forest canopy and undulating terrain exerted a definite effect on traverse surveys completed by DGPS, with its accuracy being reduced as variations in canopy closure and topography increased. Nevertheless, their kinematic DGPS traverses proved more capable of achieving a closer forest stand-area approximation than that obtained from a traditional compass-and-chain traverse.

METHODS

Study Site

Our study was located in the Oregon coastal mountain range on the McDonald-Dunn College Forest, managed by Oregon State University (Fig. A.1). The site, a 55-year-old mixed stand, comprised primarily Douglas-fir (P*seudotsuga menziesii*), big leaf maple (*Acer macrophyllum*), and red alder (*Alnus rubrus*). The stand also had minor shrub vegetation consisting of vine maple (*Acer circinatum*), salal (*Gaultheria shallon*), and salmonberry (*Rubus spectabilis*). Slopes ranged from 0 to 76% (average of ~25%). Canopy closure was 60 to 95%, with an average stand density of 280 trees per acre. The average tree was ~97 ft tall, with a dbh of 17 in.; approximate volume per acre was 15 to 24 mbf.

Prescription

McDonald-Dunn was separated into three zones for management purposes (Fig A.2). The prescription for the southern zone called for uneven-aged strategies that could be achieved through a variety of treatments. The College Forest interdisciplinary team had been responsible for devising a harvest scheduling-optimization model to maintain adequate habitat for spotted owls (*Strix occidentalis*) while using thinning and patch cuts to aid in the development of a mid- to late-successional forest (Bettinger et al., in press). These patches covered 1, 2, or 4 ac, and were dispersed throughout the planning area (Fig. A.3).

Data Collection

Sixteen study patches (~1 ac each) from this 120-ac management parcel were selected based on stand descriptions, topographies, and their location relative to other patches (Fig. 1.1). Their boundaries were delineated in the field with surveyor's flagging and paper tags (Fig A.4). Measurement stations, established along the vertices of each patch, were flagged -- their locations measured by a digital total station. Measurement accuracies were reported to within 0.02 in. of the horizontal and vertical distances.

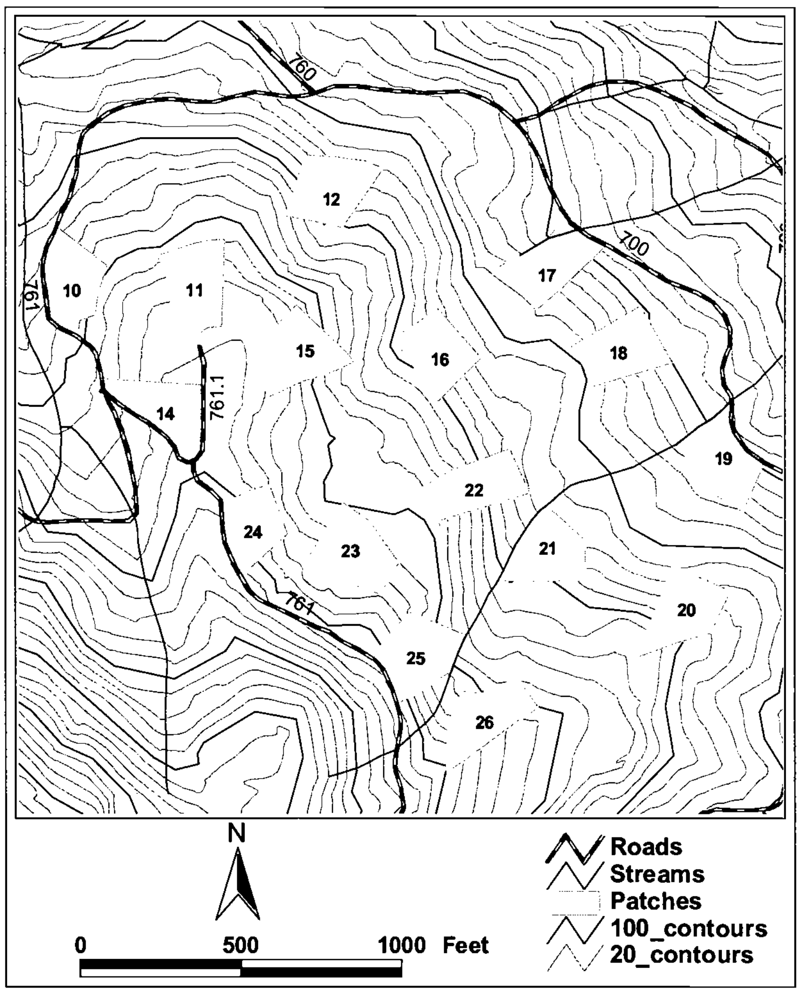

Figure 1.1 One-acre study units.

Three techniques for determining land area were compared against benchmark measurements. These included the use of: 1) a string box with a distance counter and a Suunto clinometer; 2) electronic distance- and electronic bearing-measurement devices; and 3) a global positioning system. To determine the relative efficiencies of each method, the time required to complete the operational layout and planning was separated into the three components of time spent surveying each patch, recording the data, and either downloading or entering the information into a database. Crew sizes depended on the surveying method being employed. All members had at least one year of experience with the survey equipment and were proficient in its operation.

The first method consisted of a single person measuring slope distance and slope percent, using a string box with a distance counter, a Suunto clinometer, and field notebook. Azimuths were determined with a Silva Ranger compass (Fig. 1.2). This one-person crew traveled from station to station, taking fore- and back-sights at each stop. These values were then recorded in a field book and manually entered into a database.

Figure 1.2 String box with counter, Suunto clinometer, and hand-held compass.

Office work for the first technique involved manually entering the data into a software program. RoadEng (Softree; Vancouver, BC), when used for each comparative method, differentially corrected each traverse by distributing the error equally between stations using the compass rule. This rule assumed that the measurements were not correlated and that all were of equal weight (Mikhail and Gracie 1981). The method of error distribution used here was adequate when all measurements were taken with the same amount of precision (Buckner 1983).

The second comparative method employed electronic distance- and electronic bearing-measurement devices manufactured by Laser Technology Incorporated (LTI; Fig. 1.3). The Impulse 200 EDM was linked with a Mapstar digital compass, which provided data on slope distance, slope percent, and horizontal angles. This system required a two-person crew, and the collected data were logged into a handheld digital data recorder. The lead traverser maneuvered between stations and held the reflective prism at eye level, directly above the pin flag. The rear traverser aimed the laser at the reflective prism and the distance, inclination, and azimuth were recorded in the data collector. The rear traverser then verified these resulting values before storing the point in the data collector's memory. Two data recorders, one operating on a Windows CE or DOS platform (Juniper Allegro), the other on a Windows CE platform (Tripod Data Systems Ranger), were used in tandem with the laser to determine the most efficient data recording technique. One advantage in using a DOS-based application was that the data could be directly downloaded into the mapping software.

Figure 1.3 Laser, digital compass, and TDS Ranger data collector.

The office work for the first digital method (i.e., Juniper Allegro data collector and Data Plus Software) consisted of downloading the information to a desktop computer via an ActiveSync program. Data Plus software allowed the user to structure the database to match the required input for the mapping program. The data were then imported into RoadEng, using the Terrain Module, and subsequently analyzed. Using the Allegro and the DOS-based program meant that a database could be constructed that enabled the user to download directly to the Terrain Module within RoadEng. Office work for the second digital method (TDS Ranger data collector plus Solo Field CE Software) involved a computer spreadsheet program that adjusted the coordinates to a format that RoadEng could recognize.

The third survey technique incorporated a Trimble Pro XR GPS (Fig. 1.4). Here, a one-person crew traversed the perimeter of the patches, simultaneously logging points and using the area function within the TSC1 data collector while moving between stations. This traverse was completed in a kinematic mode, so that no differentiation existed among the stations but, rather, the entire boundary was traversed as a single segment. Therefore, the GPS portion of this study did not include between-station measurements, and comparisons could be made only at the patch level.

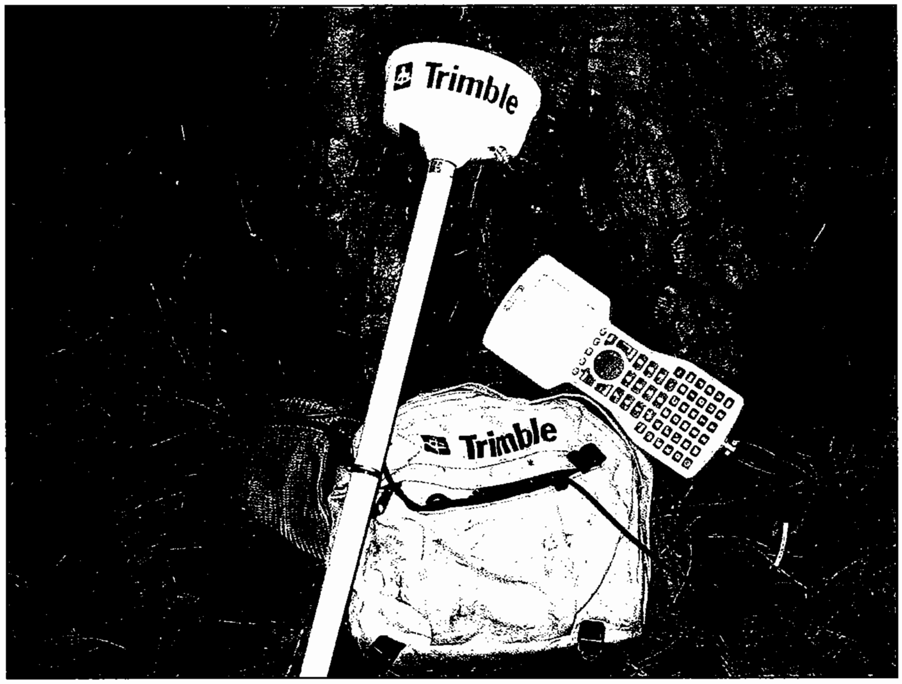

Figure 1.4. Trimble ProXR GPS with TSC1 data collector.

Office work for this third method consisted of downloading the data from the Trimble unit to a desktop computer. Trimble Pathfinder Office version 2.01 and base data provided by Pacific Survey in Medford, Oregon, were then used to differentially correct the data and determine the patch areas. These patches were exported as ESRI Shapefiles and imported into the Terrain Module within RoadEng.

The three previously described techniques were also compared with a benchmark method that could produce the most accurate forest-area measurements. Here, a Nikon DT-310 total station was used along with 2 prisms and a four-person crew (Fig. 1.5). One person utilized an offset method that minimized the number of instrument set-ups required to traverse the patch (Fig. 1.6) while collecting measurements at each station. The second and third crew members maneuvered prisms between the stations, while the fourth person used an axe and cleared sight-paths between the total station and the survey points.

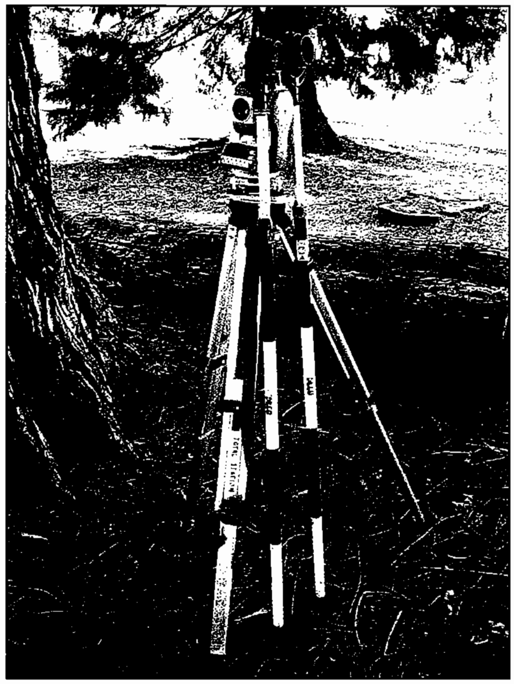

Figure 1.5 Nikon DT-310 digital total station with 2 Seco prisms and staffs.

Office work with this fourth method involved transforming the offset survey points to form the traverse surrounding each patch. Simple trigonometry and a spreadsheet program were used to determine the x, y, and z coordinates, which were then downloaded as an ASCII file into the RoadEng Terrain Module. Afterward, the data was transferred to the Survey/Map Module in order to calculate the areas.

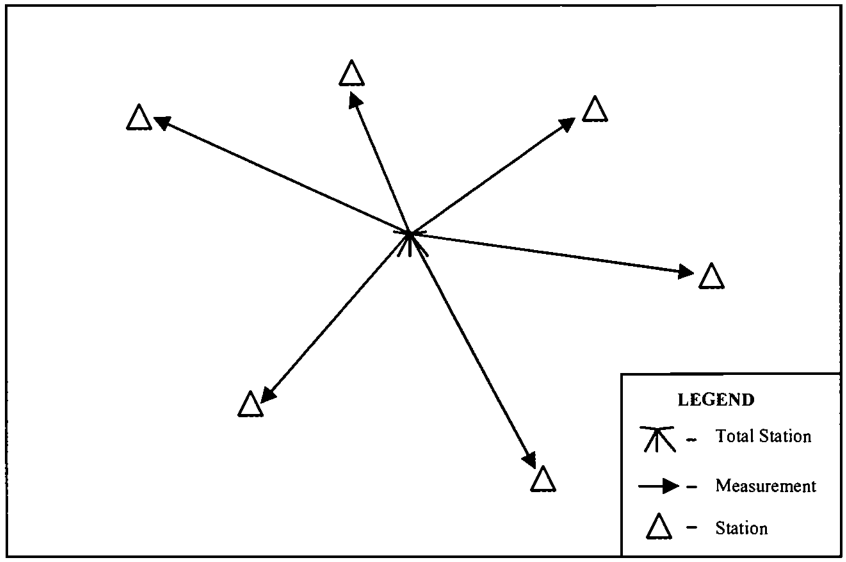

Figure 1.6 Offset method for traversing with a digital total station.

This study comprised three components: 1) gathering time and costing information to determine the relative efficiencies of each measuring technique; 2) comparing information on precision and accuracy to assess the repeatability of each method; and 3) analyzing the patch-orientation information to determine the effects of shifting the entire patch due to discrepancies in angular measurements. The relative effectiveness of each method was then calculated as the product of the total cost to survey each patch multiplied by overall patch precision.

RESULTS AND DISCUSSION

Time and Cost Information

The amount of time required to survey a patch and complete the office work varied substantially, depending on the technique (Fig. 1.7). The task was considered complete when all information was processed and entered into a mapping program. Of course, a number of subsequent steps would also be required to finalize the operational plan, but all those further steps would have been the same for each method.

To complete the traverse of the 16 patches, the method involving the laser, digital compass, and Juniper Allegro data collector required the least amount of time. The second most time-efficient technique was that using the laser, digital compass, and the TDS Ranger. The latter method required approximately two extra minutes per patch because of the additional step taken by the TDS Ranger to arrange the data in an acceptable format for the mapping program.

In contrast, implementing the string-box method consumed 19 minutes more per patch (or a 195% increase) compared with the laser/Juniper Allegro data collector. This difference resulted primarily because the traverser had to back-sight on the station and then record that information in the field book. A second contributing factor was the need to manually enter the field notes, whereas the laser method included a digital download. Likewise, the GPS method took 23 minutes longer (or a 210% increase) than did utilizing the Juniper Allegro data collector, mainly because of intermittent satellite reception due to topography, canopy closure, and satellite orbits. The GPS data also included those patches that were abandoned after one hour because of poor satellite configuration.

The average difference between the laser/Juniper Allegro method and use of the total station was 54 minutes, or a 370% longer interval. This extra time spent completing the surveys with the total station depended on the number of equipment set-ups that were required.

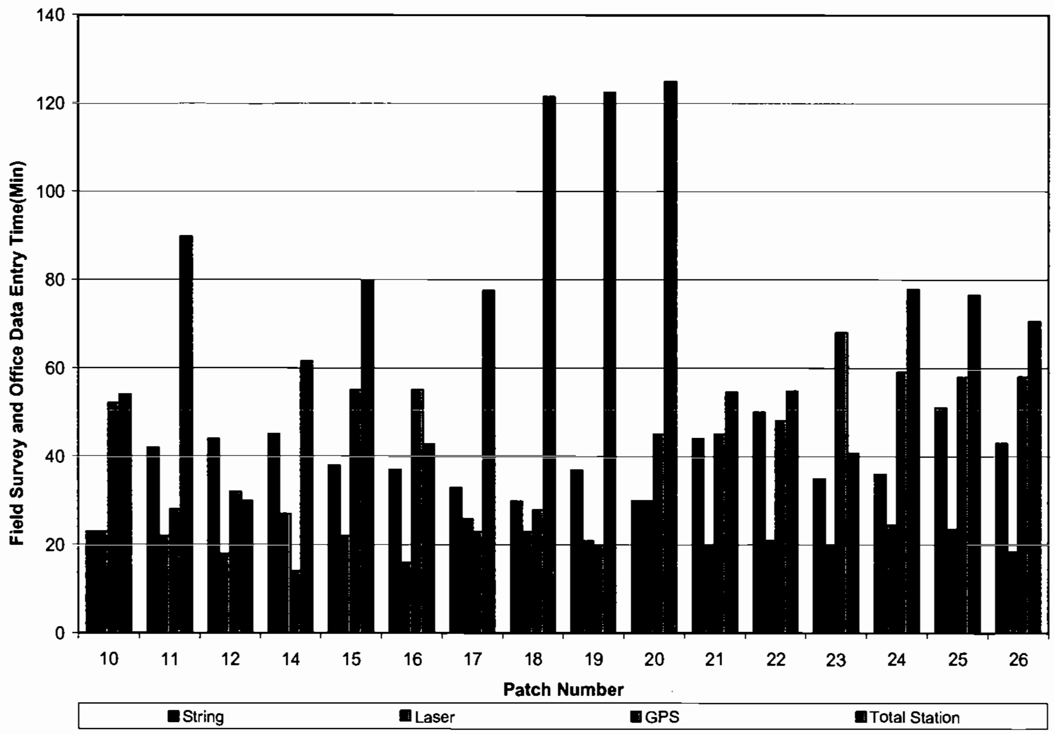

Figure 1.7 Time required to complete various forest-area measurement techniques.

The time, type of equipment, and crew size required to complete a traverse were used to calculate the variable cost of each survey method (Table 1.1). All equipment was depreciated over an approximately two-year period, with the actual time varying according to the particular operation and the equipment lifespan (Table A.1). Hourly wages, which included benefits such as health, retirement, and disability insurance, were obtained from the 2001 Associated Oregon Loggers Annual Wage Survey (Salem, OR, USA).

Table 1.1 Costs involved in completing land-area survey of 16 forested patches.

Method	Crew size	Labor cost ($/hr)	Equipment cost ($/hr)	Total time (hr)	Total cost ($)	Cost per acre ($)	Cost per mbf ($)
String Box	1	18.90	0.05	10.3	195.19	11.67	0.62
Laser (Ranger)	2	37.80	1.18	5.9	229.98	13.22	0.70
Laser (Allegro)	2	37.80	1.31	5.3	207.28	11.92	0.63
GPS	1	18.90	1.88	11.5	238.97	38.86	1.85
Total Station	4	75.60	1.13	19.7	1511.58	86.52	4.59

Overall, the least expensive methods were those with small hourly labor and initial equipment costs. The difference between the two digital-data methods could be attributed to the additional office time the TDS Ranger required for formatting the field data. Per-acre costs were determined according to hourly equipment and labor rates, the time needed to complete the forest-patch measurements, as well as the total area under treatment. Total costs on the basis of timber volume were calculated using the hourly equipment and labor rates, time to complete the measurements, stand inventory data, and total treated area.

Precision and Accuracy

Precision is the degree of closeness or conformity among repeated measurements of the same quantity (Mikhail and Gracie 1981). The average patch precision gained from each of our methods is shown in Table 1.2.

Table 1.2 Precision of measurements for patch areas, by survey method.

Method	Mean patch area (ac)	Mean difference in patch area (ac)	Percent Difference (%)	Average patch precision (%)
String Box	1.03	-0.04	3.7	1.15
Laser	1.06	-0.01	0.93	2.65
GPS	1.03	-0.04	3.7	N/A
Total Station	1.07	0	0	0.014

The average area was calculated by summing each patch area and dividing by the number of patches (16). This value was then used to determine the difference in area between the total-station method and each of the other three methods. The average area derived by the total-station technique was 0.04 acres larger than when the string box was used. Although this was a fairly small land area (1742 ft^2), one may assume a multiplicative effect, so that the average error between methods would accumulate as the traversed area increased. Therefore, this affect could dramatically impact area calculations, timber volume estimates, and other operational considerations.

Average precision varied substantially for each method. Because the survey of each patch started and ended at the same point, the precision or repeatability could be calculated from the difference in coordinates. This difference was then divided by the total perimeter distance for each patch, resulting in a percent error term that was averaged for the16 traversed patches. The laser and compass method produced the least amount of precision because the instrument was not mounted on a staff. Although the manufacturer's accuracies had been achieved in trials with the equipment mounted, this positioning was found to limit the user's mobility in the forested environment. The other method, involving the string box, resulted in an average precision of 1.15%, which was considered adequate for the relatively minimal precision of that particular equipment.

In contrast to precision, accuracy is defined as the degree of conformity or closeness of a measurement to the true value (Buckner 1983). Our survey methods were analyzed for significant differences at the station level (Table 1.3). Average accuracy was calculated from the difference in measurements between the total station and each of the two laser methods. GPS data were not included here because no between-station measurements had been recorded.

The variation in measurements between the string box and the total station can be attributed to several factors. For example, use of the string box was affected by the amount of brush and branches between stations. The string may have gotten caught on the branches, preventing the traverser from following a straight path to the next station. Likewise, the string may have become taut when maneuvering around obstacles, thereby contributing to the error.

Table 1.3 Average distance errors produced by each survey method.

Method	Average slope distance error (ft)	Average horizontal distance error (ft)	Average vertical distance error (ft)
String Box	3.02	2.78	2.82
Laser	1.33	1.14	1.81
GPS	N/A	N/A	N/A
Total Station	0	0	0

Differences in values between the total-station and the laser methods were primarily brought about by the operator. Here, the measurement point of both the laser and the target had to be positioned above the station, introducing an error term if the instruments were not held directly vertical over the target for each measurement. A common problem involved the laser operator needing to bend and shift away from the station in order to gain a clear sight path toward the target.

To compare the accuracies for each method, a multiple range test was used to confirm that all data points were from the same population. Very significant differences within both the laser and the string-box methods prompted us to remove three data points because they had been included within patches that overlapped the road. Because vehicular traffic compromised some markers, those stations could not be exactly replicated and had to be estimated. In addition, t-tests were conducted at the patch level to determine if the differences in accuracy between methods were significant. Values from both the laser and the string-box methods were significantly different ($p<0.05$) from those obtained with the total-station technique. Likewise, the t-test used to compare the string box and laser data also indicated a significant difference between these two methods ($p<0.05$).

A statistical model, using regression on the differences in horizontal distance among survey methods, was developed for estimating the true distance (total station) based on measurements derived by the other methods. The final model (Eq. 1.1) contained a binary variable for the survey method used (i.e., string box or laser) and the measured horizontal distance (HD):

$$DIFF\_HD = 0.227644 + 1.65878*Method + 0.116137*HD \qquad [1.1]$$

The results showed that the slope variable was not significant, and that the statistical model explained approximately 20% of the variation in the data (Adjusted R-Square = 0.196).

Orientation

Although all traverses closed with adequate precision and approximately equal areas, regardless of the survey technique employed, each orientation varied substantially (Fig. 1.8). Therefore, this effect on alignment might have major consequences for a number of tasks completed during operational planning and layout. For example, such errors could be costly to both parties when working with legal boundaries between property owners. This difference, found in several patches, was most evident when the digital-compass method was implemented because the position at which the user held the equipment influenced the reading. Although very good closing precision could be attained, large deviations from patch alignment also occurred. This effect could have been minimized by mounting the laser and digital compass on a staff.

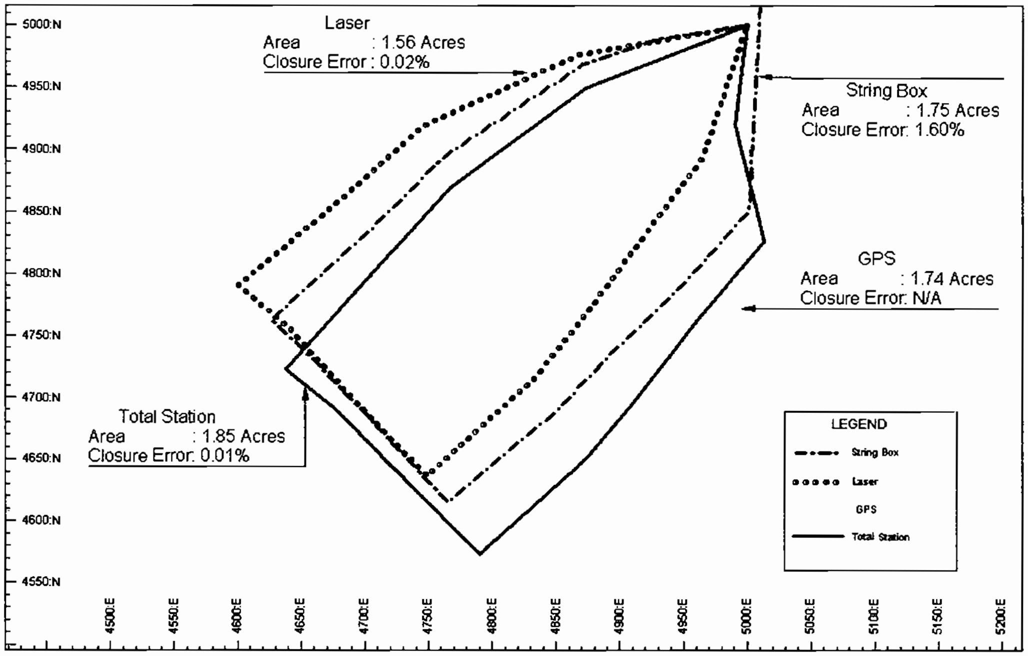

Figure 1.8 Differences in patch orientation generated by survey methods.

Effectiveness

It is difficult to account for practicality when comparing survey techniques. Liu (1995) assessed individual methods that used different equipment by multiplying the time needed to complete a task by the resulting accuracy, thereby basing effectiveness on time instead of cost. Because our study involved more than one method, a total-cost variable had to be calculated. Effectiveness for each method (Table A.2) was calculated by multiplying the total cost to traverse each patch by the closing error (Eq. 1.2). The resulting value was then divided by the total number of patches (16) to determine an overall average (Table 1.4). Here, the smaller the value, the more effective the surveying method.

$$M.E. = \frac{((\text{Total Cost})(\frac{\text{Closing Error \%}}{\text{Closing Error Total Station \%}}))}{n} \qquad [1.2]$$

Table 1.4 Average mean effectiveness values for each survey method.

Method	Total Cost ($)	Closing Error (%)	N	Mean Effectiveness (M.E.)
String Box	195.19	1.15	16	1236
Laser (Ranger)	229.98	2.65	16	3247
Laser (Allegro)	207.28	2.65	16	2902
Total Station	1511.58	0	16	94

The total-station technique produced the lowest effectiveness, being the most time-consuming and expensive of all the methods, although it had a significantly smaller closure error and lower total costs. The large difference between the laser method and the string-box technique was a result of the higher accuracy and initial costs associated with the former. Effectiveness with the GPS method was not included because no level of accuracy had been calculated.

SUMMARY AND FUTURE DIRECTIONS

Different methods for measuring forest areas may be used to meet specific land-management objectives. This study compared four techniques for completing a traverse of partial harvests within an uneven-aged management plan. The method entailing the string box, manual compass, and clinometer was approximately 6% less expensive than the laser method. However, although the initial purchase price and labor rates with the string-box technique were lower, 48% more time was spent conducting the traverse of all the patches. The total-station technique was the most expensive because of the larger crew and time required to clear the sight lines.

The effectiveness of each survey method also varied substantially. Low values were the result of a combination of small costs and/or high accuracies. The total-station method had a very low effectiveness value (94) because of the high amount of precision gained with its use. Although it was the most expensive to operate, its resulting precision was magnitudes higher than that gained by the other methods.

Relative to their specific measurement activities, each method has its strengths (time, cost, and accuracy) and weaknesses (alignment, repeatability, and cost). Therefore, the potential benefits must be weighed when allocating resources to specific duties for operational planning. Within the forest industry, the decision-making process might combine surveying tools and methods to achieve particular results. For example, the traverse of a unit boundary might be completed with a laser and manual compass, whereas a GPS system could be used in static mode to determine the coordinates of specific points on the boundary. Those coordinates would be differentially corrected and entered into RoadEng. The resulting map, now spatially located, could then be geo-referenced in a fraction of the time needed for completing the entire traverse with the GPS. Future research may focus on how many GPS points are adequate for spatially locating patches when survey methods are combined. Other studies in an operational setting might also evaluate the accuracy of the large number of inexpensive distance-measuring devices recently introduced for completing a number of tasks during layout and planning.

Further advances have been made with digital compasses since this study was completed. For example, Laser Technology Incorporated is currently testing a prototype compass that works, not on the same fluxgate compass as the Mapstar, but as a magneto resistive sensor (William Carr, pers. comm., LTI, February 21, 2003). Initial trials have demonstrated improved repeatability during both forest surveys and calibration.

Because a large number of options for digital data collectors are being marketed, one must also ensure that the available data-collection software is compatible with the mapping software. In the study presented here, several additional steps were necessary because the TDS Ranger and Solo Field CE were not compatibility with RoadEng. Nevertheless, this challenge can be corrected by using a DOS-based machine and software programs such as DataPlus Professional 2002 or LaserSoft 2003.

In conclusion, this study illustrated that, although time was saved by using the digital instruments, their performances were not always as effective as those achieved via traditional methods. Therefore, the selection of measurement techniques should be based on project objectives and requirements.

Chapter 3

COMPARING STRATEGIES FOR SKYLINE CORRIDOR LAYOUT

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ABSTRACT

In the steep terrain of the Pacific Northwest, thinning has been widely used as an effective management tool for young Douglas-fir stands (McNeel and Dodd 1996). There, skyline systems and pre-designated corridors typically are utilized for timber removal. The corridors are marked and profiled prior to harvesting to determine any potentially limiting factors for an operation's productivity. Historically, those profiles have been completed using a one-person crew, string box, hand-held compass, and clinometer. However, recent developments in electronic distance-measuring (EDM) devices have prompted land managers to investigate whether the improved accuracy and efficiency of those instruments can reduce operational planning costs and increase limiting payloads.

This study compared two techniques for collecting profile data, as well as assessing the associated costs and design payloads for 20 corridors on the Siuslaw National Forest in western Oregon. The first technique used measurements made with a traditional string box, clinometer, and hand-held compass; the second employed an EDM device, digital compass, and digital data recorder. These two survey methods were then statistically compared with the results obtained from benchmark data collected by a total station. In additional, a time study was conducted to determine the overall efficiencies of each technique. The results from this project may assist harvesting contractors in making informed decisions on the use of alternative surveying tools for collecting spatial data.

INTRODUCTION

In the Pacific Northwest, many governmental forestland managers are attempting to mimic mid-to late-successional forests by structuring younger, second-growth forests on steep slopes (Thompson et al. 2002). To expedite this process, commercial thinning is being widely applied to increase tree spacings and open the forest canopy (McNeel and Dodd 1996). Private land managers are also implementing this strategy to gain periodic returns on their investments (Curtis and Marshall 1993). Because a large amount of the timber removed from these stands is of marginal value, all aspects of the harvesting must be efficient (Kellogg et al. 1996b). Therefore, more accurate spatial data-collecting devices are being investigated for their potential in improving operational planning and layout.

Layout and profiling of harvesting corridors for thinning operations varies substantially from the preparations made for clearcutting (Kellogg et al. 1996b). The planning of skyline-thinning operations is usually more expensive because of the added requirement for marking and profiling the corridors. This is in addition to the costs incurred for laying out and surveying the harvest unit boundary. Many of these planning steps add to the time and expense for the harvesting contractor, and directly affect the profitability of the operation.

Several studies have focused on the potential benefits of electronic devices for operational layout and planning. In evaluating the use of an EDM device and electronic compass for low-volume forest road surveys, Moll (1992) concluded that, although the device was approximately 60% more time-efficient than the compass-and chain-technique, the azimuth measurements were inadequate. This problem was attributed to the angle, both horizontal and vertical, at which the compass was held and the resulting magnetic field. Since the time of that study, a number of revisions have been made to digital compasses to minimize the effect of magnetic fields (Joe Cronn, pers. comm., LTI, February 21, 2003).

Liu (1995) documented the use of a Criterion 400 to complete field surveys similar to those conducted by forest management practitioners. There, cost effectiveness was measured as the product of closure precision and time spent. Because the EDM was easy to use, accurate, and ten times more cost effective than the traditional analogue equipment, it was recommended that this laser device be adopted for forest stand traverse surveys.

Wing and Kellogg (2001) also assessed the use of a laser range finder and digital compass for traversing skyline corridors and harvest boundaries. In several pilot studies, these instruments required less time and provided greater accuracy than conventional methods, apparently because of the rangefinder's rapid capture ability. However, measurements with this highly precise technology were more difficult to obtain in thick understory brush. Turcotte (1999) measured woodpile volumes in the millyards of eastern Canada with a laser rangefinder, digital compass, and data collector. The process of data collection, which normally required three worker days, could now be completed in less than two hours, further illustrating the potential for such sophisticated equipment in an operational setting.

Edwards (1993) compared logging planning, felling, and yarding for five alternative skyline group-selection harvests. There, preparation time and costs were significantly lower for clear-cut prescriptions than for any of the selection treatments.

This difference, which was correlated with an increase in flagging and traversing of skyline thinning corridors required by the latter treatments, could have been decreased if more efficient methods of traversing had been followed.

Dunham (2001a) demonstrated that operational planning and layout costs were three to four times lower in clear-cut regions than in group-selection areas. This gap was attributed to an increase in the time spent for patch layout and traversing between prescriptions. Kellogg et al. (1998) compared the costs incurred by Forest Service employees versus contractors for four thinning treatments. Values ranged from $0.92/mbf to $14.48/mbf, and were a function of site conditions, the particular silvicultural and harvesting system employed, the size of the unit, crew experience, and travel time required. The use of precision forestry tools may have reduced the effect of such variables compared with conventional methods.

Little research has been done to assess the potential benefits, e.g., precision, accuracy, and cost, of using electronic techniques for corridor layout and profiling. Therefore, the objective of this study was to compare the associated costs and calculated payloads for three survey methods: 1) a string box, hand-held compass, and clinometer; 2) a laser, digital compass, and digital data collector; and 3) a benchmark system that used a total station for data collection.

Computer Analysis

Numerous computer analysis programs can aid forestland managers in making harvest planning and layout decisions. For example, LoggerPC4 (2003) assesses the feasibility of cable-harvesting operations. This program, developed by the United

States Forest Service and Oregon State University, bases its calculations on a specified profile, yarder, and carriage. The output provides the user with information on limiting payloads, line tensions, deflection, potential locations of required intermediate supports and tail trees, blind leads, and skyline clearance. Calculations completed by the program are based on a "critical point" (Fig. 2.1), i.e., the topographic point or horizontal and vertical positioning at which the harvesting system can extract the least amount of weight (payload) while meeting all other constraints. A catenary method is used to determine the allowable weight (payload) for each terrain point. This equation is based on line segment configuration, anchor geometry, length, and weight per unit length (Carson 1977). Weights are then reported for each terrain point along with line tensions, skyline clearance, log clearance, and line-length requirements.

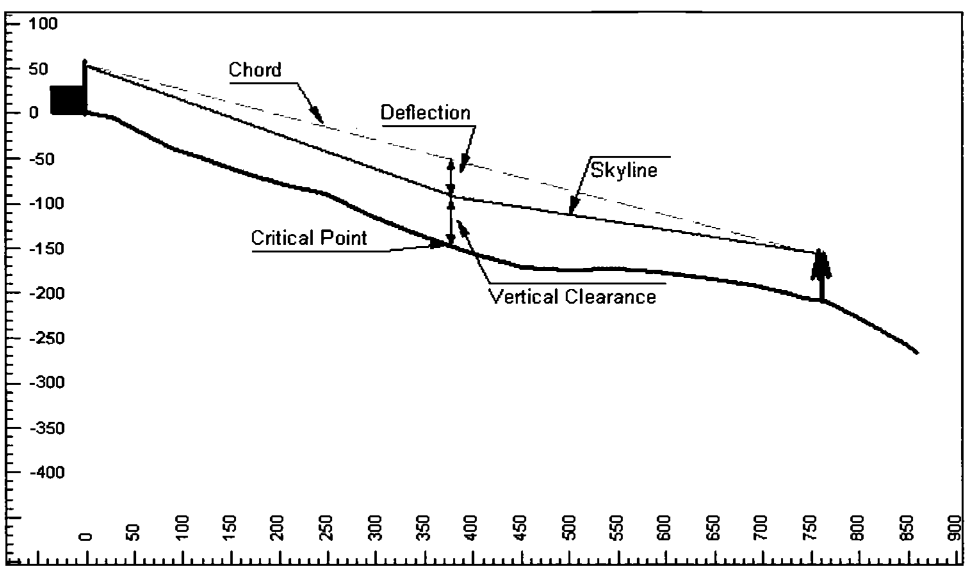

Figure 2.1 Information used by LoggerPC4 to determine limiting payload.

During multi-span analysis, two additional constraints – the force of the jack and the jack passage angles -- must be examined to determine operational feasibility. LoggerPC4 calculates the force on the jack to ensure that the skyline has sufficient downward pressure to prevent it from lifting out of the jack. The orientation recommended for this resultant force allows planners to better choose the position of the guy-line trees to offset that force. This angle is labeled as β within Fig. 2.2. These forces are calculated when the carriage is located at each terrain point; all must be positive for the corridor to be feasible.

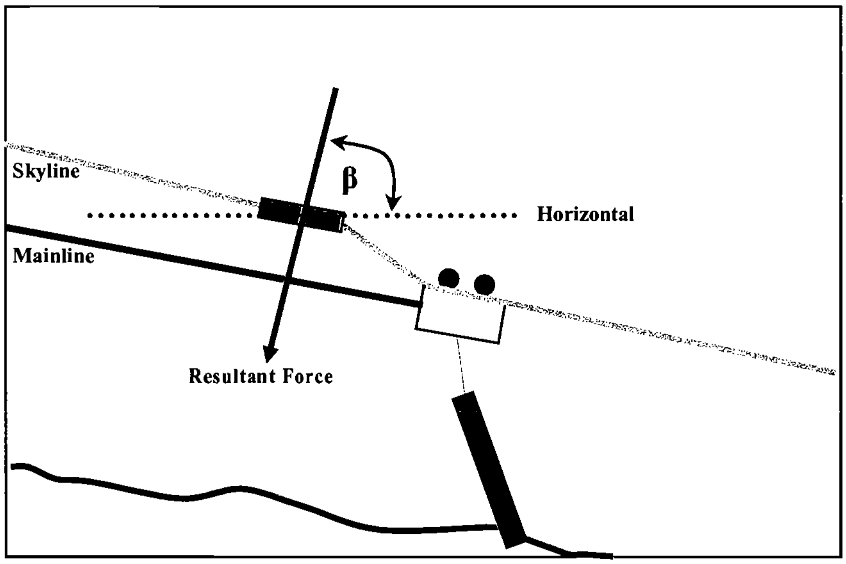

Figure 2.2 Resultant force and angle acting on intermediate support jack.

The second constraint is the jack passage angle (designated as α), which is the angle between the skyline and the mainline when the carriage is three feet away from the jack (Fig. 2.3). This distance is used for analysis because it is a reasonable, minimum position from which to predict future carriage movements. The jack passage angle is also affected by carriage speed, changes in slope along the skyline span, and skyline tension. It serves as a reasonable indicator of safe skyline carriage passage at the jack. The maximum angle for which the carriage is able to successfully pass the jack is approximately 45°.

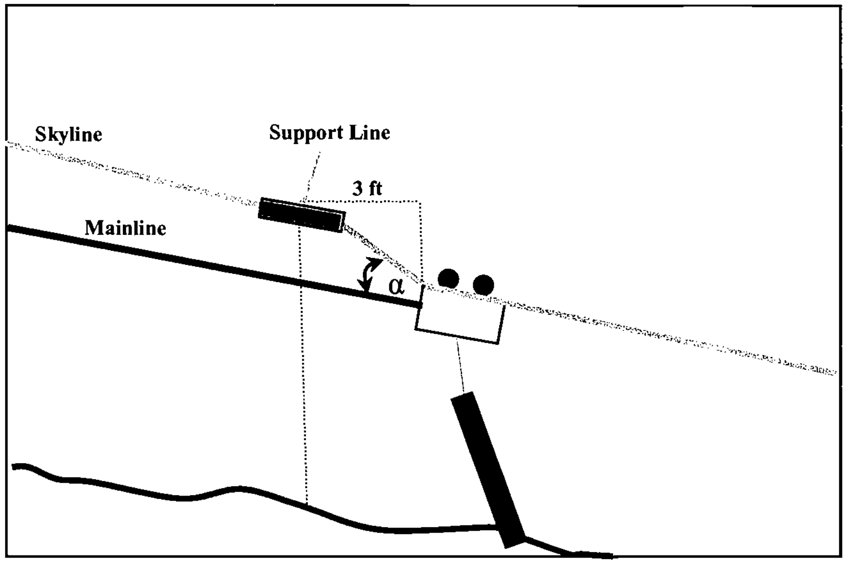

Figure 2.3 Jack passage angle and measurement of vertical distance.

METHODS

Study Site

The study tract was located in the Oregon coastal mountain range on the Siuslaw National Forest (Fig. B.2). The site was a 35-year-old mixed stand, comprising primarily Douglas-fir (*Pseudotsuga menziesii)*, bigleaf maple (*Acer macrophyllum*), and red alder (*Alnus rubrus*). Minor shrub vegetation included vine maple (*Acer circinatum*), salal (*Gaultheria shallon*), and salmonberry (*Rubus spectabilis*). The slope percent within the unit ranged from 0% to 96% (average ~45%). Prior to harvesting, the approximate volume was 25 mbf/ac, with 230 trees per ac (TPA), and an average diameter of approximately 18 in.

Silvicultural Prescription

This tract is managed by the United States Forest Service out of Florence, Oregon. The 55-ac parcel was thinned from below to 85 TPA, with an average spacing of 23 ft. Trees to remain, as chosen by the timber cutters, were to be the largest and most vigorous candidates. The harvesting contract stated that all corridors, intermediate supports, tail trees, and tail holds had to be identified and approved prior to cutting (Fig. 2.4). All corridors and leave-tree placements were then verified by the Timber Sale Administrator. The equipment used in this harvest study included a 50-ft Linkbelt Crane and a motorized slackpulling Eagle Eaglet carriage (Fig. B.1). The yarder consisted of a 50-ft tower equipped with extra improved plough steel lines and a 1200-lb multi-span-capable carriage.

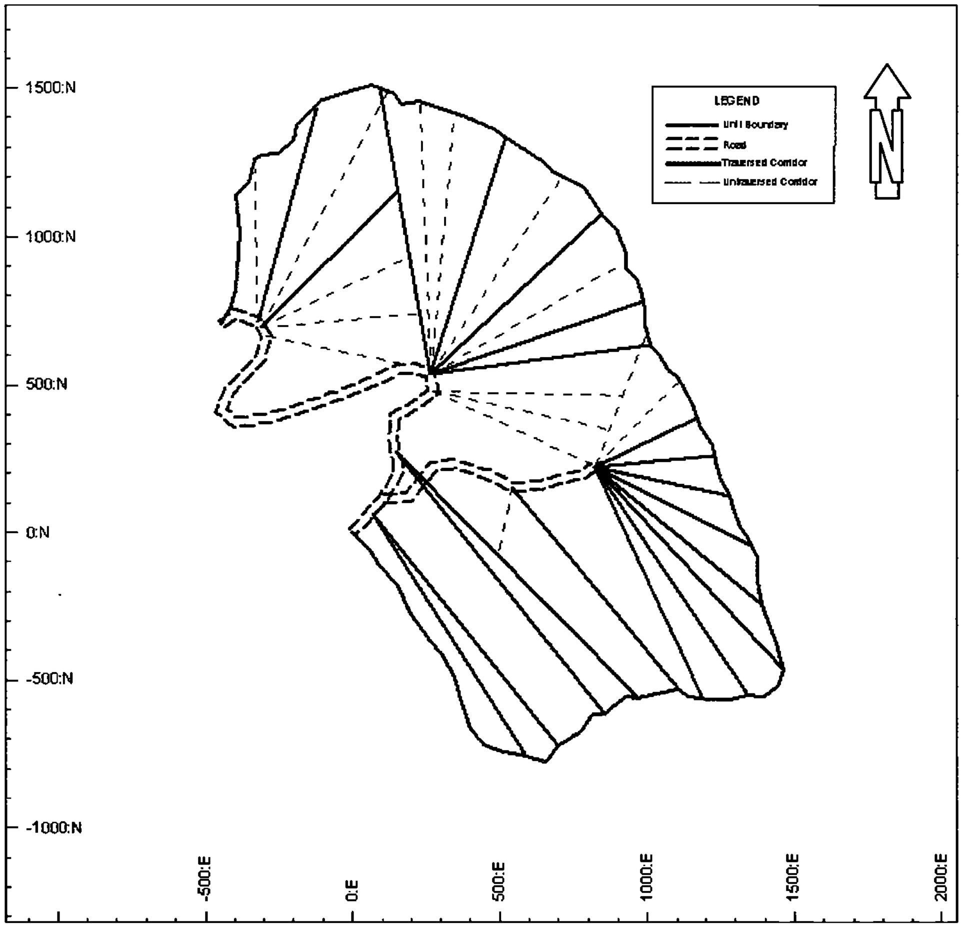

Figure 2.4 Harvest unit with access roads, unit boundaries, and skyline corridors.

Data Collection

Data were gathered on 20 skyline corridors, using two survey methods, and were entered into LoggerPC4, the skyline payload-analysis program. Each corridor was measured consecutively by the two techniques. Information was also collected on the amount of time required to flag corridors, travel to and from the site, traverse profiles, and complete the office work.

The first method involved one person traversing the profile, working away from the landing and toward the tail hold. Slope distance and vertical angles were measured with a string box and clinometer; azimuths, with a hand-held compass (Fig. 2.5). As the traverser reached a break in the topography (usually greater than a 5 to 10% change in slope), a station was recorded and marked with orange paint, at eye level, on a nearby tree. These marks served for back-sighting to measure the vertical angle. A ribbon line was used to orient the horizontal angle. When the profile was completed, the traverser walked up the same corridor and ribboned and painted the corridor's centerline.

Figure 2.5 String box with counter, Suunto clinometer, and hand-held compass.

The second method utilized a two-person crew to gather profile information along the traverse. The lead traverser ribboned the station as the rear traverser completed field notes. An Impulse 200 laser and Mapstar digital compass were used to gather horizontal and vertical distances, as well as horizontal angles (Fig. 2.6). These data were then downloaded to a digital data collector. Because the range of azimuths was not deemed adequate, only five corridors could be measured digitally; the rest were completed with a hand-held compass. The lead traverser back-sighted on the line and determined the location of the station to be marked, while the rear traverser recorded the profile information.

Figure 2.6 Laser, digital compass, and TDS Ranger data collector.

After harvesting was completed, a final survey of each corridor was conducted. For this benchmark, total-station method, a two-person crew used a Nikon DT-310 total station and Seco prism to gather horizontal and vertical distances (Fig. 2.7). The station was set up in the middle of the harvesting corridor, and the prism holder moved from the landing to the tail hold. Because the objective was to develop a benchmark or true ground profile with this technique, more stations were included than with the other two methods.

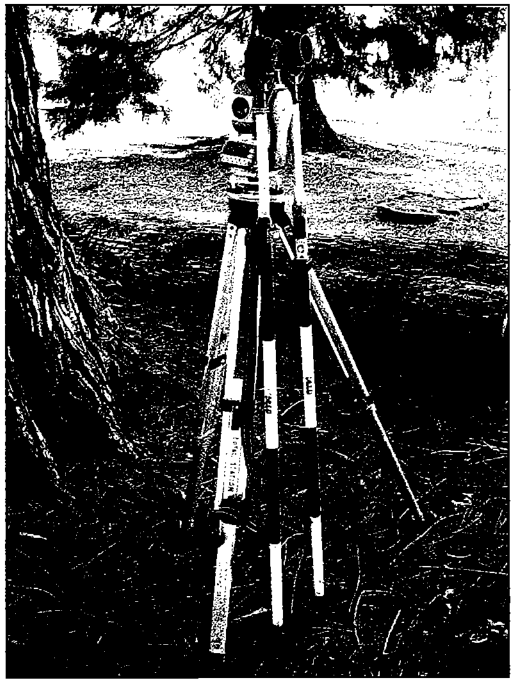

Figure 2.7 Nikon DT-310 total station with two Seco prisms and staffs.

Profile data were entered and examined using three harvesting configurations within Logger PC: 1) a standing skyline-harvesting system with tail stump (Fig. B.3.A): 2) a standing skyline and a lift tree near the boundary to increase deflection (Fig. B.3.B); and 3) a system requiring a multi-span configuration with a lift tree (Fig. B.3.C). The same harvesting configuration was followed for each survey method within a particular corridor.

RESULTS AND DISCUSSION

Time Study

A total of 392 hours accrued during the completion of the corridor layout, profiling, and mapping. In all, layout and traversing consumed 64% of the entire study period (Fig. 2.8), with values based on the times required to complete corridor profiling and ribboning using the string box, clinometer, and hand-held compass.

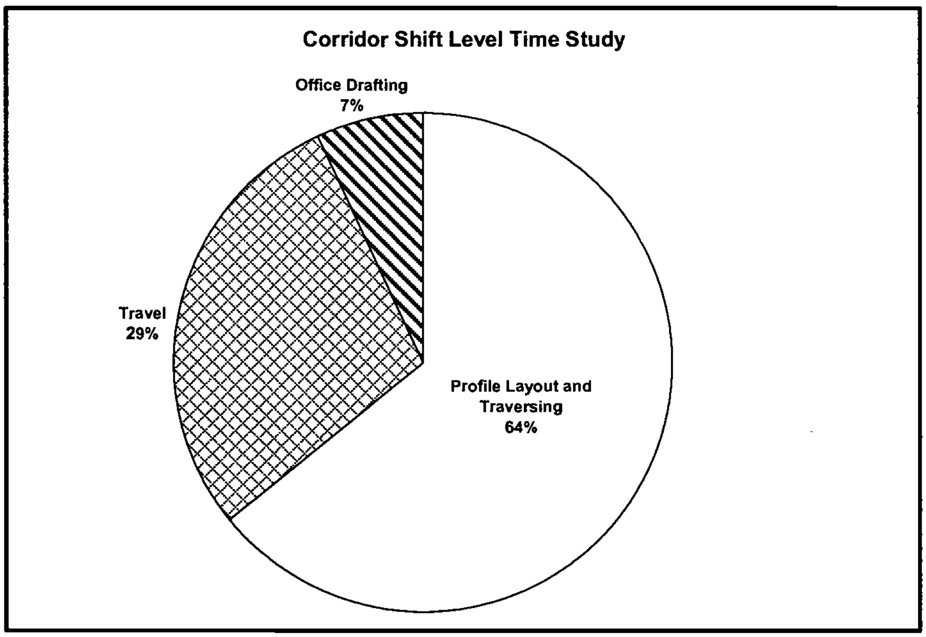

Figure 2.8 Shift-level time study of corridor layout.

The time spent in completing the same surveys differed significantly between the string-box and laser methods (Fig. 2.9), probably because of a number of anomalies within the data-collection process. For example, of the 20 corridors studied with the laser method, only five (2, 23B, 26, 31, and 33) were profiled with the digital compass because more time was needed to keep the lead traverser on bearing.

Multiple shots had to be taken and necessary adjustments were made to maintain the angle, a process that differed from the manual-compass technique, in which the traverser could back-sight on the ribbon line without numerous shots. In addition, the use of the digital data collector meant that measurements had to be downloaded to a database and reformatted to x, y, and z coordinates for analysis by LoggerPC4. The direction in which the corridor was traversed may also have contributed to these discrepancies. Two of the laser corridors that were traversed from the tail hold to the landing had >60% slopes, so that walking uphill increased the time spent on the survey.

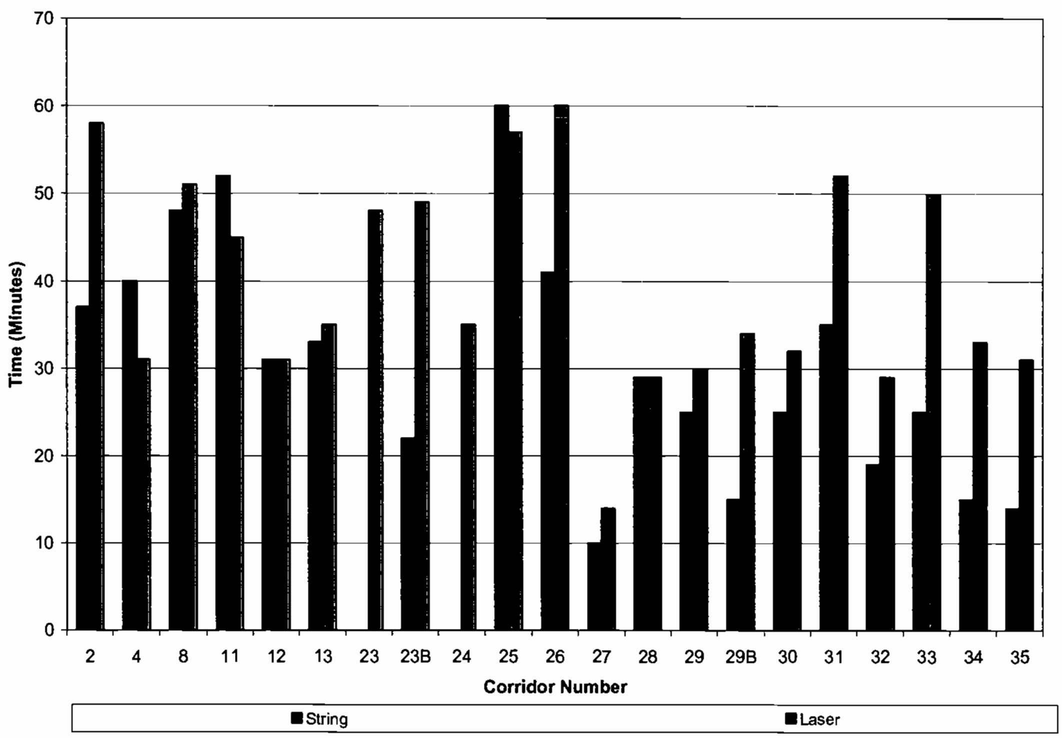

Figure 2.9 Time-study comparison of corridor measurement techniques.

Costing Information

Costs (Table 2.1) were calculated based on the hours required to complete each task and the initial purchase price of the survey equipment (depreciated over two years). This rate of depreciation varied according to the operation, with two years serving as an estimate for turnover of the technology. Information on hourly wages, including benefits, was obtained from the 2001 Associated Oregon Loggers Annual Wage Survey (Salem, OR, USA).

Table 2.1 Costs incurred per survey method for layout, traversing, and associated office work.

Method	Crew size	Labor cost ($/hr)	Equipment cost ($/hr)	Total time (hr)	Total cost ($)	Cost per mbf
String Box	1	18.90	0.05	10.8	192.95	0.35
Laser*	2	37.80	0.51 or 1.18	13.5	557.95	1.00

***Equipment costs are for either the digital compass plus data collector or for the laser plus hand-held compass.**

The volume harvested from the unit, ~558.7 mbf, was used to calculate the total cost for 19 corridors. However, the final costs were higher because a number of corridors were not included in the calculation. Likewise, costing did not include corridors that were not traversed by all three methods because no comparable base was available. The laser method proved to be almost three times more expensive than the string-box technique. Costs associated with the former combined the values obtained for corridors measured by manual compass ($0.51/hr) and those using the digital compass and digital data collector ($1.18/hour). The two-person crew needed for the laser survey doubled the labor costs, which were directly related to the slope percent and corridor length as well as the amount of underbrush to be traversed.

Payload Determinations

Payloads were calculated for both methods along each corridor (Table B.1). Although seven corridors were not surveyed with all three techniques, they remained within the data set for comparative purposes (Fig. 2.10). An example of this is Corridor 29B, which was not traversed with the total-station but was used to compare the laser and string-box methods.

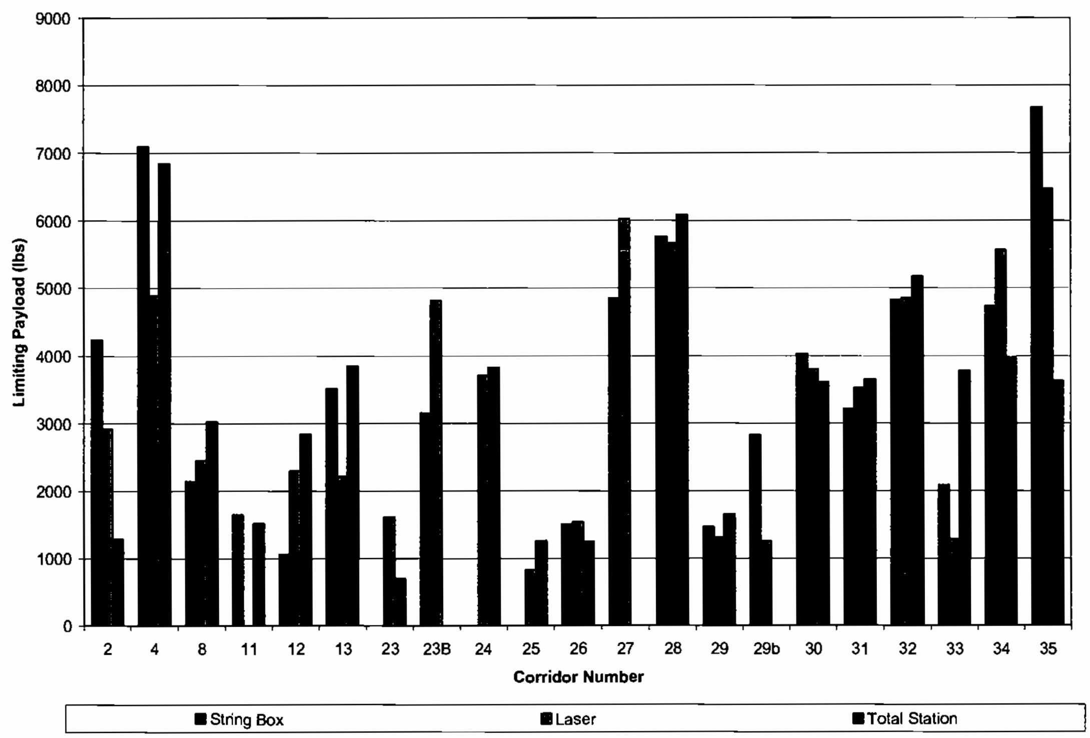

Figure 2.10 Limiting payloads (lbs) per corridor and method.

Payloads differed greatly among a number of corridors for three reasons. First, the critical point of the profile may have been altered because of the accuracy of the survey technique. For example, the critical point for Corridor 29 was located approximately 400 ft from the landing (Fig. 2.11). Although each method located the tail tree at approximately the same location, a difference in payload of over 10% resulted from small changes in the elevation of the corridor.

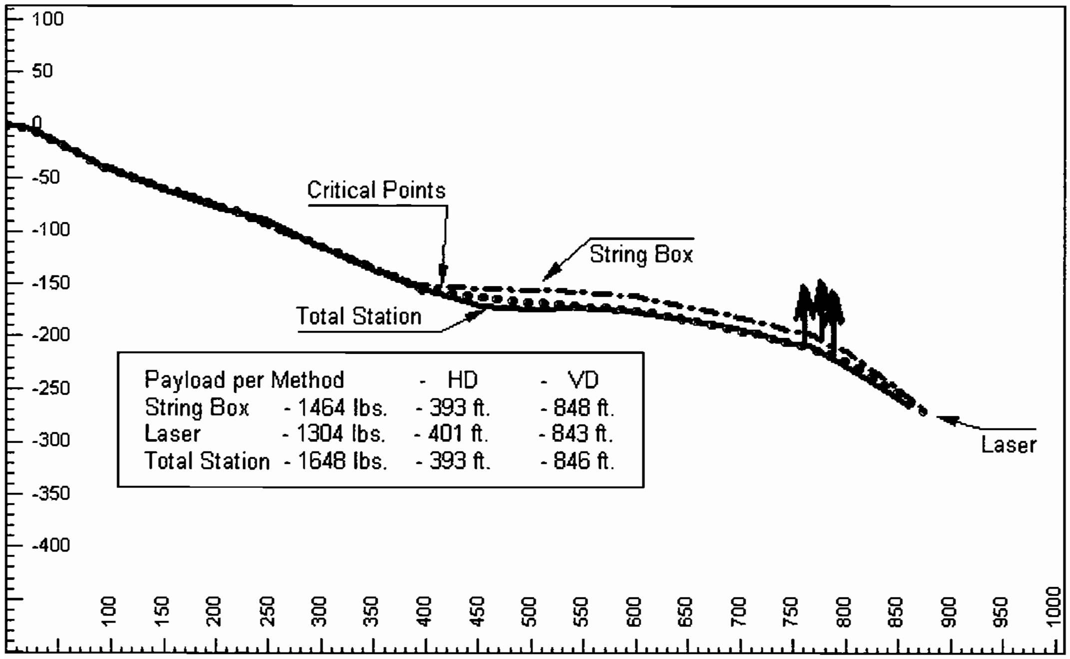

Figure 2.11 Movement in the critical point due to differences in elevational measurements among survey methods.

The second reason for the difference in calculated payload may have been the apparent change in elevation or horizontal distance of a lift or tail tree from the landing (Fig. 2.12). Therefore, the magnitude of this effect was partly a function of the total difference in distance among methods. Another factor contributing to the large variation in elevations generated by the laser was the fact that the survey was conducted from tail hold to landing. This made it more difficult to stand upright and hold the target at eye level. If the target was held away from the body, however, the corridor appeared steeper than it actually was.

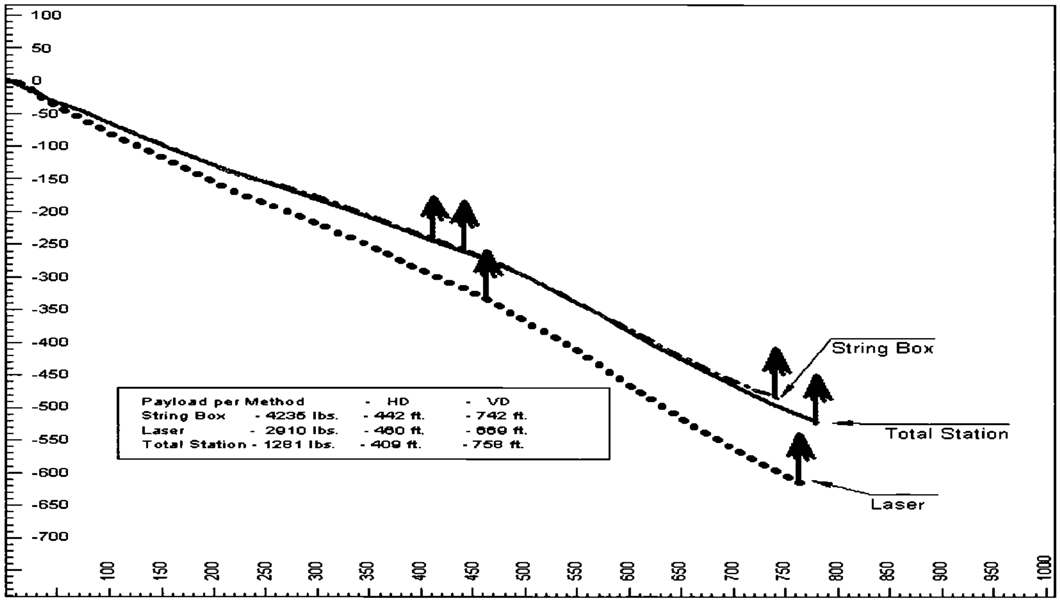

Figure 2.12 Movement in the critical point due to differences in the surveyed elevations of the intermediate support.

Finally, the third factor affecting payload calculations was how the individual survey methods recorded elevation or horizontal distance of the tail hold and intermediate support tree (Fig. 2.13). This difference was observed for five of the corridors.

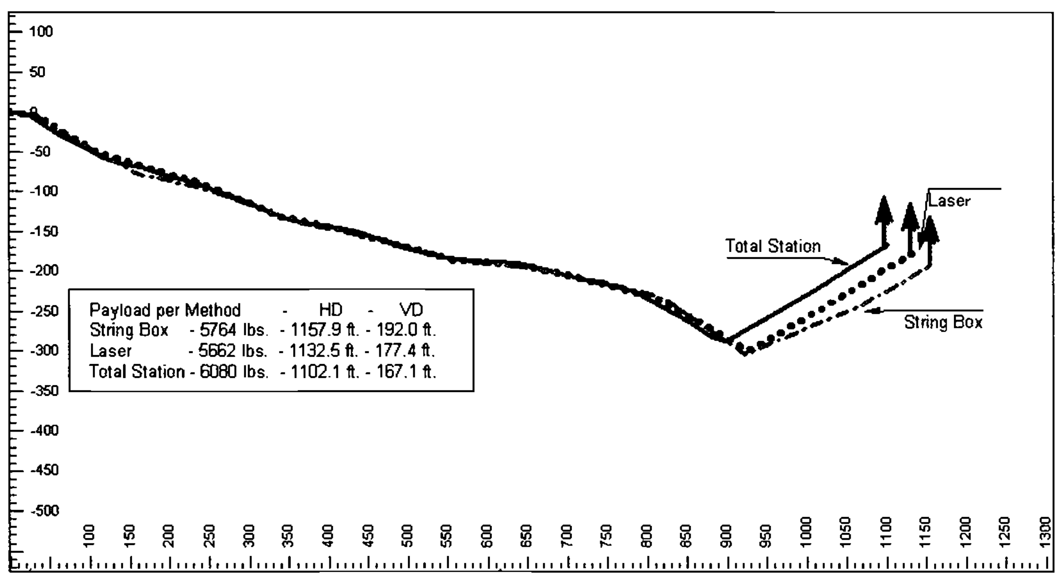

Figure 2.13 Movement in critical point due to differences in the measurements of tail-hold elevations.

Sensitivity Analysis

A sensitivity analysis was completed on a randomly chosen corridor to determine the effect of small vertical shifts in the critical point (Table 2.2). This corridor was limited by skyline tension; therefore, when the elevation of the critical point decreased, tension increased, resulting in a lower allowable payload. Increases in elevation caused an opposite response. Although all lift and tail trees were analyzed at the same rigging height, a small variation in elevation at these points (due to the surveying method used) substantially affected the limiting payload.

Table 2.2 Sensitivity analysis of the critical-point elevation.

Corridor number	Adjustment in critical-point elevation (ft)	String-box payload (lbs)	Laser payload (lbs)	Total-station payload (lbs)
28	+2	5837(+73)*	5734(+72)	6181 (+101)
	+5	5944(+180)	5849(+187)	6340(+260)
	+10	6275(+511)	6038(+376)	6604(+524)
	-2	5696(-68)	5455(-207)	5969(-111)
	-5	5593(-171)	5337(-325)	5698(-382)
	-10	5422(-342)	5132(-530)	5433(-647)

*** Numbers in brackets are differences between field-calculated payload and the payload that resulted from the elevational adjustment.**

Statistical Information

A statistical analysis was completed on 14 of the corridors that had been traversed by all three methods. For each corridor, the limiting payloads for the string-box and laser methods were subtracted from that for the total station. Based on t-tests, the resultant differences were non-significant (P-Value = 0.57), thereby showing that survey method did not seriously affect the payload estimations. Although fluctuations in some corridors' limiting payloads were substantial (e.g., a 4042-lb. deviation between string-box and total-station methods for Corridor 35), the total differences were insignificant among methods. This was perhaps a result of the sample size not being large enough to account for that amount of variation. That, combined with the sensitivity of the critical-point calculation, may have outweighed the difference in payloads. Average total-station payloads were 440 lbs greater than those computed with the string-box data; that difference ranged from an under-estimate of 1781 lbs to an over-estimate of 4042 lbs. Moreover, the laser payload was approximately 130 lbs heavier than that calculated with the total-station values, with the differences ranging between -1636 lbs. to +2839 lbs.

Multi-span Operations

Angular, distance, and force differences were found within the five corridors that required intermediate supports (Table 2.3), and were based on the magnitude of apparent differences in distance and elevations of lift trees among survey methods. Although none of the techniques resulted in infeasible conditions, the large variations that resulted could mean greater challenges in more difficult terrain when viable analyses are not physically possible due to introduced surveying errors.

Table 2.3 Average differences in multi-span analysis among data from total-station, laser, and string-box methods.

Method	Resultant angles (°)	Jack force (lbs)	Vertical distance (ft)	Jack passage angles (°)
Laser	8.5	437	1.75	6
String Box	4	856	1	7.5

RECOMMENDED PRACTICES FOR IMPLEMENTATION

When small changes occur in the location/elevation of the critical point, payload calculations can vary substantially. Although the variations identified in this study were case-specific and not statistically significant, forestland managers can be confident that the less labor-intensive and lower-cost string-box method will provide data similar to those produced by a total-station or laser method.

Further research is needed to assess whether these new digital measurement devices and compasses can increase the efficiency and accuracy of ground profiling. For example, LTI is testing a prototype compass that does not work on a fluxgate compass but rather on a magneto resistive sensor (William Carr, pers. comm., LTI, February 21, 2003). This might improve the repeatability of the compass results without having to use a staff during forest surveys. Mounting the laser and compass on a staff for stability during data collection could also be a viable option, although it may be challenging to maneuver with a large staff through the understory.

Inexpensive electronic distance-measuring devices may also provide adequate alternatives to the string box or LTI Laser. However, their accuracy in applied settings is still unknown and requires further research to determine effectiveness. Likewise, numerous digital data collectors are being marketed in the Pacific Northwest. Nonetheless, one must be sure that the available data-collection software is compatible with the mapping software. In the study presented here, several additional steps were included because the TDS Ranger and Solo Field CE were incompatible with Logger PC4. However, this challenge can be overcome by using a DOS-based machine and current programs, such as Data Plus Professional 2002 or LaserSoft 2003.

CONCLUSIONS

This study investigated the magnitude of difference in calculated payloads and associated costs when three separate survey techniques and tools were used to complete the layout and profiling of 20 skyline corridors in the Siuslaw National Forest. Payloads varied substantially, though not significantly, perhaps because of either the magnitude of the differences or the sensitivity of the payload calculations to the topographic location of the critical point. Therefore, one can assume that the least expensive method (string box) could be used to estimate the payload with the same level of accuracy as the more expensive laser method.

COMPARING FIELD MEASUREMENT STRATEGIES FOR OPERATIONAL PLANNING AND LAYOUT

Chapter 4

SUMMARY

Planning and layout of harvest operations may be achieved through a variety of methods. The objective of this two-fold project was to determine the accuracy and efficiency of measuring techniques, as applied in the Oregon Coast Range.

The first study involved the implementation of four survey methods to complete an uneven-aged management plan. Although adequate results were obtained with each method, their usefulness depended on pre-determined objectives. The most accurate data were gained via the total-station technique, whereas the string-box method was the most cost-effective because of its low initial purchase price and the need for only a one-person crew. Finally, although the efficiency and accuracy of the laser method was very good, the repeatability of the Mapstar compass hampered statistical comparisons.

The second study investigated the layout and profiling of 20 commercial thinning corridors in the Siuslaw National Forest. Two survey methods were compared for accuracy and efficiency. Ground-profiling information was used to calculate skyline payloads, then compared with benchmark data produced from a total station. The limiting payloads identified from each technique were drastically affected by the apparent positioning of the critical point, although those differences were not statistically significant. However, some basic trends were noted. For example, if the

elevation of the critical point, lift, or tail tree was increased, the payload decreased. The opposite was also true. Because that difference in calculated payload among methods was insignificant, forestland managers would be best advised to utilize the string-box method, which proved to be most cost-effective.

In conclusion, this study examined the benefits and limitations of various tools to complete specific tasks during operational layout and planning. Although the most costly measuring method was not always the most accurate, benefits could be realized with each. Therefore, operations managers should determine their project objectives before deciding which technique to use when implementing a harvesting plan.

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APPENDICES

APPENDIX A

OREGON OVERVIEW MAP, MCDONALD-DUNN OVERVIEW MAP, HARVEST SCHEDULING MAP OUTPUT, PATCH INFORMATION, EQUIPMENT COST SPECIFICATIONS

Figure A.1 McDonald-Dunn Research Forest, Corvallis, Oregon

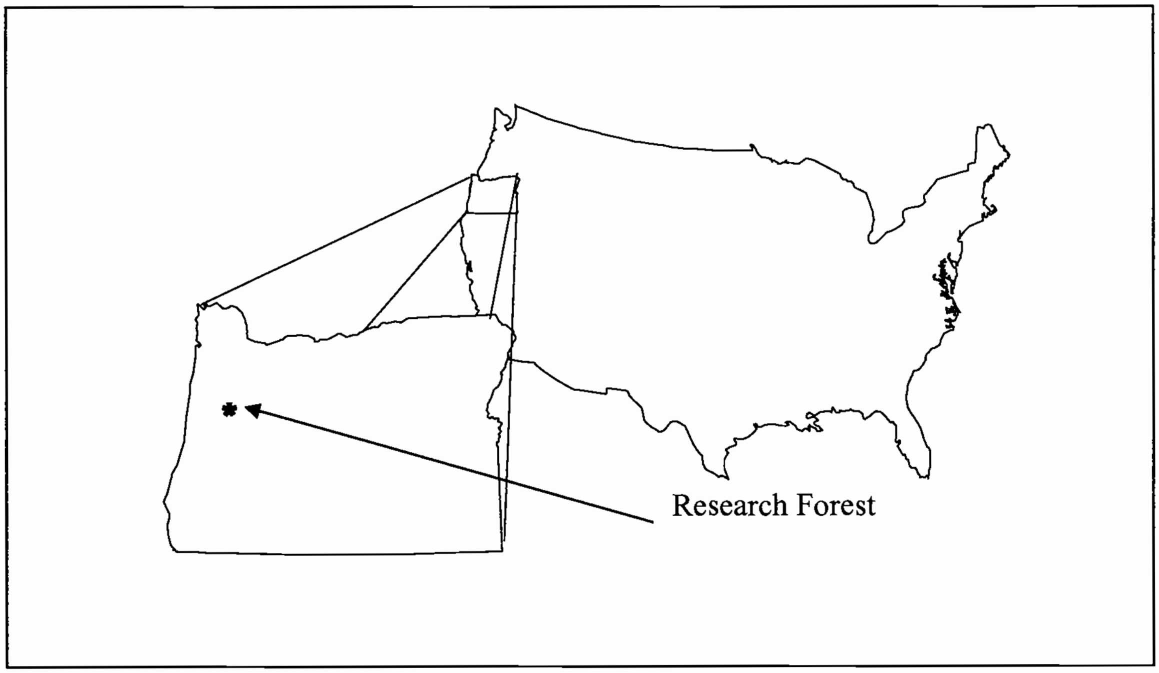


Figure A.2 Map of the McDonald-Dunn Research Forest, Corvallis, Oregon.

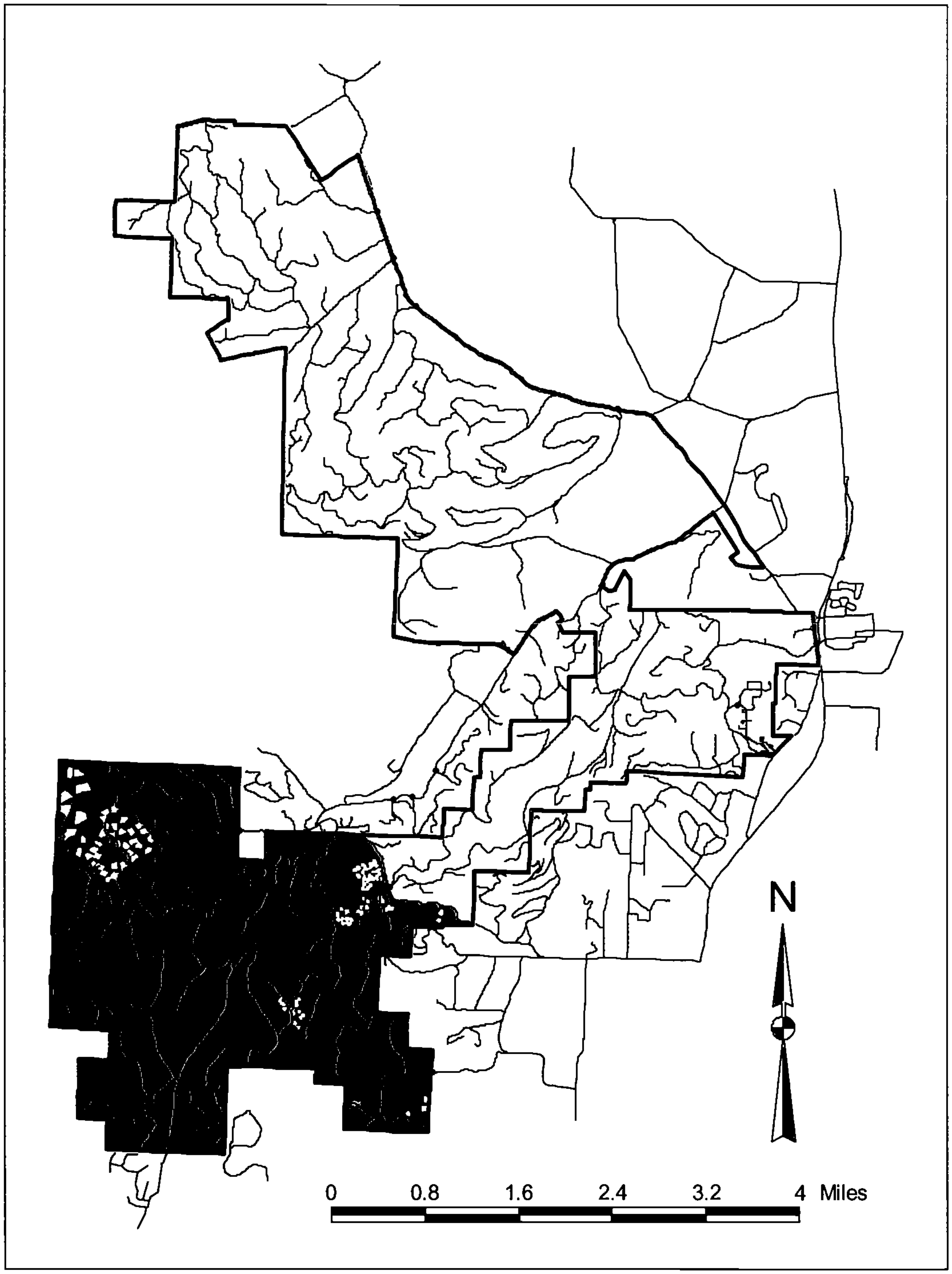


Figure A.3 Harvest-Scheduling Model Output.

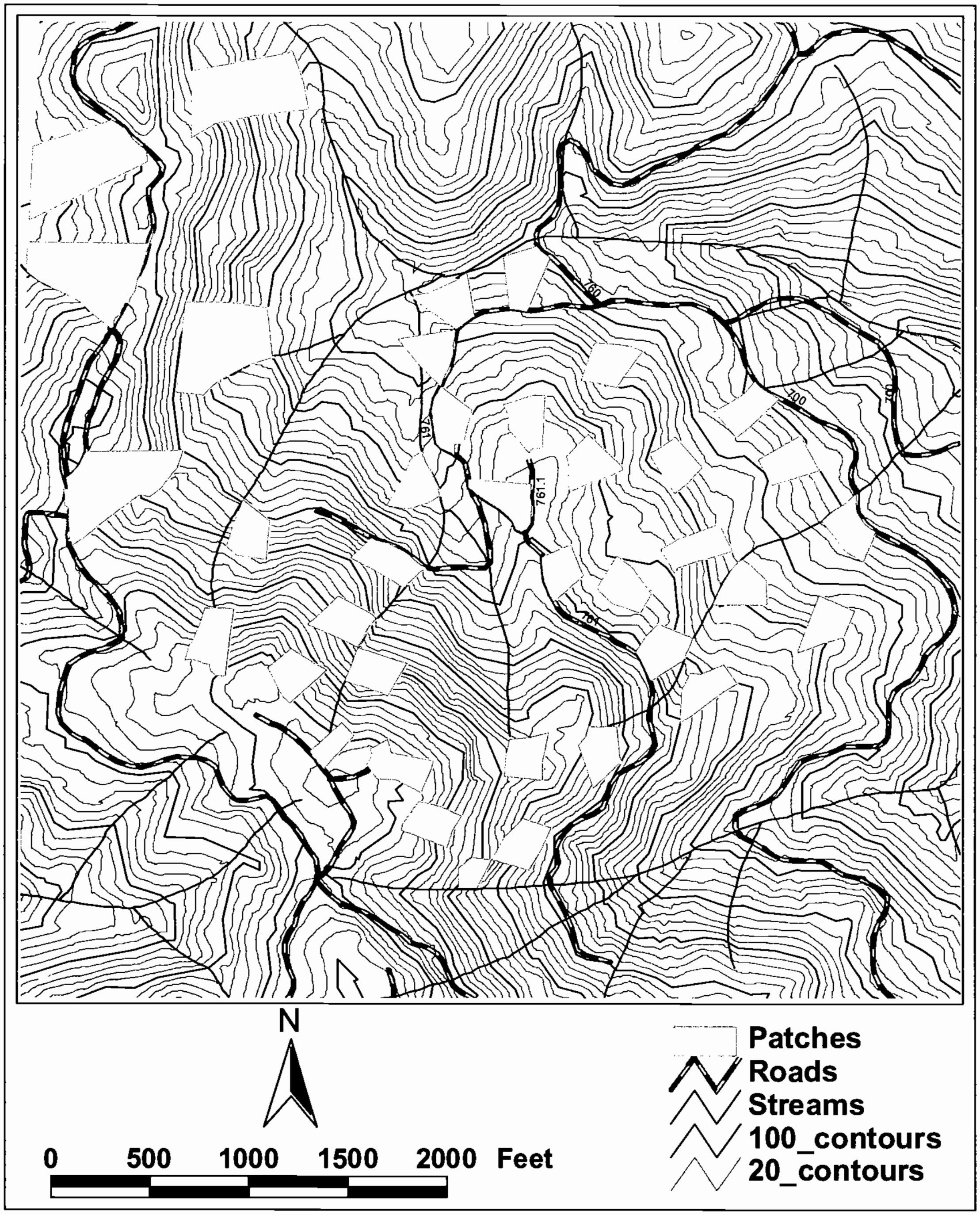


Figure A.4 Typical surveyor ribbons and tags.

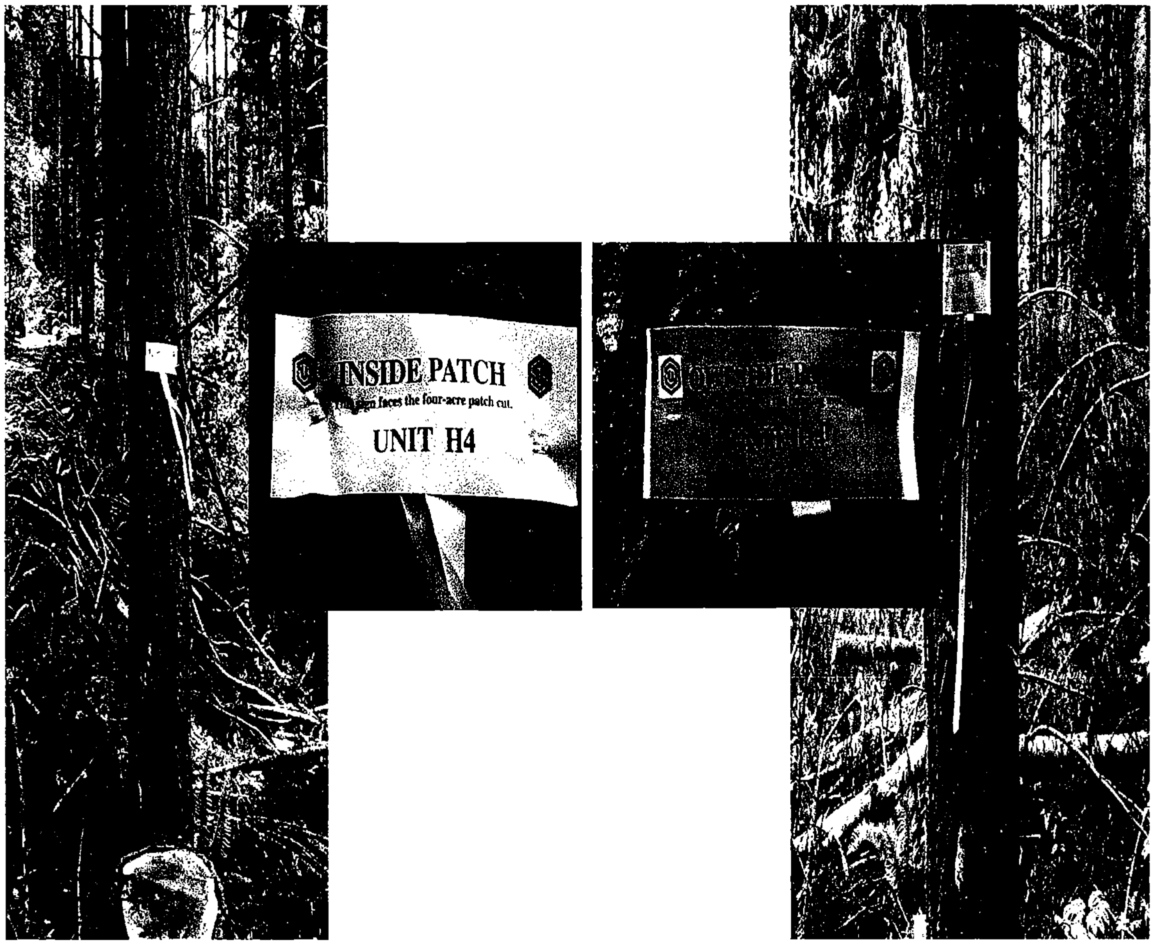


Table A.1 Equipment Costing Specifications

Table A. Equipment used for string-box method.

Instrument	Purchase price	Hourly cost
Method 1		
String Box with counter	$125.00	$0.02
Suunto Compass	$49.95	$0.01
Suunto Clinometer	$79.95	$0.01
Field Book	$11.95	$0.00
Totals	**$266.85**	**$0.05**

Table B. Equipment used for two laser methods.

Instrument	Purchase price (1)	Purchase price (2)	Hourly cost (1)	Hourly cost (2)
Method 2				
LTI 200 Laser	$2895.00	$2895.00	$0.50	$0.90
Mapstar Digital Compass	$1495.00	$1495.00	$0.26	$0.26
Digital Data Recorder (TDS Ranger)	$2495.00		$0.43	
Digital Data Recorder (Allegro)		$3275.00		$0.56
Reflector	$6.50	$6.50	$0.00	$0.00
Totals	**$6891.50**	**$7671.50**	**$1.18**	**$1.31**

Table C. Equipment used for GPS method.

Instrument	Purchase price	Hourly cost
Method 3		
Trimble GeoExplorer	$10,995.00	$1.88
Totals	**$10,995.00**	**$1.88**

Table D. Equipment used for total-station method.

Instrument	Purchase price	Hourly cost
Method 4		
Nikon DT-310 Total Station*	$5785.16	$0.99
2-Sentra Prism	$201.00	$0.07
2-Leveling Staff	$123.95	$0.04
Tripod	$155.00	$0.03
Field Book	$11.95	$0.00
Totals	**$6277.06**	**$1.13**

*Example calculation:

$$\frac{\$5785.16}{2 \text{ years} \times 365 \text{ days} \times 8 \text{ hrs}} = \$0.99/\text{hr}$$

Table A.2 Patch Summaries

Patch no.	Method	Area (ac)	Patch perimeter (ft)	Closure precision (%)	Base data (/TS)	Cost ($)	**Effectiveness**
10	String Box	1.29	980.3	1.69	56.33	7.26	**409**
	Laser (Ranger)	1.45	1025.2	1.36	45.33	14.94	**677**
	Laser (Allegro)	1.45	1025.2	1.36	45.33	13.36	**606**
	GPS				0.00	18.01	**0**
	Total Station	1.42	1029.3	0.03	1.00	69.06	**69**
11	String Box	1.08	901.1	1.16	116.00	13.27	**1539**
	Laser (Ranger)	1.18	943.2	0.48	48.00	14.29	**686**
	Laser (Allegro)	1.18	943.2	0.48	48.00	12.71	**610**
	GPS	1.09	889.7		0.00	9.70	**0**
	Total Station	1.1	984.9	0.01	1.00	114.78	**115**
12	String Box	0.96	836.2	1.47	147.00	13.90	**2043**
	Laser (Ranger)	0.97	852.5	0.58	58.00	11.69	**678**
	Laser (Allegro)	0.97	852.5	0.58	58.00	10.10	**586**
	GPS	1.05	963.4		0.00	11.08	**0**
	Total Station	0.99	852.7	0.01	1.00	38.37	**38**
14	String Box	0.94	971.5	1.43	143.00	14.21	**2032**
	Laser (Ranger)	1.04	1019.3	4.06	406.00	17.54	**7121**
	Laser (Allegro)	1.04	1019.3	4.06	406.00	15.97	**6484**
	GPS	1.09	1095		0.00	4.85	**0**
	Total Station	1.08	1020.1	0.01	1.00	78.65	79
15	String Box	0.85	826.5	0.62	62.00	12.00	744
	Laser (Ranger)	0.87	844.3	2.16	216.00	14.29	**3087**
	Laser (Allegro)	0.87	844.3	2.16	216.00	12.71	**2745**
	GPS				0.00	19.05	**0**
	Total Station	0.88	847	0.01	1.00	101.99	**102**
16	String Box	0.89	806.7	0.97	32.33	11.69	**378**
	Laser (Ranger)	0.96	828.3	1.64	54.67	10.39	**568**
	Laser (Allegro)	0.96	828.3	1.64	54.67	8.80	**481**
	GPS				0.00	19.05	**0**
	Total Station	0.87	763.9	0.03	1.00	54.67	**55**
17	String Box	1.75	1155.8	1.6	160.00	10.42	**1667**
	Laser (Ranger)	1.56	1107.8	0.02	2.00	16.89	**34**
	Laser (Allegro)	1.56	1107.8	0.02	2.00	15.32	**31**
	GPS	1.74	1231		0.00	7.97	**0**
	Total Station	1.85	1194.8	0.01	1.00	99.11	**99**
18	String Box	0.94	795	1.12	112.00	9.48	**1062**
	Laser (Ranger)	1	815.3	6.97	697.00	14.94	**10413**
	Laser (Allegro)	1	815.3	6.97	697.00	13.36	**9312**
	GPS	0	115.9		0.00	9.70	**0**
	Total Station	0.97	803.4	0.01	1.00	155.38	**155**
19	String Box	1.16	1429.1	1.13	56.50	11.69	**660**
	Laser (Ranger)	1.27	1468.9	6.08	304.00	13.64	**4147**
	Laser (Allegro)	1.27	1468.9	6.08	304.00	12.06	**3666**
	GPS	1.18	1611		0.00	6.93	**0**
	Total Station	1.3	1480	0.02	1.00	156.66	**157**
20	String Box	0.86	879.1	1.16	38.67	9.48	**367**
	Laser (Ranger)	0.82	870.4	1.08	36.00	19.49	**702**
	Laser (Allegro)	0.82	870.4	1.08	36.00	17.93	**645**
	GPS				0.00	15.59	**0**

	Total Station	0.87	881.1	0.03	1.00	159.85	**160**
21	String Box	1.21	905.3	0.47	47.00	13.90	**653**
	Laser (Ranger)	1.24	925.8	1.12	112.00	12.99	**1455**
	Laser (Allegro)	1.24	925.8	1.12	112.00	11.41	**1278**
	GPS				0.00	15.59	**0**
	Total Station	1.23	915.3	0.01	1.00	69.70	**70**
22	String Box	1.03	863.4	0.9	90.00	15.79	**1421**
	Laser (Ranger)	1.09	887.1	0.7	70.00	13.64	**955**
	Laser (Allegro)	1.09	887.1	0.7	70.00	12.06	**844**
	GPS				0.00	16.62	**0**
	Total Station	1.09	893.4	0.01	1.00	70.02	**70**
23	String Box	0.93	804.4	0.98	98.00	11.05	**1083**
	Laser (Ranger)	0.95	810.8	2.32	232.00	12.99	**3014**
	Laser (Allegro)	0.95	810.8	2.32	232.00	11.41	**2647**
	GPS				0.00	23.55	**0**
	Total Station	0.93	812.6	0.01	1.00	52.11	**52**
24	String Box	0.91	803.8	0.91	45.50	11.37	**517**
	Laser (Ranger)	0.96	817.8	0.78	39.00	15.92	**621**
	Laser (Allegro)	0.96	817.8	0.78	39.00	14.34	**559**
	GPS				0.00	20.43	**0**
	Total Station	0.96	833.65	0.02	1.00	99.43	**99**
25	String Box	1.05	851.41	2.35	235.00	16.11	**3786**
	Laser (Ranger)	1.13	908.85	11.02	1102.00	15.27	**16828**
	Laser (Allegro)	1.13	908.85	11.02	1102.00	13.69	**15086**
	GPS		231.45		0.00	20.09	**0**
	Total Station	1.01	858.39	0.01	1.00	97.83	**98**
26	String Box	0.88	850.78	1.04	104.00	13.58	**1412**
	Laser (Ranger)	0.9	873.01	0.81	81.00	12.02	**974**
	Laser (Allegro)	0.9	873.01	0.81	81.00	10.43	**845**
	GPS				0.00	20.09	**0**
	Total Station	0.92	888.72	0.01	1.00	90.16	**90**

APPENDIX B

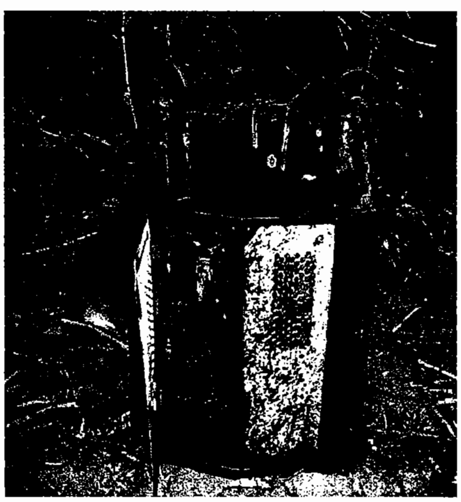
EQUIPMENT SPECIFICATIONS, OVERVIEW MAP, EXAMPLE LOGGERPC4 OUTPUT, SURVEY EQUIPMENT COSTING INFORMATION, CRITICAL POINT INFORMATION

Figure B.1 Equipment Specifications used for LoggerPC4.

Yarder Information

Model: 1966 Linkbelt
Crane
Tower Height: 50 ft
Horsepower: 350 hp
Skyline Diameter: 0.75 in.
Skyline Length: 1,650 ft.
Mainline Diameter: 0.5625 in.
Mainline Length: 1700 ft.
Haulback Diameter: 0.5 in.
Haulback Length: 2000 ft.

Carriage Information



Model: Eagle Eaglet
Engine: 12 hp
Weight: 1,300 lbs.
Load Capacity: 12000 lbs.
Skyline Diameter: 5/8 – 1 1/8
Skidding Line Diameter: ½ - 5/8
Line Speed: 250–300 ft/min
Intermediate Support Capable

Figure B.2 Location Map of Oregon and the Siuslaw Study Site.

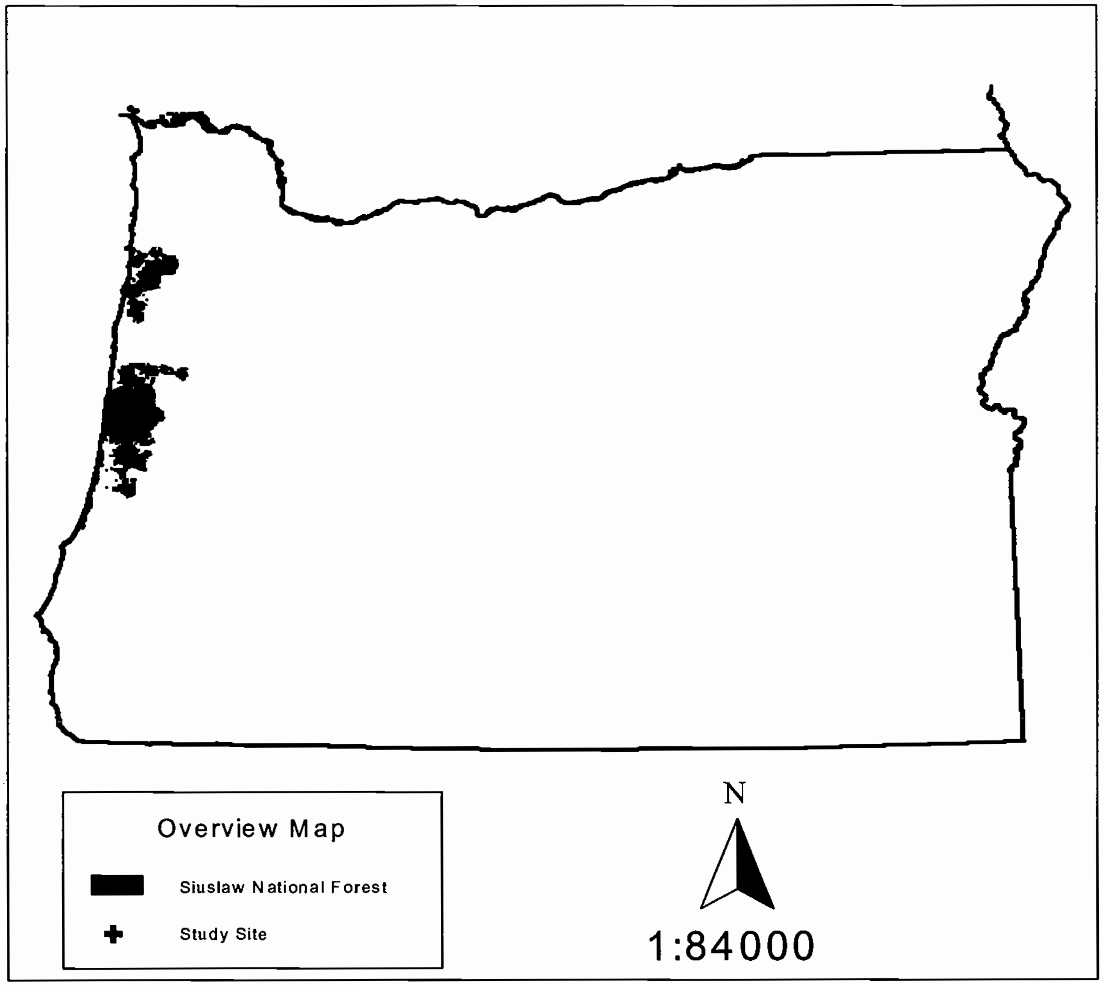
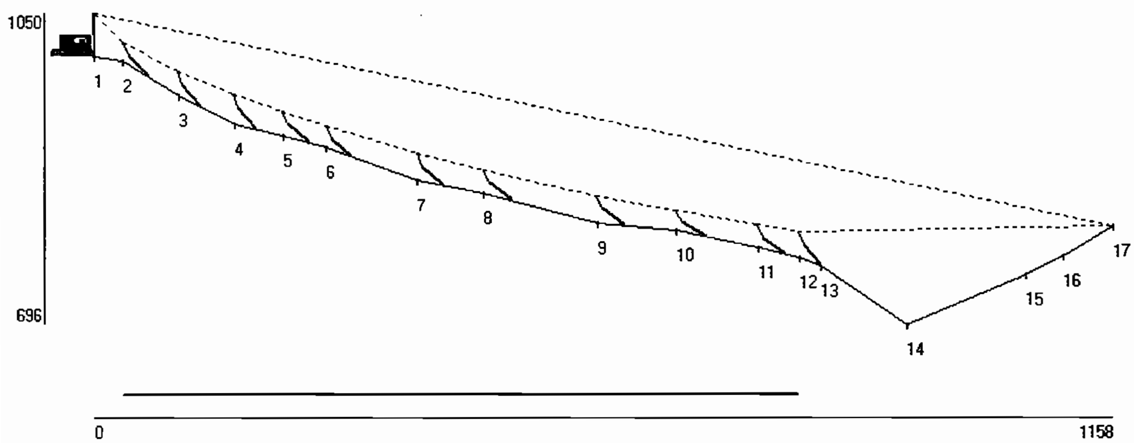
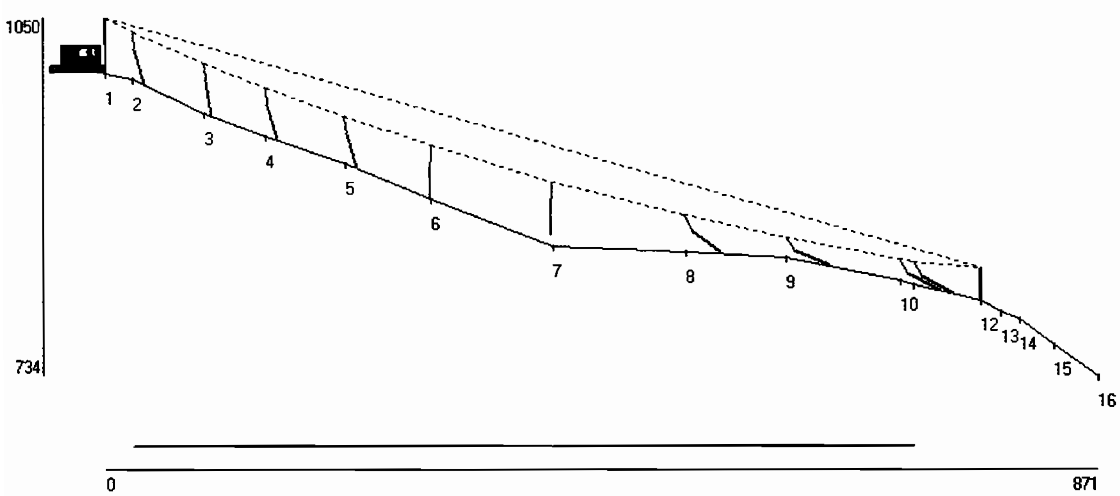


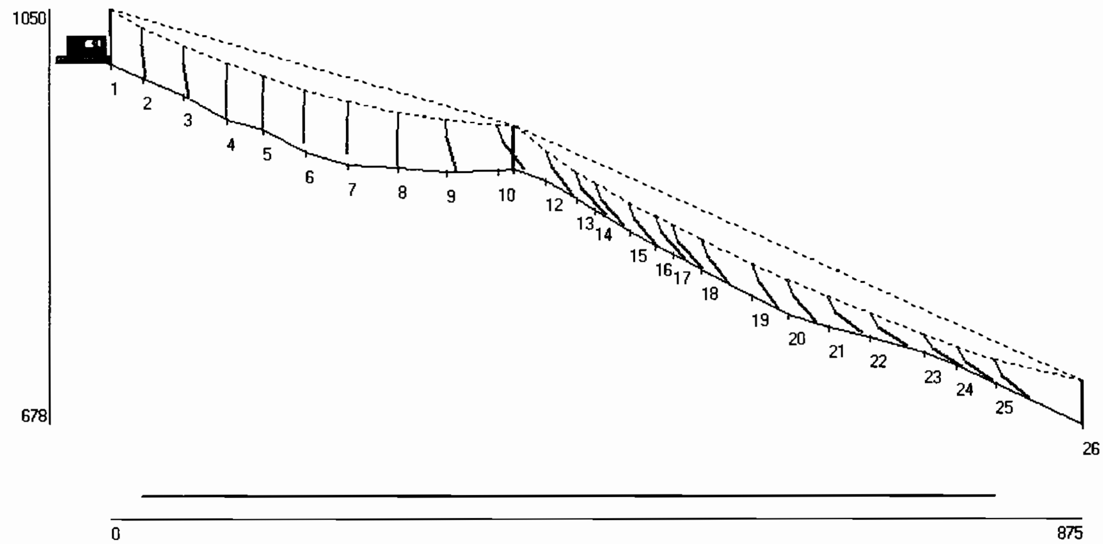
Figure B.3 Examples of configurations for skyline-harvesting systems, based on LoggerPC4 output.



A) Standing system with tail hold.



B) Standing system with lift tree.



C) Multi-span system with intermediate support and tail tree.

Table B.1 Corridor information for each surveying method.

Corridor Number	Limiting Payload	Multispan Height	Tail tree Height	Critical Point			Resultant Angle	Jack Forces	Vertical Distance	Angle	
				Station	HD	VD					
2	1281	40	40	7	213	864	53	3728	3	16	Total Station
	2910	40	40	13	491	642	45	4472	4	20	Laser
	4235	40	40	5	152	902	49	5478	4	25	String Box
4	6838		35	12	297	769					
	4888		35	16	328	542					
	7092		35	10	409	703					
8	3019	40	40	6	175	922	61	5274	3	29	
	2452	40	40	5	189	951	71	5056	2	27	
	2139	40	40	4	198	925	65	4568	2	22	
11	1515		40	11	294	861					
	1645		40	8	288	850					
12	2834	40	40	10	278	847	54	4382	4	31	
	2296	40	40	9	265	780	52	3938	3	21	
	1053	40	40	8	265	833	62	4014	2	20	
13	3849	40	40	8	237	838	47	5817	7	46	
	2213	40	40	8	292	856	61	5474	3	38	
	3511	40	40	6	250	838	47	5216	7	49	
23	697		40	12	699	810					
	1612		40								
23B											
	4811	40	40	7	281	915	56	5844	4	42	
	3154	40	40	6	406	894	66	6651	1	28	
24	3826		1	17	647	810					
	3704		1	10	667	795					
25	1253		1	25	885	735					
	822		1	13	842	771					
26	1248		1	28	838	758					
	1532		1	14	824	757					
	1500		1	16	812	753					
27											
	6019		30	3	94	979					
	4846		30	3	99	980					
28	6080		1	27	1102	833					
	5662		1	11	789	772					
	5764		1	12	801	772					
29	1648		30	10	393	846					
	1304		30	7	401	843					
	1464		30	7	393	848					
29b											
	1250		30	6	406	851					
	2821		30	6	427	846					
30	3610		30	12	305	879					
	3804		30	6	298	881					
	4027		30	6	293	887					
31	3650		30	7	249	898					
	3529		30	8	437	853					
	3215		30	5	233	907					
32	5169		40	11	259	910					
	4847		40	5	220	917					
	4827		40	5	220	920					
33	3777		40	7	248	918					
	1279		40	7	249	917					
	2081		40	7	257	919					
34	3965		40	7	227	901					
	5561		40	5	266	877					
	4731		40	4	172	924					
35	3627		30	5	133	936					
	6466		30	5	197	897					
	7669		30	5	203	895					