Setting Design Evaluation Incorporating Pacific Northwest Loggers' Preference

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ABSTRACT

Timber harvesting methods are changing rapidly and costs are increasing in response to increasingly stringent environmental constraints on logging operations. Forest engineers must balance many complex physical, biological and silvicultural variables to produce optimally designed settings, but empirical data to assist in the process of setting design are lacking. This paper describes an alternative approach that allows the forest engineer to draw upon the experience of logging contractors to compare alternatives and design efficient harvest settings.

Introduction

Industrial design together with established market research principles via loggers' perceived importance of harvest cost variables form a representative, broad scale sample of timber production specialists, loggers. Findings establish the factors that affect harvest costs as perceived by loggers. The factors are used to determine the utility of a variety of setting design attributes. The results are applied to evaluate the design of contemporary forest harvest operations. The survey establishes the feedback link between appraisal and planning, providing guiding details for timber harvest setting design. The interaction of planning variables affecting harvest cost is poorly understood. Forest planners will be aided by this study in determining the consequences of design decisions especially those involving structural retention (STR) prescriptions.

The three main contributions from this research are first, the methodology borrows from market research techniques to bring psychometric data into the forest management and engineering field. Secondly, the industrial design philosophy embedded in the evaluation technique presented incorporates human factors into forest design and engineering. Finally, it is a new approach to the application of psychological data where the product being evaluated, setting design, is constrained by physical, biological, and silvicultural design variables. This is the first example of conjoint analysis of forest engineering data.

Problem statement

Logging operations are under severe environmental constraints that have the effect of increasing operation costs. Many times the increase in cost is not attributed to specific operation variables. The problem is one of identifying and controlling those variables that contribute to harvest costs. Design trades off the attributes of timber sales and results in an optimally engineered harvest setting. Present processes that help the forest engineer improve setting designs do not account for additional costs associated with improved environmental practices, for example structural retention. The loggers are aware of the increased cost of harvesting as they often shoulder the financial burden (Weigand and Burdett 1990). Design level changes in decision making assures higher efficiency at the landing based on the integration of many fields of knowledge (Dyson 1990).

Strategic decisions have enduring effects, are broad in scope, and are difficult to reverse. Decisions made about placement of harvest units are certainly irrevocable once harvested; affect a broad scope of values at the watershed level; and endure through rotations as logging modifies the vegetation and basin structure. Planning evaluates options before action and proposes decisions that limit both cost and concern for future impacts (Depta 1984). Setting design (e.g., boundary placement, harvest equipment, tree retention) is fundamental for describing the means of timber harvest. Site characteristics (e.g., timber, terrain, access) are critical to the efficient extraction of logs. Logging production depends on setting design and site characteristics but interaction between design attributes is difficult to measure.

Current dilemma of forest planners

There is some doubt whether design engineers are using the correct setting parameters to optimize objectives and value. Beyond some of the basic features that loggers prefer (e.g., uphill over downhill cable yarding), planners do not know what loggers think about the attributes of setting design. Loggers know how operation constraints affect production. The setting designers get feedback often after the sale layout is complete—ready to be cut and yarded.

Timber value appraisals, like the residual value or transaction evidence methods, include very little information about setting layout and design. For example, if the trade-offs between the amount of sidehill yarding and yarding distance were known, foresters could design harvest systems that offered high preference to loggers, who judge improved daily production as preferrable—measured here by the abstract units of utility, **u**. The measure of utility for most loggers is shift level of production (e.g., log truck loads per day; daily operating cost; $/Mbf). If utility is the satisfaction obtained from goods, then setting designs with high utility are preferred and will attract bidders.

Economic rationale for judging setting design procedures (e.g., identifying unit boundaries, assigning equipment types, road access) presume certain priorities (e.g., economic efficiency, payload, deflection, yarding distance). The interaction between setting design variables and how contract loggers perceive the interrelated variables is presently unknown.

In the beginning of the design process and evaluation of decisions about setting size, internal configuration, and layout, options appear less distinct. Consideration of the loggers' ideas about this level of design will yield higher daily production while maintaining acceptable environmental protection of timber sales.

Harvest planners are still learning about the economics and operational feasibility of timber sales that include elevated levels of structural retention (STR). With STR silvicultural systems, forest structure is retained as "aggregated" or "dispersed" trees over a setting (Figure 1) so ecological process and function can be retained or regenerated. Prescribing logging systems with STR involves two principal costs: foregone or deferred timber revenue and decrease in unit revenues because of increased unit harvesting costs ($/Mbf). The former affects the landowner. The latter affects the logger directly and is the concern in this study; specifically, identifying the interactions among important variables of setting design. Costs associated with STR vary with the level, pattern, and type of trees left in reserve on the harvest unit.

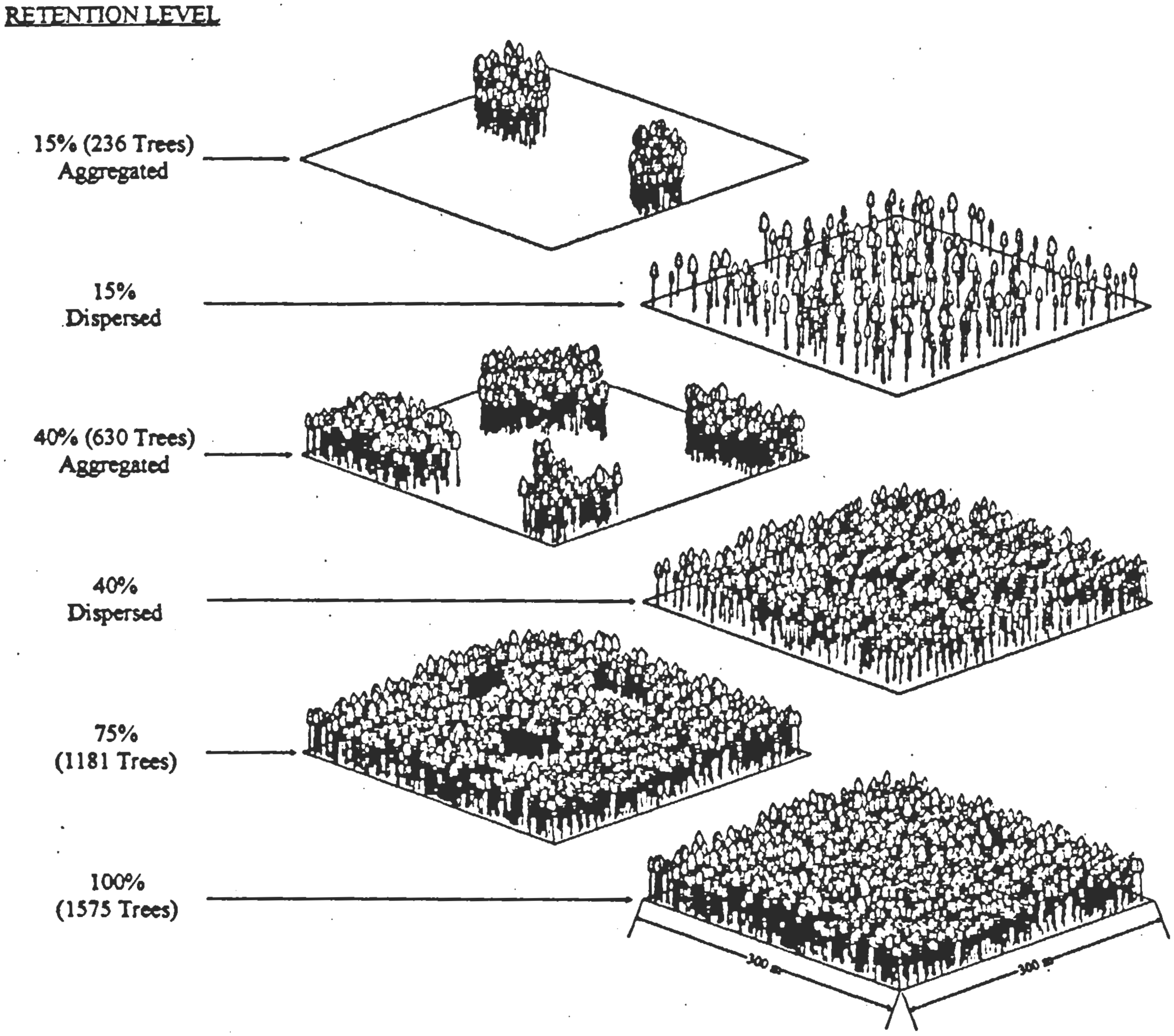
Planning of harvest and transportation systems has made technological improvements in recent years (Schiess et al. 1988) recognizing ecological (Franklin 1992, Mitsch and Jorgensen 1989) and silvicultural processes (Oliver et al. 1992, Swanson and Berg 1991). Silvicultural and forest engineering systems influence the efficiency of timber production (Depta 1984). Settings are measured by a range of variables; planners are often in doubt about the relationship between variables. The value of a setting may be improved by minimizing costs. If loggers' preference for setting variables is optimal in the design then the daily production will increase.

Production studies measure site-specific conditions with unique combinations of equipment and various levels of crew proficiency. Since Brandstrom (1933) first applied industrial design techniques in the Pacific Northwest numerous regression based production equations based on site, equipment, and stand character have been produced (Aubuchon 1982). Conventional production study (Table 1) often collapses to report daily or shift level (e.g., daily volume output, log truck loads per day), which has a great impact on costs and revenue. Forests are biological systems and are more complex and varied than controlled production systems (Odum 1989). Trying to extrapolate from these equations to partial harvest alternatives (e.g., thinning, STR) is difficult.

Typically, the landowner, with the forest engineer, designs the transportation system and the harvest settings (location and configuration). Timber is offered for sale by the setting or a group of settings. A purchaser buys the timber and usually contracts to a logger for the harvesting. Rarely does the logger offer input about the setting design. Adjustments, usually on a small scale, are by the logger *in situ* with the hopes of gaining greater production—the loggers measure of utility.

Timber value (stumpage) includes the influences of harvest costs that result from regulations, layout, and operator experience (e.g., residual value appraisal). A timber purchaser depends on the logging contractor's costs to be representative of the market. The logger's price (e.g., logging cost) to harvest a particular setting, is a complex function of landing the timber. Loggers improve efficiency when it is to their advantage.

A means to gauge logger's perception helps appraise cost because the logger's bid is a synthesis of cost to deliver the logs. Ray and others (1994) used contingent value methods and reported the perceptions loggers have about creating "aesthetic" harvest units. Southeastern United States loggers can produce "aesthetically pleasing" harvest units to satisfy public demands but the cost would be slightly more than conventional clearcutting (Ray et al. 1994). The advantage to the landowner and



MESO-SCALE GRAPHICAL SILVICULTURAL MODEL

Area = 9 ha. Stocking = 175 TPH

Height = 62m, Crown width = 11m ~ 20% of stocking

Height = 49m, Crown width = 8m ~ 40% of stocking

Height = 41m, Crown width = 5m ~ 40% of stocking

Figure 1. Structural retention patterns and levels are variable and depend on the site level characteristics. Aggregated and dispersed varible retention are displayed at a variety of levels.

Table 1. Time and Motion studies are site specific and depend on a wide variety of input variables. Extrapolation to a broad range of site conditions is questionable.

Reference	Regression Equations	R^2
Linjala 1979	Logs/Hr = 16.9881 + 2.28639*(Setters) + 5.65854*(Chokers) - 0.0183524	0.2781
Curtis 1978	Logs/Hr = 23.755 + 2.7776*(Logs) - 0.63694	0.13
Mann 1979	Turn Time (min) = 0.61040 + 0.00317*(SYDIST) + 0.01958*(LATDIST) + 0.33913*(LOGS) + 0.00167*(VOLUME) + 0.33088* (RIGGERS)	0.4727

logger is continued access to the forest. Structural retention (STR) is being broadly implemented to retain forest function but there are few measures of impact on forest planning and production. Appraising costs from STR is left to loggers, who learn by trial and error. These appraisals are rooted in perception of harvest costs and have not been measured and only partially described (Keegan et al. 1995, Weigand and Burdett 1992). Experienced loggers integrate years of knowledge as they estimate cost. Critical variables identified by loggers can be used by planners to improve the design of efficient settings to meet both economic and ecologic objectives.

Harvest planning based on costs that loggers identify would help design more efficient harvest settings in the absence of detailed empirical information. Some relationships about log size, yarding direction, and yarding distance are well-known but the actual trade-offs loggers make have not been studied. The market for settings, in this case, is the loggers and is studied to understand how loggers form opinions and arrive at estimates of cost. A definitive study focusing on economics, engineering, and silvicultural systems will take years to complete (DeBell and Curtis 1993). Optimizing forest management regimes requires understanding of the trade-offs between harvest cost variables. Loggers perception of production can be considered a judgment.

In one sense, forestry has returned to the "old growth" syndrome, where high timber values mask harvest system inefficiency and can absorb the added costs of poor designs. Old growth timber offered this luxury but the second growth timber supply is distributed across smaller timber, lower quality logs with higher harvest costs, and a diminishing timberland base. Second growth timber will not be as economically forgiving with design mistakes. As log prices decline, forest management becomes less profitable and harvest costs proportionally higher. Regardless of timber price, the forest engineer should develop efficient harvest designs. As constraints on harvest increase, efficiency becomes more important, one of the many transformations in American business (Hawken and McDonough 1993). If the variables that make work more efficient are identified then the design process can make use of this information to improve harvest operations. As sweeping changes in our forest management practices outpace our ability to assess the consequences of implementation, forest engineers need guides for the practical design of harvest settings.

Methods

We employ part-worth utility, **u**; an estimate of preference from conjoint analysis associated with each level of an attribute that defines a product (after Hair et al. 1992). Utility values are a relative measure of timber sale attributes to propose better setting design evaluation based on loggers' preferences. This study uses the logging design information gained through the market survey process described by Berg (1995) to apply utility values for setting design evaluation. Loggers are identified as a crucial link in the forest operations design process. Their perceptions help to evaluate the relative utility of timber harvest setting layout.

Logger's perception was the principal line of evidence to evaluate the trade-offs between attributes based on the utility values from conjoint analysis (Churchill 1991, Sawtooth Software 1987). Specialized adaptive conjoint applications (Adaptive Conjoint Analysis, ACA; Sawtooth Software 1987) take advantage of the rapid querying capability of computers. Individual part worth utility values, **u**, were computed using ordinary least squares (Sawtooth Software 1987, p. B-1; Hair et al. 1992, p. 408). Conjoint part-worths allow computation of an aggregate utility for each level of an attribute. The levels of each attribute are selected based on realistic, actionable, and communicable criteria and easily understood by the respondents, loggers (Table 2). Overall setting utility combines the attribute utility using an additive composition rule, where a combination of attributes, is represented as:

$$\textbf{Preference}_{Setting} = \textbf{PW}_1 + \textbf{PW}_2 + \textbf{PW}_3 + \textbf{PW}_4$$

Preference $_{Setting}$ is composed of the estimated part worths (PW_1, PW_2, PW_3, PW_4) for levels of the attributes and assumes no interaction between terms (after Hair et al. 1992). The utility value of a setting is the sum of the individual part-worth utility from Table 2. As a measure of the overall utility comparing one setting to another, the sum of utilities can be compared. Important comparisons can be made across the table between the different harvest systems and silvicultural regimes.

*Table 2. Utility values, **u**, for yarding distance and direction combined (after Berg 1995).*

Yarding Distance and Direction	Utility Values	
	Cable	Ground
<500 ft, Uphill	44	22
<500 ft, Downhill	19	49
500' - 1000', Uphill	43	4
500' - 1000', Downhill	2	32
>1000 ft, Uphill	25	0
>1000 ft, Downhill	0	9

Results

Conjoint analysis generated the utility values shown in Table 3; columns are the individual conjoint studies (CC, AGGR, DISP); overall for both cable and ground-based logging systems and individual results for each of the three silvicultural systems (clearcut, aggregated, and dispersed). Rows are the attribute and levels; entries in the table are the part-worth utility values, **u**, for the each level of the attribute. Interpolation between levels is valid within an attribute but extrapolation beyond the range of the level is suspect. The units for utility are utils, which are relative within a specific conjoint study (i.e., Cable-Clearcut).

Within an attribute, the relative importance of the levels can be assessed. For example, for yarding distance and direction, the greatest utility is for short, uphill (u= 44). But there is little advantage over moderate distance (500-1000 feet) uphill (u=43). The decision could be made to layout the longer distance with no substantial loss in the utility of the setting while gaining a great advantage in size of setting from an operations viewpoint.

Generally, ground based setting designs are more forgiving than cable logging primarily because of high cost associated with the setup time for tower logging. However, ground based operations are more sensitive for attributes of distance and piece size because of the increasing effect of turn cycle time and equipment limitations, respectively.

Yarding direction - There is a distinct preference for uphill yarding in cable settings. Utility values indicate that loggers favor downhill yarding (u=49,32,9) to uphill (u=22,4,0 respectively) when ground skidding. Cable systems in both clearcut and aggregated retention have greater utility for uphill (u=57,68,83) over downhill (u=6,17,23) or sidehill (u=22,12,11) yarding (Table

*Table 3. Utility values, **u**, for yarding distance (three levels) and yarding direction (three levels) seperately (after Berg 1995).*

Attributes	Cable Silvicultural Regime			Ground Silvicultural Regime		
Yarding Direction	CC	Aggr	DISP	CC	Aggr	DISP
Uphill	57	68	83	12		27
Sidehill	22	12	11	14		6
Downhill	6	17	23	56		66
Yarding Distance						
<500'		52	45		64	66
500' - 1000'		30	29		27	22
>1000 ft		1	1		1	0

3). However, prescribing dispersed retention, the utility indicates loggers favor downhill (u=23) to sidehill (u= 11) yarding even though it was likely to be more expensive and dangerous. When sidehill logging, gravity pulls the logs downhill into the residual stand that may cause more downtime due to hang-ups and damage during yarding in dispersed STR. Downhill cable yarding is preferred to sidehill when corridors are in dispersed retention, a situation in thinning forest stands.

Yarding distance - External distances (distance from the landing to the farthest point in the setting) beyond 1000 feet should be minimized and completely avoided when ground skidding in dispersed retention or thinning; external distances of 500 feet or less are preferred. This is most apparent in cable harvest systems where the short and moderate yarding distances are of almost equal preference.

Loggers do not mind STR but pointed out that improper placement of reserve patches can seriously impede production. They felt that if they could help select leave trees, given specifications for retention, the production could be optimized. The setting designers have the opportunity to keep difficult yarding conditions as reserve areas or on the setting boundary. However, ecologically this approach may not maintain the site quality (e.g., structural diversity, dispersal and refuge habitat) or protect native forest conditions across the landscape.

Forest engineering and design implications

The design implications of boundary placement should consider the amount of broken terrain and limit the size of settings where conditions are of low preference (e.g., steep incised streams, broken cross slopes, terraced slopes). The terrain and slope both interact in terms of how much a woods crew has to move around, which can influence the production because of crew exhaustion.

The most important element of this study allows loggers to provide design information to planners. Utility values, transformed into design criteria, can guide design decisions made by forest engineers. Setting evaluation is a quantitative measure of setting preference and is the comparative utility between settings. There may be a number of feasible solutions to the setting layout but they may differ in acceptability. With utility values for specific design parameters, the relative merit of one design over another can be evaluated.

A map of the Siouxon Creek planning area F report (University of Washington 1992) shows three individual settings, A, B, and C (Figure 2). The utility values are proportioned based on total skyline length corresponding to the attribute levels within the setting boundary (Table 4). Setting A has 96% uphill yarding, very little sidehill yarding (4%), and no downhill for a clearcut yarding direction utility value of u=56. Setting B has mostly uphill yarding (70%), and estimated 30% sidehill, and no downhill with a utility of u=47. Setting C has the lowest utility for yarding direction, u=28, because of both a high proportion of downhill (30%) and sidehill (40%) yarding (Table 5). A setting with high utility may achieve the high value through a number of combinations of attributes. Preferences for the settings indicate that setting A is the preferred design for clearcutting and C is the least preferred because of the high utility placed on uphill yarding (or disincentive for downhill yarding).

The interactions of cost variables associated structural retention (STR) are notably different than those associated with clearcutting. The application of STR to these units shows a different result (Table 6). Aggregated STR uses a different set of utility values and yarding distance is of much greater importance. Setting C, with many short turns, is preferred above all, in spite of the higher proportion of downhill and sidehill yarding. Setting B has both long yarding distances and 30% sidehill yarding, making it the least preferred design with aggregated STR.

Table 4. Setting level utility values proportioned by length of yarding in three directions. The sum of the part-worth utility values yields the setting level utility values for three settings (A, B, and C).

Yarding Direciton	Setting A	 B	 C
Uphill	0.96*57=55	0.70*57=40	0.30*57=17
Sidehill	0.04*22=1	0.30*22=7	0.40*22=9
Downhill			0.30*6=2
Attribute Utility	56	47	28

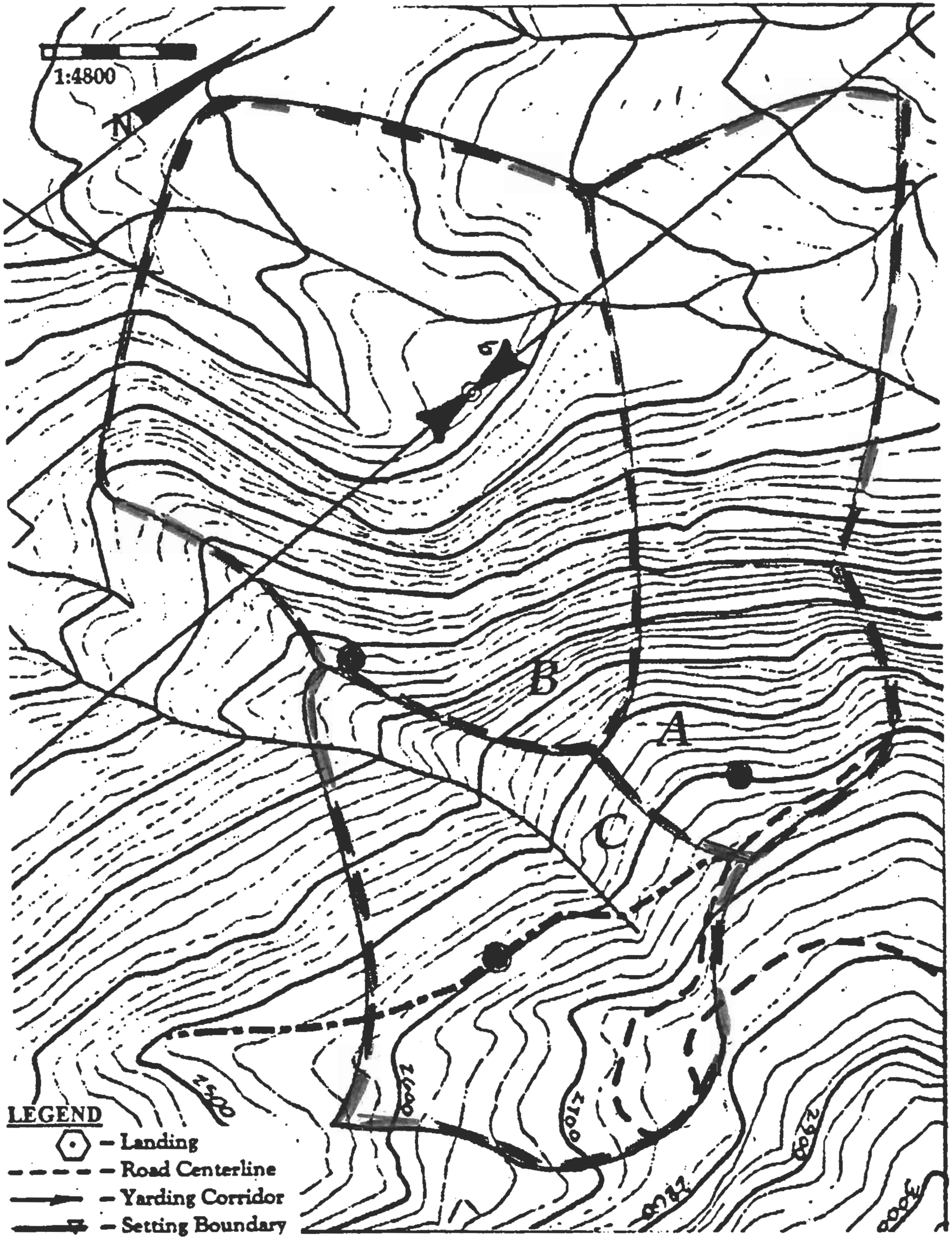


Figure 2. Settings A, B, and C demonstrate the difference is layout. A is a long, uphill yarding opportunity. B has a number of sidehill corridors. C is a central landing with short distances and multiple yarding directions (University of Washington 1992).

Table 5. Comparison of the setting level utility values for clearcut harvest of settings A, B, and C.

	Setting		
	A	B	C
Yarding Direction	56	47	28
Topography	40	37	26
Yarding Direction & Distance	24	18	40
Setting Utility	120	102	94

Table 6. Comparison of the setting utility values for structural retention harvest of settings A, B, and C.

Silvicultural System		Setting		
		A	B	C
Aggregated STR	Yarding Direction	66	51	30
	Yarding Distance	6	10	50
Setting Utility		72	61	80
Dispersed STR	Yarding Direction	80	61	36
	Yarding Distance	5	9	43
Setting Utility		86	71	80

Dispersed retention also has a low utility for any yarding direction other than uphill; even with a fair amount of sidehill yarding (30%), setting C is equally acceptable as setting A. This is because of the high utility placed on short yarding distance. Setting C does not differ from setting A based on the loggers utility of dispersed retention. For STR operations, setting C suggests landings centrally located, yarding directions well distributed, and relatively short yarding distances are near optimal for STR. Yarding road change times are reduced and the difficult yarding directions are minimized.

Conclusions

This evaluation method allows the designer to see design changes needed in the setting layout. While far from foolproof, the development of a quantitative rating system is useful to planners. The consequences of decisions at the primary level of harvest planning can now be judged based on the loggers' perception. This process closes the loop in the design process by including loggers and relaying design information to forest engineers.

Forest engineers measure parameters of setting design and identify the relationships between variables. The quantitative utility values of setting design attributes help evaluate trade-offs and compare harvest designs that differ by the levels of design attributes. Once foresters and engineers understand the logger's preferences and perceptions, they can prescribe operations that reduce operational costs. Incorporating utility value into existing planning tools (e.g., PLANS; Twito et al. 1987) would expand the evaluation of settings beyond the purely technical into the operational chances for success.

The industrial design philosophy embedded in the evaluation technique presented incorporates human factors into forest operations design and engineering, offering planners another quantified decision tool for establishment of efficient, safe, and environmentally sound timber harvest. Adaptive management mandates (Walters 1986) that we begin and then move forward and react to new information to improve our collective ability, for example, to make better decisions about setting design.

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