United States
Department of
Agriculture

Forest Service

Pacific Northwest
Research Station

General Technical
Report
PNW-GTR-215
July 1988

The SKYTOWER and SKYMOBILE Programs for Locating and Designing Skyline Harvest Units

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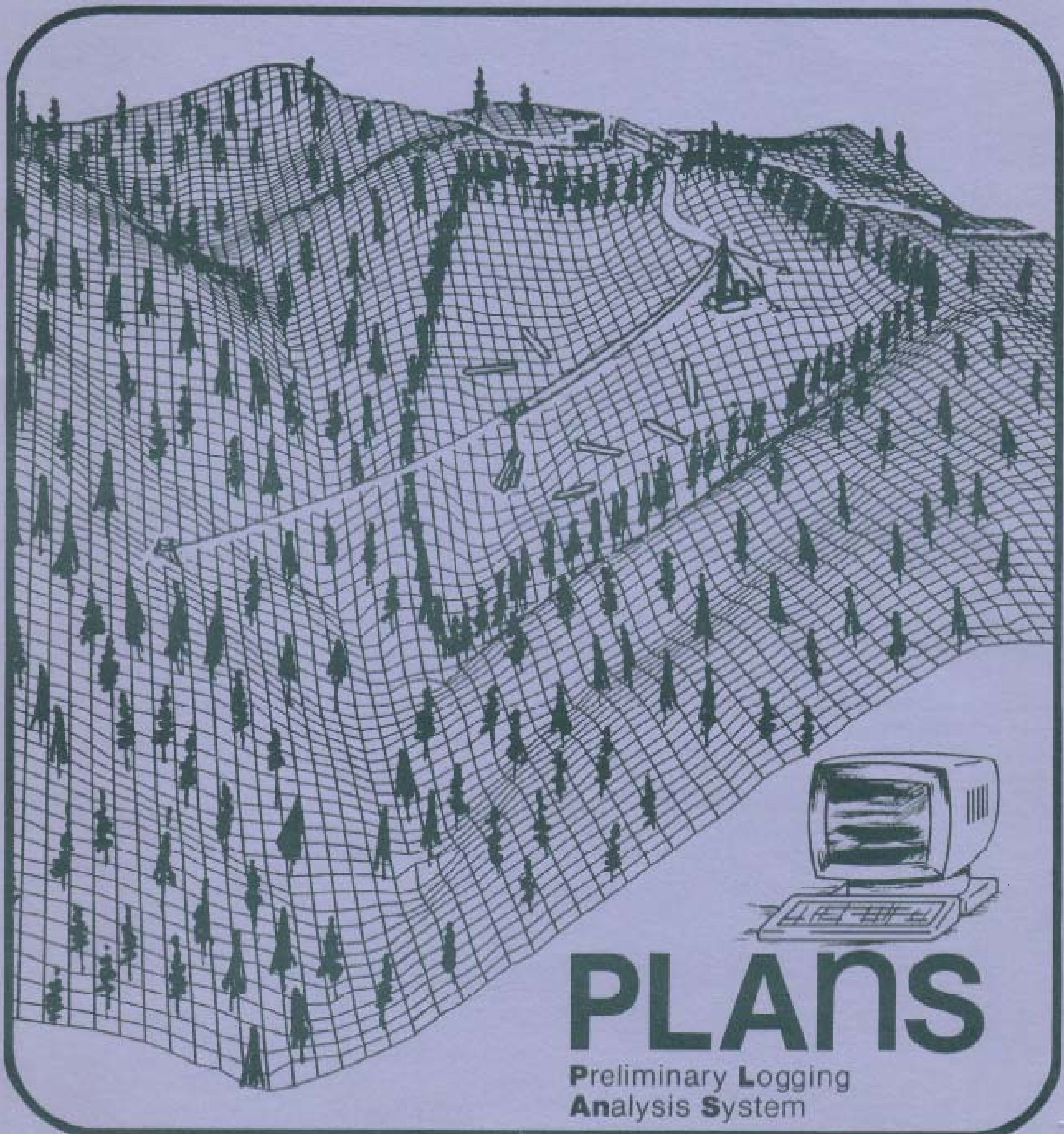

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Abstract

Twito, Roger H.; McGaughey, Robert J.; Reutebuch, Stephen E. 1988. The SKYTOWER and SKYMOBILE programs for locating and designing skyline harvest units. Gen. Tech. Rep. PNW-GTR-215. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 35 p.

PLANS, a software package for integrated timber-harvest planning, uses digital terrain models to provide the topographic data needed to fit harvest and transportation designs to specific terrain. SKYTOWER and SKYMOBILE are integral programs in the PLANS package and are used to design the timber-harvest units for skyline systems. SKYTOWER determines skyline payloads and spans for towers operating in fan-shaped settings from large central landings. The maximum yarding limit for each profile in groups of 18 circularly arranged yarding corridors is displayed after a landing is digitized on the digital terrain model. This unit can be modified to meet the planning needs. SKYMOBILE is similar except it is used for mobile yarders operating in parallel settings and permits several adjoining skyline spans to be designed on the same profile. Both use similar algorithms that permit quick solutions for either the longest span a designated payload can be yarded over or the largest payload that can be yarded over a designated span. Both program algorithms provide convenient ways to adjust the design and to locate '.' and mark the final design on the topographic map. The algorithms for these skyline solutions, which are approximations of exact catenary solutions for cables, are explained as are limitations of the methods used. Guides giving detailed operating instructions for the programs are available from the authors.

Keywords: Computer programs/programing, logging operations analysis/design, timber harvest planning, road building (forest/logging).

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Introduction

Cable yarding—moving logs from stump to landing with a machine operating from a stationary position—is a commonly used harvesting method in the Pacific Northwest The steep terrain of the region favors harvesting methods that do not require machinery to travel overland to the logs but that .bring the logs to a landing with cables. The term "yarding" generally means the logs can be at least partially lifted (suspended) during the trip to the landing. This suspension, a generally preferred harvesting practice in steep terrain, can be accomplished with skyline systems. The economic and environmental success of skyline harvesting operations is strongly influenced, however, by the type of skyline selected for an operation and by how well the skyline is positioned on the terrain. Good. positioning of the, skyline span permits hauling an ample volume (payload) of logs in each yarding cycle, which results in greater production and lower costs. Poor positioning can result in excessive soil disturbance, hangups, reduced production, equipment breakdowns, unsafe operations, and unworkable harvest units.

Good planning is needed to develop well-positioned skyline spans. To maintain a consistent level of quality and yet, in problem terrain, provide a balance between payload and road construction, planning must be supported by an analytic process. A full range of alternatives must also be considered for each area. Intensive planning of this type is consistent with the mandates for the National Forest System under the National Forest Management Act of 1976 (U.S. Laws, Statutes, etc. 1976). Timber - harvest settings and road alternatives are the design foundation of various area-level-analysis approaches used to make National Forest land management and transportation planning decisions (Jones and others 1986). If the initial timber-harvest and road-network alternatives are suspect (that is, developed using an excessive amount of intuition and cost averages rather than, analysis and site-specific cost estimates), the planning decisions projected from the alternatives may be wrong.

The Preliminary Logging Analysis System Using DTMs

This report introduces two programs, SKYTOWER and SKYMOBILE, designed to provide planners with an efficient analytic process for designing timber-harvest settings for skyline systems. These programs are included in PLANS (preliminary logging analysis system), which is a family of computer programs for timber-harvest planning (Twito and others 1987c). PLANS uses a stored digital terrain model (DTM), a rectangular matrix of elevations representing the ground surface of the planning area, to instantly supply the topographic data needed for fitting the timber-harvest designs to the terrain. PLANS can be applied to management units of up to 50,000 acres; emphasis is on developing a feasible harvesting plan well in advance of anticipated harvest activities. SKYMOBILE and SKYTOWER provide planners with efficient tools to evaluate the payload capacity of skyline yarding systems from terrain profiles extracted from the DTM for the planning area. SKYMOBILE is used to analyze individual profiles and is best suited for planning harvest areas where the yarder is moved with each corridor change. SKYTOWER is used to analyze settings yarded in a fan-shaped pattern to a central landing. These, along with the other PLANS programs, allow planners to quickly identify good landing sites and road locations. They can concentrate detailed unit planning, ground verification, and layout efforts on the most promising harvesting options because they have already eliminated the least promising alternatives from consideration. Iii addition, PLANS makes it easier for users to develop and select the most favorable harvesting plan from among several that appear promising.

Other programs in PLANS help planners design highlead yarding units (HIGHLEAD; Twito and others 1987b),lay out preliminary transportation systems (ROUTES; Reutebuch in press), estimate cable-yarding cost and production (SIMYAR; McGaughey and Twito 1987), visualize topography (VISUAL and SLOPE; McGaughey and Twito 1988), and develop DTMs from topographic maps (MAP; Twito and others 1987a).

PLANS was developed for a microcomputer-based interactive graphics system with the following components:

- Hewlett-Packard[1] 9020B microcomputer with one megabyte of core memory
- and BASIC operating system
- Hewlett-Packard 7908P with 16.5-megabyte disk drive
- Hewlett-Packard 2932A dot-matrix printer.
- Hewlett-Packard 7580B eight-pen drum plotter
- Calcomp 9480 36- by 48-inch digitizer with 12-button cursor

Most interactive graphics computer systems can support a package similar to PLANS; however, converting the package to another system or language may require considerable effort.

Review of Skyline Logging Analysis Methods

Since the days of Mills (1932) and his graphic solutions for catenary formulas, efforts have been made to provide easier ways to compute the loads a skyline system can carry. The chain and board method is one such approach (Lysons and Mann 1967). It required that potential skyline corridors be measured from a topographic map (or surveyed on the ground) and plotted into profile form. The skyline payload was then calculated with the chain and board simulation and the appropriate tables. Though the method was time consuming (it took about 30 minutes for each profile), it produced reasonable estimates of skyline payload.

Most of the subsequent methods for analyzing skyline payloads divided the problem into the same two parts as did the. chain and board method: The first part required obtaining the ground profile, and the second required analyzing a skyline's payload potential on a span fit to that profile. Although obtaining the ground profile was functionally the more straightforward of the two parts, it was often more time consuming than solving for the skyline payload.

Obtaining terrain profiles from topographic maps and analyzing skyline system payloads improved with the introduction of computer-based methods (Carson and others 1971). Programs based on computers interfacing with digitizers and plotters provided machine-plotted profiles of digitized yarding corridors and calculated the resulting payload for each corridor. Computer-based methods permitted planners to construct and analyze a skyline profile in about one-fifth of the time required by the chain and board method; however, the level of convenience provided by these early computer methods was still insufficient to encourage planners to thoroughly analyze full-rotation, total-area plans. Considerable effort was required to digitize the profiles needed to develop thorough plans for large areas.

[1] Use of a trade name does not imply endorsement or approval of any product by the USDA Forest Service to the exclusion of others that may be suitable.

Burke (1974) suggested using a DTM for harvest planning. A DTM in computer memory could provide instant access to the terrain profiles needed to develop a harvest plan. Because thorough planning requires investigating many profiles, DTMs offered great potential for saving time.

A DTM-based timber-harvest planning system that operated on a desk-top computer system was presented by Young and Lemkow (1976). Their system addressed skyline analysis as a function of deflection rather than payload. Their overall approach, although limited by what today is considered an inadequate computer system[2] demonstrated the possible efficiency of a DTM-based planning system. Others (Reimer 1979, Reutebuch and Evison 1984, Twito and Mifflin 1982) improved on this prototype DTM-based system by expanding the analysis to use improved computer systems.

The Skyline Analysis Programs

SKYTOWER and SKYMOBILE are important components in PLANS, because timber harvest plans are comprised of combinations of roads and harvest units that collectively make efficient removal of wood fiber possible. With these two programs, skyline-harvest units can be designed quickly and efficiently.

When using these programs, timber-harvest planners should sketch an intuitive network of skyline-harvest settings directly on a topographic map that includes such details as landings, roads, and rough yarding boundaries (Twito and McGaughey 1984). Such a plan will, initially, contain marginal units that cannot be logged. This plan is, however, only a starting point for an interactive process common to most computer-aided design (Prince 1971). The programs encourage logging planners to analyze a trial design, alter its parameters, and reanalyze to converge on a feasible solution; planners are aided by repeated graphic displays on the computer screen showing the progress of a design.

The two skyline programs have the same analytical structure. Both analyze the three basic types of skylines: live, running, and standing. SKYTOWER is used to design large, circular settings that are yarded to a stationary tower, and SKYMOBILE is used to design parallel settings that normally will be yarded with mobile skyline cranes. Both require the following data on yarding equipment to analyze payloads for a profile:

- Maximum slope yarding distance, in feet
- Desired payload, in pounds
- Minimum required ground clearance for the carriage, in feet
- Carriage height, in feet, where logs are fully suspended
- Carriage weight, in pounds
- Tower height, in feet
- Tailhold height, in feet

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[2] A Hewlett Packard 9830 desk-top computer system with no graphics screen, 16K bytes of random access memory, and an 8-bit processor.

The weight of the operating lines is also needed for live and standing skylines:

- Allowable skyline tension, in pounds
- Skyline weight, in pounds per foot
- Mainline weight, in pounds per foot

and for the running skyline:

- Allowable haulback tension, in pounds
- Haulback line weight, in pounds per foot
- Main plus slackpulling line weight, in pounds per foot

SKYTOWER Operating Procedure

The first step in using SKYTOWER is to digitize the landing location on the topographic map. SKYTOWER will automatically generate 18 evenly spaced profiles radiating from the landing. Each profile will be analyzed to determine the maximum span the desired payload can be yarded over. A diagram (fig. 1) is drawn on the computer screen to show the potential yarding coverage (the dashed line), and the user is given several options for modifying the yarding pattern.

Yarding coverage can be modified by removing individual profiles or a series of profiles from the design; for example, in figure 1 the upper half (profiles 1 through 10) was deleted from the harvest unit. Such deletions are used when only a portion of the full circle needs to be yarded. Extra profiles can be added (19) to investigate yarding potential in marginal areas. Finally, the yarding requirements or specifications for individual profiles can be altered to fit the exact needs of the planner. This was done on profiles 11, 13, 1,4, 15, and 17 and is shown in the plan view by a solid-line yarding boundary at a different location on those profiles than the dashed-line yarding boundary established from the initial design criteria. Changes in the yarding of individual profiles can take several forms. First, equipment specifications can be changed and the profile reanalyzed. The planners can specify a 15-foot tailhold tree rather than a 3-foot stump tailhold for a profile to improve deflection and thereby increase the span or payload capacity. Second, the tailhold can be moved to a new position to correspond with a road or boundary with an adjacent unit. The position of the digitizer cursor is tracked on the computer screen thereby making specific map features along a profile easy to locate.

Another option available in SKYTOWER is establishing yarding limits. Yarding limits are useful when only a portion of the designed span is to be yarded. For example, when a tailholds moved outside the unit boundary to increase deflection, only that portion of the span within the boundary should be yarded. In this case, the user sets a yarding limit at the unit boundary. Payload analysis will be done only for the portion of the span within the yarding limits.

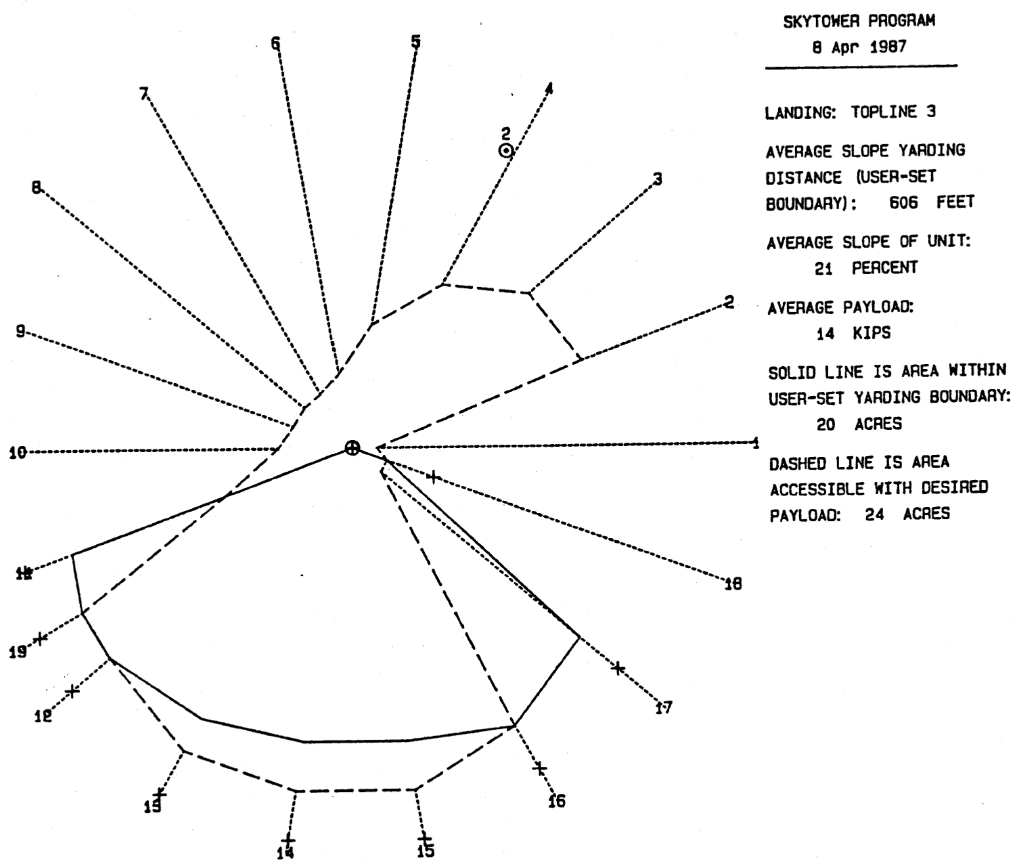

Figure 1—SKYTOWER produces a map-scaled plot of the unit design showing the computer-established maximum reach of the yarder (dashed line) and the user-set yarding boundary (solid line).

SKYTOWER allows other options for modifying individual profiles. The program can automatically solve for the maximum length that a desired payload can be yarded across. When users want to have more control over the analytic process, they can position the tailhold and let SKYTOWER determine the payload that can be yarded. SKYTOWER provides two ways to analyze payloads. First is the amount of lift, which allows users to set a tail hold; the program reports the areas along the span where the desired payload will be fully suspended when yarded. Even when full suspension over the entire profile is not required, it can be important for the planners to know if the desired payload can be fully suspended over portions of the profile, such as streams and other fragile areas. The second method, maximum payload, calculates the maximum amount that can be yarded over the span. This payload may exceed the desired payload, and when it does, it has an increased tendency to drag all the way across the span. Although less information on the profile's potential to provide full suspension is provided by this option, the maximum possible payload may be useful for production forecasts in areas where full suspension is not needed.

Regardless of the modifications made to the yarding coverage, changes are displayed immediately on the computer screen to show the user the current status of the overall design.

When a unit design is complete, SKYTOWER produces a plot similar to figure 1 on the drum plotter; this plot facilitates the transfer of the design to the topographic map. Two yarding boundaries are shown on the plot. The first is the computer-set boundary (dashed line) that is solved using the initially set yarding requirements. The second boundary (solid line) results from modifying the unit by deleting or adding profiles, or by altering the yarding specifications or requirements. This plot is a part of the plan documentation. If unit-boundary changes are required, the computer-set boundary indicates the potential for expanding coverage from a single landing. This plot and accompanying printed summary shows what was done to produce that specific design.

SKYMOBILE Operating Procedure

The first step in using SKYMOBILE is to digitize endpoints of the desired terrain profile. The endpoints do not have to coincide with tailhold or landing locations. The only constraint on profile endpoints is that they be within the DTM.. The profile is extracted from the DTM and displayed on the computer screen.

With the profile on the computer screen, the planner can input the location of the tower (using the viewing-screen cursor) at any point along the profile. The location of the digitizer cursor is tracked on the screen with a small flashing cross, which helps to locate specific points on the profile. When planners position the digitizer cursor on a roadside landing on the map, for example, that location along the profile is marked on the screen. Then the on-screen cursor can be aligned with the marker to input the tower location.

SKYMOBILE provides two options for placing tailholds. First, the user can specify an exact location (in the same way the tower position was specified), and the computer will solve for the maximum payload that can be yarded across the span. Second, the computer solves for the maximum span the desired payload can be yarded across given the yarding-system specifications. Letting the computer position the tailhold is a quick way to assess the suitability of the terrain to skyline yarding. When planners know the potential, they can modify the design to better fit overall requirements.

SKYMOBILE allows several nonoverlapping spans to be analyzed on the same profile so that the position of midslope roads can be determined. Figure 2 shows a profile with three linked spans. Spans A and B share the same tailhold; span A yards uphill and span B yards downhill. Span C shares a tower (yarder) with span B and yards uphill.

After a profile is analyzed, the locations of towers and tailholds can be transferred to the topographic base map. The digitizer cursor can be used as a locater to find each poi nt. A hard copy of the profile and the yarding-system specifications can be printed for the planning records.

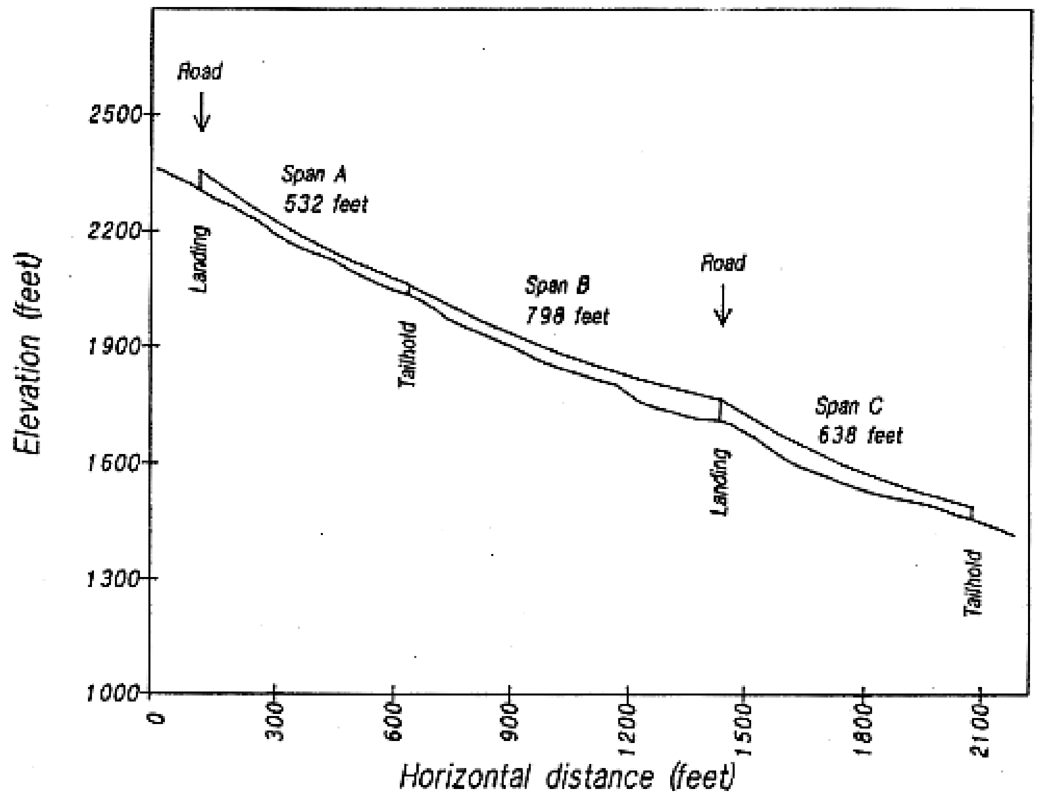

Figure 2—Multiple spans can be linked on a single profile by using SKYMOBILE to help position midslope roads.

Special strategies for using SKYMOBILE—This program, because it analyzes only individual profiles, requires some special manipulations to achieve correct road locations and yarding-access designs for area planning. One possible strategy is shown in figure 3. The objective is to design a network of midslope roads to provide access to all the intervening timber for mobile skyline cranes that will yard uphill to the roads. The first step (A) is to analyze a series of full-slope profiles and solve for the required road locations on each profile as shown in figure 1. Control points for roads should not be established at elevations so different that a connection cannot be made within reasonable road-grade limits. After all control points for the top, middle, and lower midslope roads are established, the road-gradeline locations should be marked on the harvest plan (step B). In PLANS, this can be done by using the procedure presented in ROUTES (Reutebuch, 1988), which locates gradelines by using the DTM. Then it is an easy matter to check skyline payloads over the area between the roads by using shorter profiles (step C). SKYMOBILE lends itself well to this operation. Profiles can be digitized, and then the planner can request the maximum payload that the span provides. Because less than one minute is needed to analyze profiles in this manner, road locations can be checked quickly and new locations developed if needed.

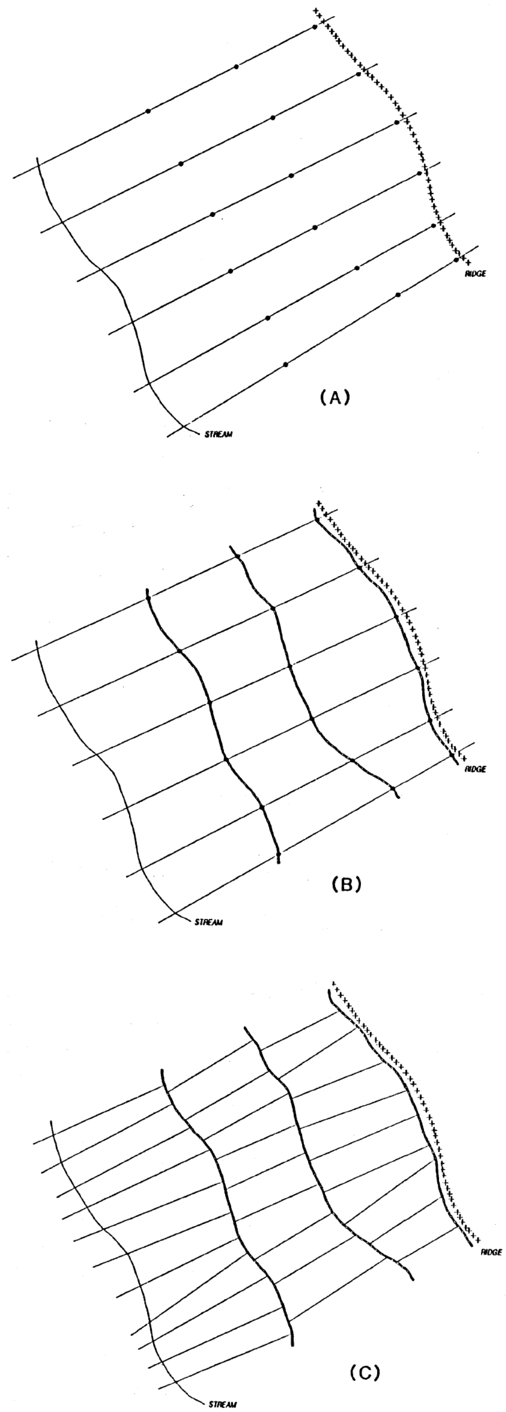

Figure 3—SKYMOBILE can be used to analyze a series of parallel profiles to position midslope roads. First, several parallel profiles (A) are analyzed to locate landings. These landing sites are used with ROUTES to locate roads (8). Finally, short profiles (C) are checked to verify road locations and design complete yarding coverage.

Another way that SKYMOBILE can be used effectively is for determining the skyline access on existing road networks for commercial thinning operations. The maximum yarding distance for the required payload can be quickly determined- for a series of profiles perpendicular to the truck roads. This yarding distance is the limit of commercial thinning. This technique and the rationale for its use are presented by Twito and Mifflin (1982b).

Analytic Description of the Skyline programs

The algorithms in the skyline program use a DTM to help planners develop a pattern of yarding coverage over extensive areas of terrain. The methods are not designed for layouts of individual sales as some accuracy has been sacrificed for rapid analysis. The sacrifices are not sufficient, however, to jeopardize the validity of planning efforts. The algorithms report one payload that can be yarded over the full length of the span and produce map-scale projections of areas accessible by different types of yarding systems; this provides a basis to evaluate yarding options for the harvest plan.

Skyline Algorithm Flowchart

The skyline algorithm is outlined on the flow chart in figure 4. The technical basis of this flow chart will be explained and examples given to illustrate the various paths through the algorithm.

Skyline types—Block 1.0 shows the types of skyline systems that can be analyzed. Each of the systems (live, running, and standing skylines) can be analyzed for three yarding patterns: (1) fan-shaped where many skyroad profiles converge on a central landing, (2) single profiles that are typically used when mobile spars yard to small roadside landings in parallel settings, and (3) longer single profiles where multiple, adjacent skyline spans can be analyzed (this pattern occurs on terrain with long, sustained slopes where several midslope roads and skyline spans may be required to provide access to all the timber).

Skyline inputs—The inputs in blocks 1.1.1, 1.1.2, and 1 .2 in figure 4 are standard inputs needed to calculate the payload. These parameters have been used in other skyline programs (Carson 1975b), and their application in the PLANS SKYTOWER and SKYMOBILE programs is similar to most of the prior analyses.

A major difference between these programs and prior solutions is the treatment of carriage clearance. The minimum ground clearance for the carriage and the carriage clearance where the logs become fully suspended are input parameters. The load-path (the load path is the arc traced by the skyline carriage from the tailhold to the headspar when the carriage supports, fully or partially, a designated weight of logs) algorithm will establish an arc that clears all the terrain points by a height that equals, or exceeds, minimum ground clearance. When the minimum ground clearance is less than the carriage clearance where the logs become fully suspended, the logs will usually be partially supported by the carriage and partially supported by the ground; this is one-end suspension. When this is designated, full suspension is still possible over portions of the span, such as streams and low areas along the profile. If full suspension over the entire span is required, a minimum carriage clearance equal to the clearance required for full suspension of the logs should be entered. If the full suspension clearance is greater than the minimum carriage clearance of the ground, then only two-thirds of the designated payload (plus all the carriage weight) is loaded on the skyline. The assumption is that if full suspension of the logs is not required,

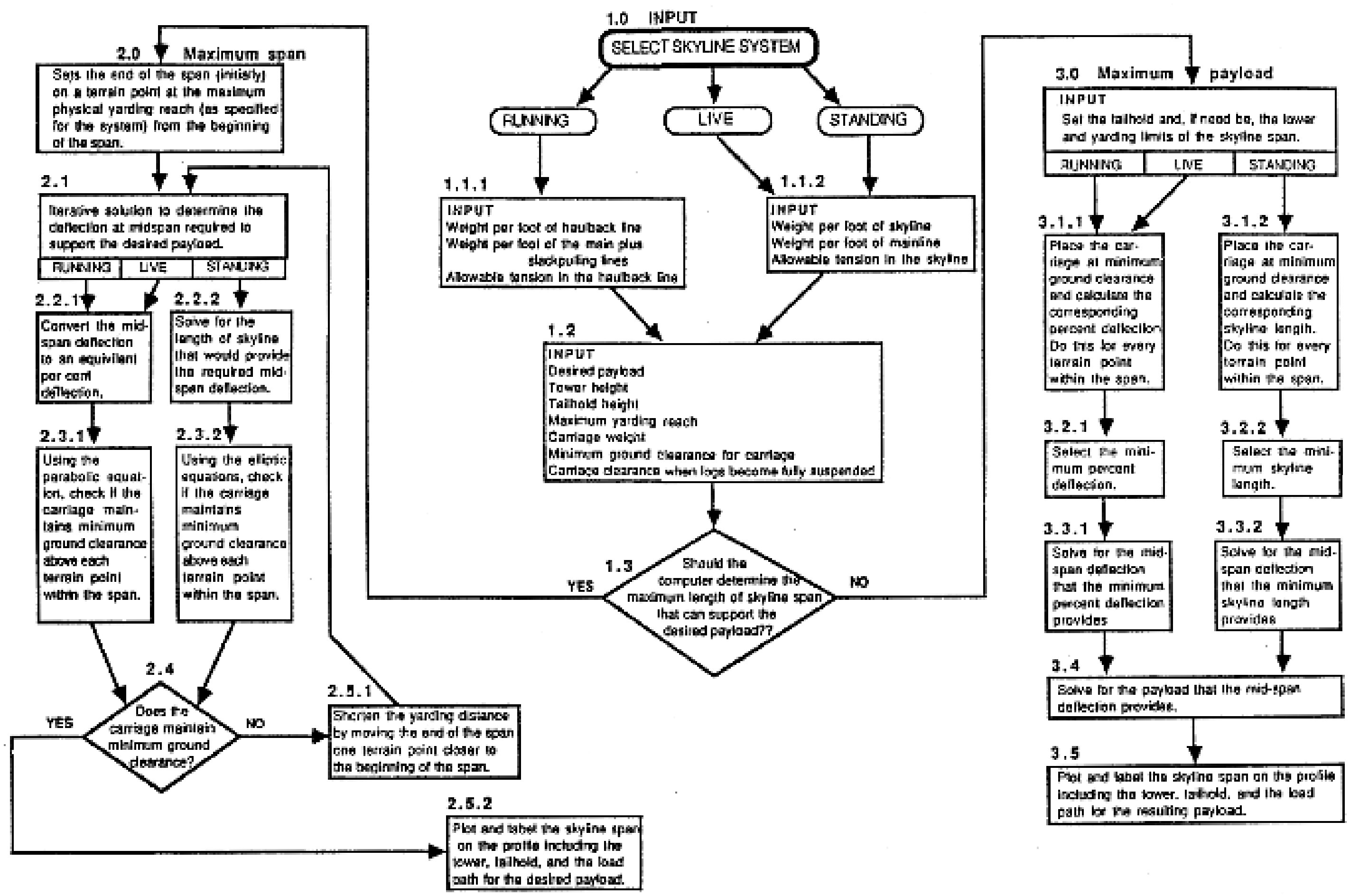

Figure 4—Flowchart of the SKYTOWER and SKYMOBILE algorithms.

then one-third of the weight of the log turn will be supported by the ground. The load path resulting from this reduced payload is plotted, and its clearance over each terrain point on the profile is checked. If this clearance exceeds the clearance where the logs become fully suspended, then ground support of the-full payload might not occur. A correction routine is required that solves for the load path by using the entire payload at full suspension. This load path for a heavier load again checks the clearance over each terrain point. If this clearance still exceeds the clearance where the logs become fully suspended, then the logs can actually fly free of the ground. Because the load path for the full payload is lower, it will not clear the terrain points by as great a distance as the load path based on a reduced payload. This could mean that full suspension will not occur, or that the range over the profile where it does occur is reduced from the extent to which it was indicated by the first load path. Rather than plotting a second load path, the algorithm marks the point on the profile plot where full suspension can occur with an "F" under the load path.

The standing skyline cannot provide a double-load path for full and partial suspension. Unlike the running and live skyline, the standing skyline cannot be adjusted to a greater payload by increasing the span's line length and deflection. If a dip in the ground occurs and results in full suspension of the logs, the payload must be reduced by one-third to compensate for the lack of ground support. These areas of full suspension are indicated and two payloads are labeled, one for full suspension and the other for partial suspension.

Maximum Span vs. Maximum Payload Option

Block 1.3 of the flow chart (fig. 4) shows the two basic options offered by the SKYTOWER and SKYMOBILE programs. The first option lets the planner input a desired payload and the maximum yarding distance that the selected skyline system is capable of reaching. In this mode, the algorithm directly solves for the longest span capable of supporting the desired payload. In the SKYTOWER program, the maximum area having a full payload that can be accessed from a landing is indicated. The latter option lets the planner select the skyline span, then the program calculates the largest payload (up to or in excess of the desired payload) that can be yarded over the span. This routine is useful when the planner is willing to compromise on payload size to reach logical unit boundaries. These two options are generally used interchangeably throughout the planning process.

Desired payload vs. maximum payload option--Two suboptions are available under the maximum payload option. One limits the payloads to those no greater than the desired payload. This option helps users determine when full suspension of an adequate (desired) payload can be achieved. The second option solves for the maximum payload without regard to the desired payload. This option is useful when harvesting costs are being examined.

Parabolic vs. Elliptic Curve for Load Path

The load path of the skyline, from which carriage clearance is evaluated, is an important analytic tool in the SKYTOWER and SKYMOBILE programs. Two categories of curves, parabolic and elliptic, represent the load paths for the three types of skylines. Both methods use an iterative solution (block 2.1 in fig. 4) to determine the midspan deflection required to support the desired payload. This solution, though modified to also accommodate the standing and live skylines, is based on the method presented by Carson (1975a) for a running skyline (fig. 5) where:

W_g = desired payload, in pounds;
W_{car} = weight of the skyline carriage, in pounds;
W_1 = weight, in pounds per foot, of the skyline (live or standing skyline) or the haulback line (running skyline);
W_3 = weight, in pounds per foot, of the mainline (live or standing skyline) or the slackpulling plus mainline (running skyline); .
T_3 = skyline working tension, in pounds, at the headspar (live or standing skyline) or haulback working tension, in pounds, at the headspar (running skyline);
L = horizontal span between headspar and tail hold, in feet;
H = vertical separation between anchor points, in feet;
S = skyline coefficient -1 for live and standing skylines and 2 for the running skyline; and
Y_2 = height difference (vertical _) between the anchor point at the headspar and the loaded carriage at midspan, in feet.

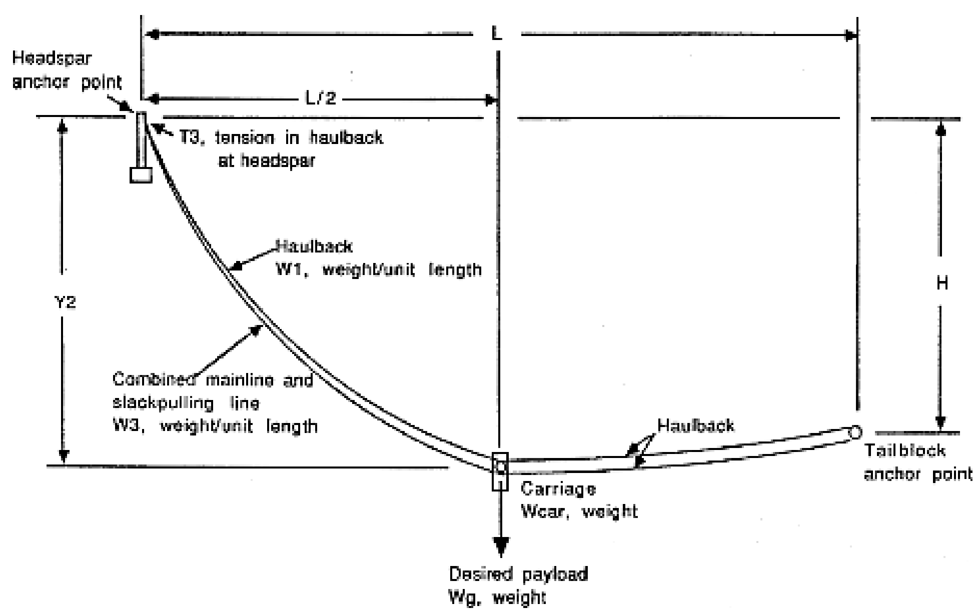

Figure 5—Schematic of the running skyline

The iterative sequence in equation group I solves the vertical Δ, Y_2, of the carriage at midspan resulting from a given payload:

Equation group I:

$$Y_2 = \frac{H}{2}$$

$$H_2 = \frac{T_3 L}{\sqrt{H^2 + L^2}}$$

$$\text{loop: } K_1 = W_1 \sqrt{Y_2^2 + (L/2)^2}$$

$$K_2 = W_1 \sqrt{(Y_2 - H)^2 + (L/2)^2}$$

$$K_3 = W_3 \sqrt{Y_2^2 + (L/2)^2}$$

$$Y_2 = \frac{\left(W_g + W_{car} + \frac{2SH_2H}{L} + \frac{K_4}{2}\right)}{\frac{4SH_2}{L}}$$

$$F_1 = \sqrt{H_2^2\left(1 + \frac{Y_2 - H}{L/2}\right)^2 - \frac{H_2K_2(Y_2 - H)}{L/2} + \frac{K_2^2}{4}}$$

$$F_3 = |T_3 - W_1 Y_2 - F_1|$$

$$F_2 = H_2 \frac{(T_3 - W_1 Y_2)}{F_1}$$

$$H_2 = F_2$$

If F3<0.01, then Y2 is the desired value for the vertical Δ of the carriage at midspan.

If F3>0.01, then repeat the force balance computations beginning at loop using the last values for H_2 and Y_2.

The solved midspan deflection will be nearly the same for equal-strength skyline systems regardless of type. An elliptic curve is used to model the load path of the fixed-length standing skyline; a parabolic curve is used to model the load path for the adjustable-length live and running skylines. The parabolic curve is higher than the elliptic curve at all points except the midspan point. Figure 6 displays a comparison between the two load paths for an adjustable-length (live) and a fixed-length (standing) skyline that are equal in span, line strength, and weight.

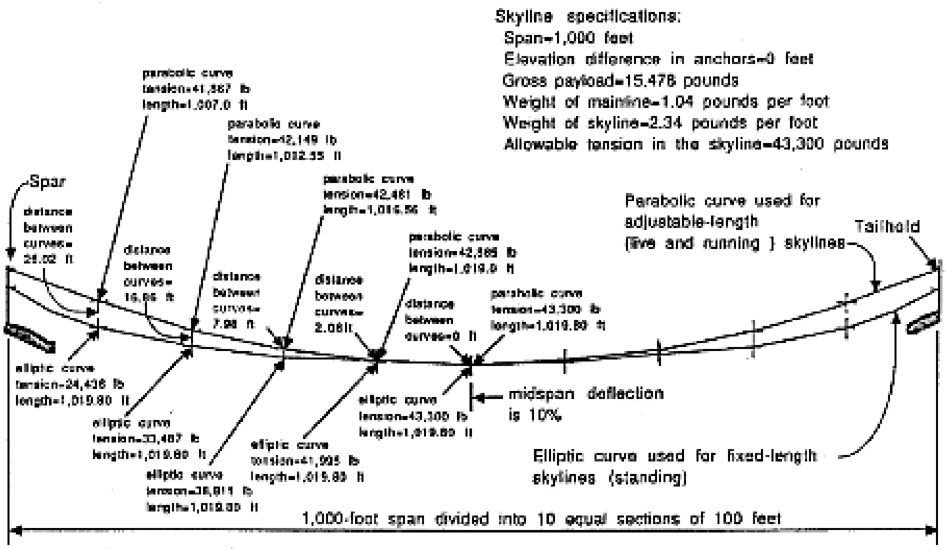

Figure 6—Comparison of the load paths of a standing skyline system (represented by the elliptic curve) and a live skyline system (represented by the parabolic curve).

The amount of carriage lift is the same at midspan; but as the carriage is moved toward the tower on the elliptic curve, the load path drops 26.02 feet below the parabolic curve. Simultaneously, the tension in the standing skyline is reduced from 43,300 pounds when the carriage is at midspan to 24,436 pounds when the loaded carriage is 100 feet from the spar. The adjustable-length skyline (represented by the parabolic curve) can be shortened to the point where it remains almost fully tensioned (near 43,300 pounds) and, consequently, provides a higher load path because the carriage is raised higher above the ground. The tensions labeled for various points on the parabolic curve do not remain at 43,300 pounds, as a perfect adjustment of line length would permit, but do remain within a reasonable range of that value. The reason is that the parabolic curve is not an exact model of the load-path curve for the live or running skyline but is only a convenient approximation. The skyline lengths, tension, and the distance between the two load paths on the right side of the span in figure 6 are about the same as those shown for the left half of the span.

The running skyline system is designed to maintain a high payload by maintaining nearly maximum haulback line tension through the interlock, but the same is not true of the live skyline. Some logging specialists recommend that the number of line-length adjustments required in normal operations with a live skyline be constrained. This was not done in the SKYTOWER and SKYMOBILE programs for three reasons:

1. Harvest planning that controls the number of line adjustments for live skylines reflects a degree of detail beyond what is reasonable for area-level planning.

2. All the lift indicated by the parabolic load-path curve is seldom needed, and on most profiles one or two adjustments of the line length let the carriage clear high points and thereby make the skyline span workable.

3. The parabolic curve is a convenient, speedy, and reasonably accurate formulation that is a key ingredient in rapid skyline analysis in the PLANS programs. In our opinion, no other choices were available for live-skyline analysis that offered so much validity for such a small computational effort.

The formula for the parabolic curve used in the SKYTOWER and SKYMOBILE programs uses the following variables:

P_1 = percentage of deflection expressed in decimal form,
L = horizontal span between headspar and tailhold,
H = vertical separation between anchor points,
X_1 = horizontal distance from headspar to point on the parabolic curve, and
Y = vertical Δ from headspar to point on the parabolic curve;

in the following equation group that solves the vertical Δ of the parabolic curve at any point in the span when the percentage of deflection is known, or solves the percentage of deflection when the vertical Δ and a horizontal point on the parabolic curve are known:

Equation group II:

$$Y = \frac{(4P_1 X_1^2)}{L} + [H/L - 4P_1] X_1 \;;$$

when X_1 is at midspan; that is, $X_1 = L/2$;

$$Y = \frac{H}{2} - P_1 L \;;$$

to solve for P_1 with a known carriage position:

$$P_1 = \frac{YL - HX_1}{4X_1(X_1 - L)} \;.$$

The elliptic curve is used to represent the load path of the standing skyline because the total distance from the headspar through any point on the curve to the tailhold. is the same. This provides a reasonable approximation of the path followed by a load suspended from a fixed length skyline.

The formula for the elliptic curve used in the SKYTOWER and SKYMOBILE programs uses the following variables:

Y_2 = vertical Δ between the anchor point at the head spar and the elliptic curve at midspan, in feet;
L = horizontal span between headspar and tailhold;
H = vertical separation between anchor points;
X = horizontal Δ from headspar to any span point on the elliptic curve;
S_0 = stretched skyline length; and
Y = vertical Δ from headspar to any known horizontal (X) point on the elliptic curve;

in equation group III to solve the vertical Δ of an elliptic curve at any point in the span when the vertical Δ at the midspan point is known.

Equation Group III:

$$S_0 = \sqrt{(L/2)^2 + Y_2^2} + \sqrt{(L/2)^2 + (Y_2 - H)^2} \ ;$$

$$\xi = \frac{S_0}{\sqrt{L^2 + H^2}} \ ;$$

$$A = \xi^2 + \frac{H^2(\xi^2 - 1)}{L_2} \ ;$$

$$B = \xi(1 - \frac{2X}{L}) \ ;$$

$$C = (1 - \frac{2X}{L})^2 - \frac{H^2(\xi^2 - 1)}{L_2}) \ ;$$

$$\eta = \frac{-B + (|H| / H)\sqrt{B^2 - AC}}{A} \ ;$$

$$Y = \frac{H(1+\xi\eta) + L\sqrt{(\xi^2 - 1)(1 - \eta^2)}}{2} \ .$$

This elliptic curve is not a perfect model of the standing skyline (see "Limitations"), and its imperfections err on the conservative side. Therefore, slightly more carriage clearance will be present than the elliptic load path indicates.

Another analytic method is required for situations where the planner specifies a span, and the SKYTOWER and SKYMOBILE programs solve for the maximum payload the designated span can support. In such a case, the skyline span is checked at each terrain point, and either the span's minimum percentage of deflection or the minimum length of skyline is determined. Once this is done, a direct solution for the midspan deflection is obtained through the parabolic or elliptic equation. Determining the value of midspan deflection (in feet) permits a direct solution for the skyline's payload. This is done by using skyline-payload equations based on those of Carson (1976), but restricting the equation to midspan analysis and expanding for the various types of skylines where:

Y_1	=	vertical Δ between the anchor point at the head spar and the loaded carriage at midspan;
W_n	=	net payload;
W_{net}	=	net payload adjusted for partial ground support of the log turn;
W_{car}	=	weight of the skyline carriage;
W_1	=	weight, in pounds per foot, of the skyline (live or standing skyline) or the haulback line (running skyline);
W_s	=	weight, in pounds per foot, of the mainline (live or standing skyline) or slackpullng line plus mainline (running skyline);
T_3	=	skyline working tension at the yarder (single-line skyline) or haulback line working tension at the yarder (running skyline);
L	=	horizontal span between headspar and tailhold, in feet;
H	=	vertical separation between anchor points, in feet; and
S	=	skyline coefficient—1 for live and standing skylines and 2 for the running skyline;

are used in equation group IV to solve for the safe payload when the vertical Δ of the carriage at midspan, the weight and working stress -of the lines, carriage weight, and span geometry are known.

Equation group IV:

$$t_3 = \frac{2(Y_1 - H)}{L}$$

$$t_1 = \frac{2Y_1}{L}$$

$$H_2 = \frac{W_1 L}{4\sqrt{1 + t_3^2}}\left[t_3 + \sqrt{4\left(\frac{2T_3}{W_1 L} - \frac{2Y_1}{L}\right)^2 - 1}\right]$$

$$K_1 = \frac{W_1 L \sqrt{1 + t_1^2}}{2}$$

$$K_2 = \frac{W_1 L \sqrt{1 + t_3^2}}{2}$$

$$K_3 = \frac{W_3 L \sqrt{1 + t_1^2}}{2}$$

$$W_n = SH_2(t_1 + t_3) - \frac{(K_1 + SK_2 + K_3)}{2} - W_{car}$$

$$W_{net} = 1.5W_n$$

Differences in applying the four basic equation groups used in the SKYTOWER and SKYMOBILE programs are evident in the following examples.

Example 1: Maximum Payload With Specified Span for a Running Skyline

The general process shown here also applies to the solution of a live skyline.

The planner must enter the following specifications for this example:

Weight per foot of the haulback line = 1.04 pounds
Weight per foot of the mainline plus slackpulling line = 2.08 pounds
Allowable tension in the haulback line = 18,500 pounds
Tower height = 50 feet
Tailhold height = 35 feet
Maximum yarding reach = 890 feet
Carriage weight = 600 pounds
Minimum ground clearance for the carriage = 25 feet
Carriage clearance where logs become fully suspended = 55 feet

The ground profile shown in figure 7 is normally obtained, in a PLANS design, by digitizing the landing (SKYTOWER) or the two endpoints of the profile (SKYMOBILE) from a topographic map for which a DTM is available.

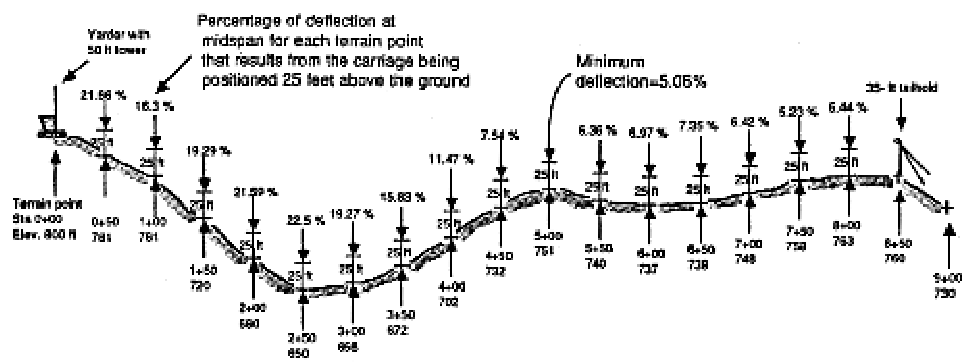

Figure 7—Finding the minimum percentage of deflection within a running skyline span.

The planner can position both the yarder and the tailhold on the profile to establish the required skyline span. In this example, the yarder has been positioned at station 0+00 and the tailhold at station 8+50 by the planner, who wants to know the maximum payload that can be yarded across that span. The solution begins by calculating the percentage of deflection of a parabolic curve at each of the terrain points between the yarder and the tailhold. Each curve is established to pass over its respective terrain points at a height equal to the minimum ground clearance specified for the carriage, which is 25 feet in this example. Sixteen terrain points occur between the yarder and the tailhold, each with a percentage of deflection solved and labeled (see fig. 7). The minimum percentage of deflection, 5.06 percent, occurs at station 5+00, which means this point limits the payload that can be yarded from the tailhold to the yarder. The midspan deflection for the parabolic curve passing through this point is solved by using equation group II; the resulting Y-value of -70.51 feet is calculated as the sum of one-half the elevation difference between the yarder and the tailhold (-27.5 feet) minus the midspan deflection (43.01 feet). This Y is used as Y_1 in equation group IV to determine the resulting payload of 8,619 pounds. The load path for this payload is plotted (see fig. 8) by using the parabolic curve (equation group II). Note that it intersects a point 25 feet above the terrain point at station 5+00, and it clears all other terrain points by more than 25 feet. This method determines the payload of the skyline span-a single payload that can be moved across the entire skyline span.

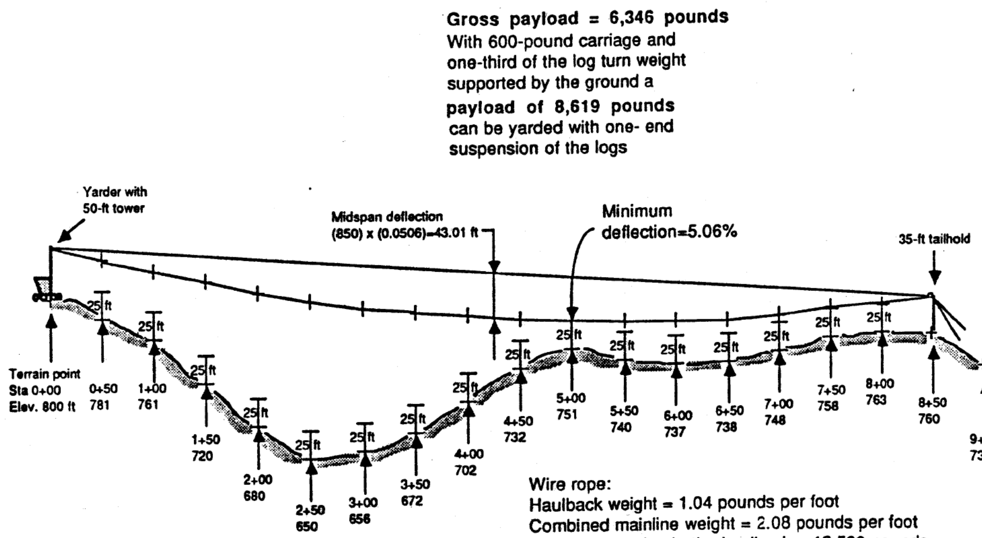

Figure 8 —Using the span's minimum percentage of deflection to obtain the initial skyline payload and load path for a running skyline.

The distance from the load path to each terrain point is checked, and if it exceeds the height where the logs become fully suspended (55 feet in this example), the full payload (8,619 pounds plus the 600-pound carriage) may have to be supported by the skyline. An iterative procedure (equation group I) is used to solve for the midspan deflection needed to support this 9,219-pound load. This midspan deflection in feet is converted to an equivalent percentage of deflection, which is used to calculate a second load path. This second load path, with a deflection of 7.02 percent (see fig. 9), is checked to see if it clears any terrain points by a height that is equal to or greater than the clearance required for full suspension of the logs. The example shows this occurred over the terrain from stations 1+00 to 4+00. It does not matter that the carriage clearance for the full suspension load path is less than the required minimum of 25 feet in other portions of the span (that is, station 5+00) because the full suspension load path does not apply where partial suspension occurs (from the yarder to station 1+00 and from station 4+50 to the tailhold).

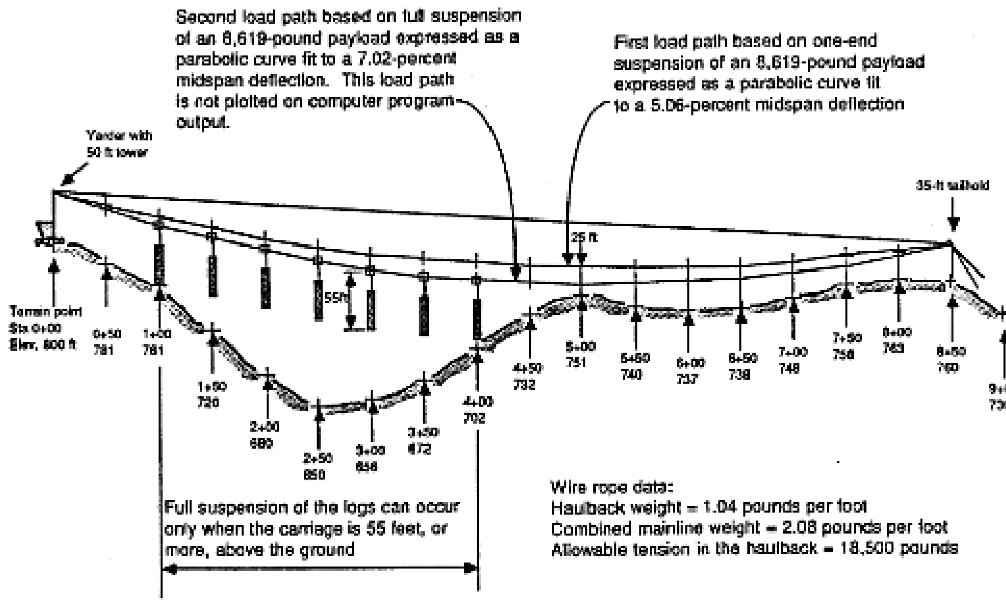

Figure 9—Method used to check if and where full suspension can occur on skyline spans requiring only one-end suspension of the logs.

In the plotted output of the PLANS program, the second load path is not shown, but the letter "F" is at the terrain points where full suspension of the logs from the second load path can occur-that is, from station 1+00 to station 4+00.

Example 2: Maximum Payload With Specified Span for a Standing Skyline

The planner must enter the following pertinent specifications for this example:

Weight per foot of the skyline = 2.08 pounds
Weight per foot of the mainline = 1.04 pounds
Allowable tension in the skyline = 37,000 pounds
Tower height = 50 feet
T ail hold height = 35 feet
Maximum yarding reach = 890 feet
Carriage weight = 600 pounds
Minimum ground clearance for the carriage = 25 feet
Carriage clearance where logs become fully suspended = 55 feet

The profile and the skyline span are established in a manner similar to example 1. In this example (see fig. 10), the planner wants to know the maximum payload that can be yarded from the tail hold, station 8+50, to the yarder, station 0+00. The analysis begins by calculating a skyline length (based on two straight-line segments) that can support the carriage 25 feet (minimum ground clearance for the carriage) above the first terrain point between the yarder and the tail hold. This calculation is repeated at each of the 15 remaining terrain points under the span, and the shortest of the 16 skyline lengths is used for the span analysis. For this example, the span's minimum skyline length of 852. 89 feet is based on clearing the terrain point at station 8+00.

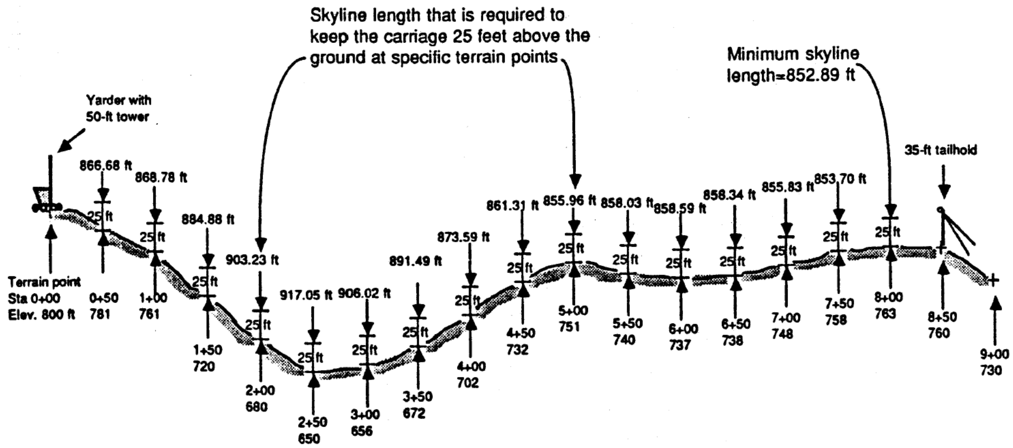

Figure 10—Finding the minimum skyline length within a standing skyline span.

When the minimum skyline length has been calculated, the midspan deflection and load path are solved for by using the elliptic curve (equation group III). Equation group IV uses the midspan deflection to solve for the payloads, 3,112 pounds with partial suspension and 2,075 pounds with full suspension. The load path for this example is shown in figure 11. The terrain points where full suspension occurs are from station 0+50 to station 4+50.

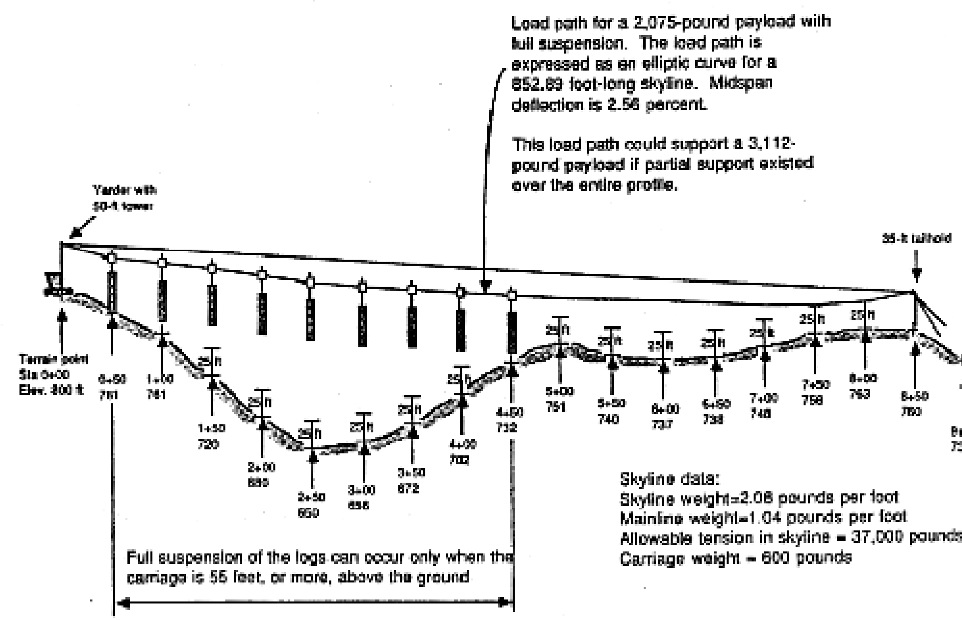

Figure 11—-Using of the span's minimum skyline length to obtain the initial payload, load path, and full suspension limits of a standing skyline.

This single load path of the standing skyline, unlike the running skyline example with one load path for partial suspension and a second for full suspension, reveals some special considerations for standing skyline systems that do not apply to running or live skyline systems. The length of the standing skyline is not changed during yarding operations; therefore, if the load path at any point is high enough above the terrain so that the log turn is fully suspended, the skyline must support the full payload without the benefit of increased deflection. The payload must be reduced to the load (less carriage weight) that can be fully suspended from the skyline at midspan. In the SKYTOWER and SKYMOBILE programs, this results in a one-third reduction in the payload. Program output will label such load paths with both payloads, and the terrain points where the logs are fully suspended will be labeled with an "F."

Example 3: Use of Yarding Limits

In many cases, using a low tailhold, like a stump, can be desirable in logging operations, but yarding right up to the low tailhold while maintaining adequate carriage clearance from the ground is impossible on most terrain. This is especially true with the standing skyline system, which provides less lift near the ends of the span than do the running skyline and the live skyline (see fig. 6). To overcome this problem in the SKYTOWER and SKYMOBILE programs, and in logging operations, yarding limits are set at either (or both) ends of the span. This forces the analysis to exclude terrain points outside. the yarding limits from constraints for minimum carriage clearance. Figure 12 shows the same terrain and skyline system used in example 2 with a yarding limit set slightly beyond station 7+00. The limiting skyline length for this terrain becomes 8.55.83 feet based on the terrain point at station 7+00. Without the yarding limit the skyline length was 852.89 feet, so the yarding limit has made it possible to yard the span with a skyline almost 3 feet longer than before.

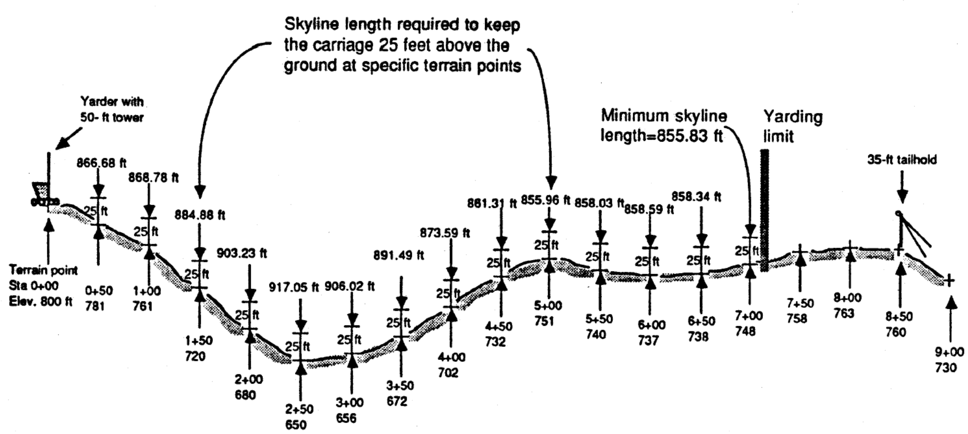

Figure 12—Finding the minimum skyline length within a standing skyline span with a set yarding limit.

This longer skyline results in the payload for full suspension increasing from 2,075 pounds to 5,613 pounds (fig. 13). The midspan deflection increases from 2.56 percent to 4.90 percent, and the length of the profile over which full suspension occurs is reduced from 400 feet to 300 feet. Although the payload for partial suspension also increases from 3,112 pounds to 8,270 pounds, this payload cannot be safely yarded across the draw at station 2+50, because full suspension will occur there.

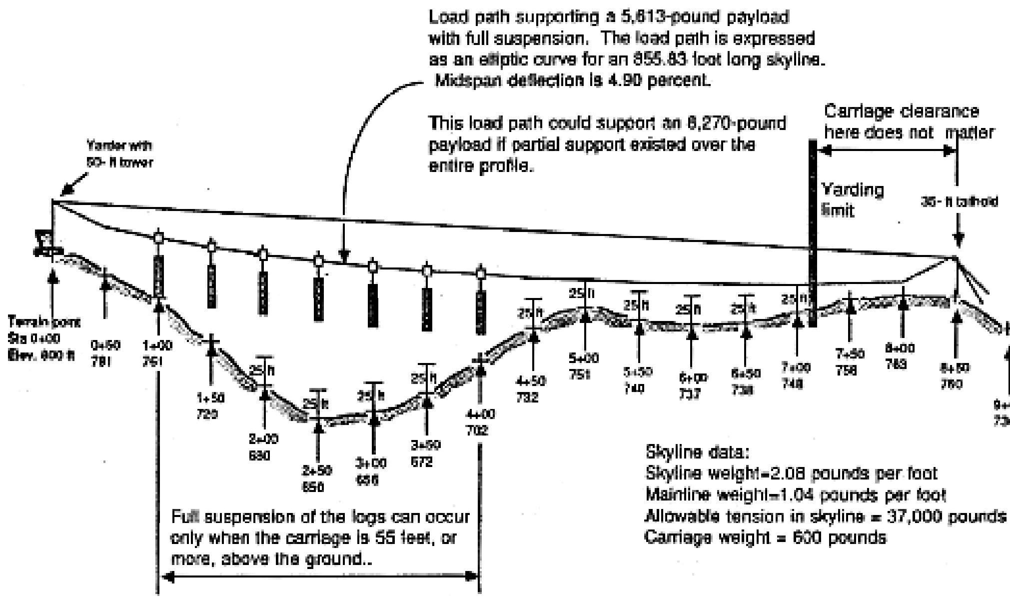

Figure 13—Using of the span's minimum skyline length to obtain the initial payload, load path, and full suspension limits of a standing skyline with a set yarding limit.

Example 4: Maximum Span With a Specified Payload for a Running Skyline

All the specifications that apply to example 1 apply to this example. In addition, the planner must specify the desired payload for the system, which is 10,000 pounds.

The ground profile (see fig. 14) shows the initial position of the yarder set at station 0+00.

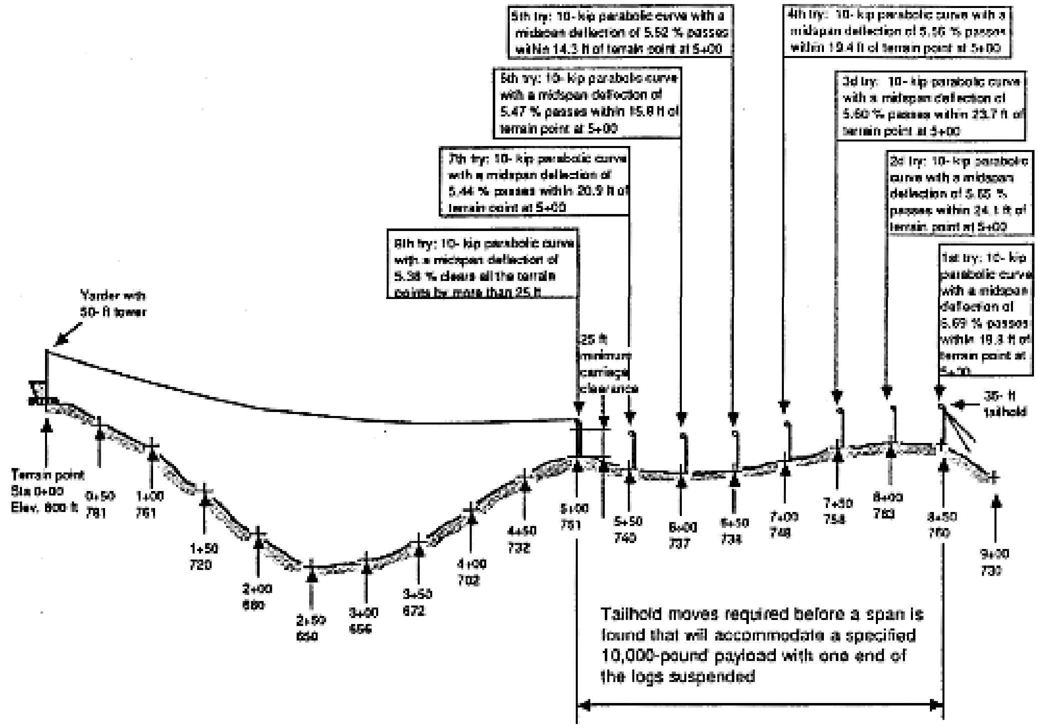

Figure 14—Procedure used to find the longest running skyline span that can accommodate a payload of 10,000 pounds.

When the skyline algorithm is directed to solve for the longest span over which the desired payload (10 kips) can be yarded, the following steps take place (fig. 14). The first span examined for the 10-kip payload has the tail hold at station 8+50. This position is set by the algorithm because the terrain point at station 8+50 is the farthest terrain point that is still within the yarder's maximum reach of 890 feet. The midspan deflection (5.69 percent) required to transport the 10-kip payload is determined via the iterative procedure (equation group I). A parabolic load path for the 5.69-percent curve is calculated (equation group II), and its clearance over each terrain point is checked. If the clearance equals or exceeds the minimum carriage clearance of 25 feet for all terrain points, the resulting skyline span can support the specified payload. The first load path came within 19.8 feet of the terrain point at station 5+00. Because this was less than the minimum carriage clearance of 25 feet, the routine moves the tail hold one terrain point closer to the yarder (to station 8+00) and repeats the process. For the situation shown in figure 14, seven different spans failed, all as a result of their load paths passing too close to the terrain point at station 5+00. On the eighth try, when the tail hold was moved all the way in to the terrain point at station 5+00, a successful span with a midspan deflection of 5.38 percent was found.

Once a span meeting the planner's specifications is found, some additional analysis is required. The initial load path is plotted on the graphics screen, and its clearance over each terrain point is checked. If the clearance is greater, at any point, than the carriage clearance where the logs become fully suspended, then additional analysis is needed. A second iteration uses the full 10,000-pound payload plus the carriage weight. This is what the load on the skyline would be if the logs were fully suspended. In this case (see fig.15), the midspan deflection resulting from this iteration is 7.64 percent, and the elevations for the corresponding second parabolic load path are calculated. The elevations of the second load path (which are lower than the initial load path) may not clear the ground sufficiently for the logs to be suspended. If this is the case, full suspension will not occur. This is not the case, however, in figure 14. The second load path with 7.64-percent deflection over that portion of the span from stations 1 +50 to 4+00 still clears the terrain points by the carriage clearance at which the logs become fully suspended. An "F" is plotted on the PLANS graphics output at each terrain point where the specified payload of logs can be fully suspended.

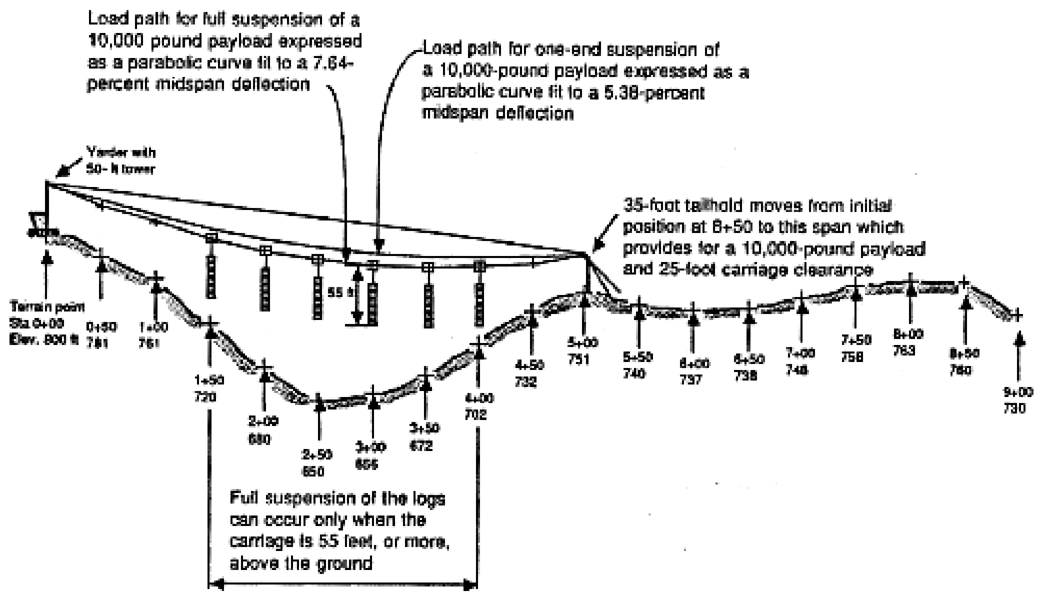

Figure 15—The load path and full suspension limits for the longest running skyline span that can support the 10,000-pound payload.

Example 5: Maximum Payloads in Excess of Specified Payloads for a Running Skyline

Occasionally a planner may want to know the maximum payload that can be yarded over a profile. The SKYTOWER and SKYMOBILE programs consider only the specified payload when solving for the maximum span. Figure 15 shows a substantial amount of lift and clearance associated with a specified 10,000-pound payload. SKYTOWER and SKYMOBILE can solve for the full load-carrying capacity of skyline spans even if the resulting payload exceeds the specified payload.

To solve for the maximum payload, the user must specify locations for the yarder and tailhold-stations 0+00 and 5+00, respectively. The skyline programs then solve directly for the maximum payload. This example is for a running skyline system with the same design criteria as was used in example 4. Figure 16 shows the limiting percentage of deflection (16 percent) resulting from the load path passing within 25 feet (that is, minimum carriage clearance) of the terrain point at station 1+00.

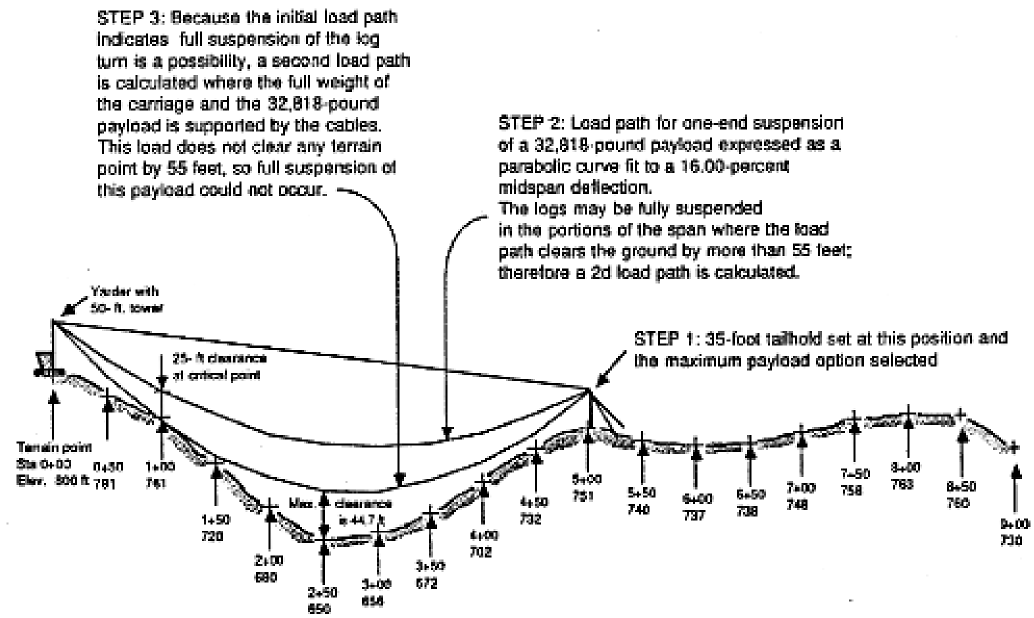

Figure 16—The maximum payload and load path for a running skyline span.

Solving for the maximum payload by using the midspan deflection, in feet, of this curve (equation group IV) results in a payload of 32,818 pounds for logs partially supported by the ground. The initial load path clears the ground over some terrain points by more than the height at which logs are fully suspended (55 feet), which indicates that full suspension is a possibility. This possibility cannot be realized, however, because the second load path, which puts the full 32,818-pound weight of the turn plus the '600-pound carriage on the skyline, does not clear any terrain point sufficiently to allow full suspension. The maximum clearance is 44.7 feet for the terrain point at station 2+50, which falls short of the 55-foot clearance needed for full suspension of the logs. Circumstances may indicate that a check for full suspension of the logs is needed, but the check may disclose that full suspension cannot occur.

Example 6: Maximum Span With a Specified Payload for a Standing Skyline

All the specifications that apply to example 2 apply to this example. In addition, the planner specifies that the desired payload for the system is 10,000 pounds.

The solution is the same as that in example 4 except for changing from a running to a standing skyline system. Unlike the running skyline (of example 4), the standing skyline load path does not use the parabolic curve and cannot accommodate two load paths. Figure 17, which applies to this example, is very similar to figure 14, except the load path is based on an elliptic curve calculated from equation group III. The slight differences in calculated midspan deflection are due to the differences between the mainline weight of the standing skyline and the weight of the mainline plus slackpulling line in the running skyline. The elliptic load path in this example comes slightly closer to the terrain point at station 5+00 because it is generally lower than an equivalent parabolic load path that was applied in example 4. The same tailhold position (at station 5+00) provided the longest skyline span capable of handling the desired 10-kip payload in both cases. This would not always be true, even with the equivalent-strength[3] skylines used in these examples. The running and live skylines have an operational advantage of being able to lift the payload higher by operating at all points in the span with fully tensioned wire ropes. This often means that running and live skylines can operate the same payload over a longer span than can the standing skyline.

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[3] The running skyline's haulback line is one-half the weight and strength of the single span skyline.

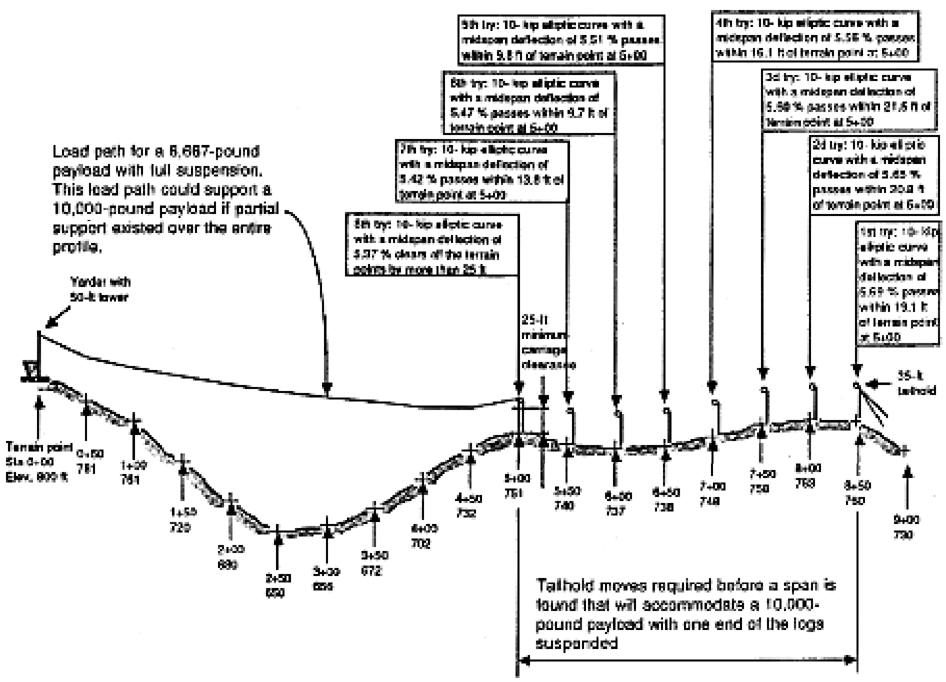

Figure 17—Procedure used to find the longest standing skyline span that can accommodate a payload of 10,000 pounds.

Example 7: Maximum Payloads in Excess of Specified Payloads for a Standing Skyline

In example 6, a span for a standing skyline capable of supporting the desired 10-kip payload was established. The planner can determine the maximum-load carrying capacity of this span by having the SKYTOWER and SKYMOBILE programs solve for payloads in excess of the desired payload. The results of this analysis show (see fig. 18) that the span can support a payload of 22,988 pounds on the portions of the span where one-end suspension of the logs occurs. On the portion of the span where full suspension occurs (stations 1 +50 to 3+50), the payload is reduced to 15,726 pounds because the full weight of the logs has to be supported by the standing skyline.

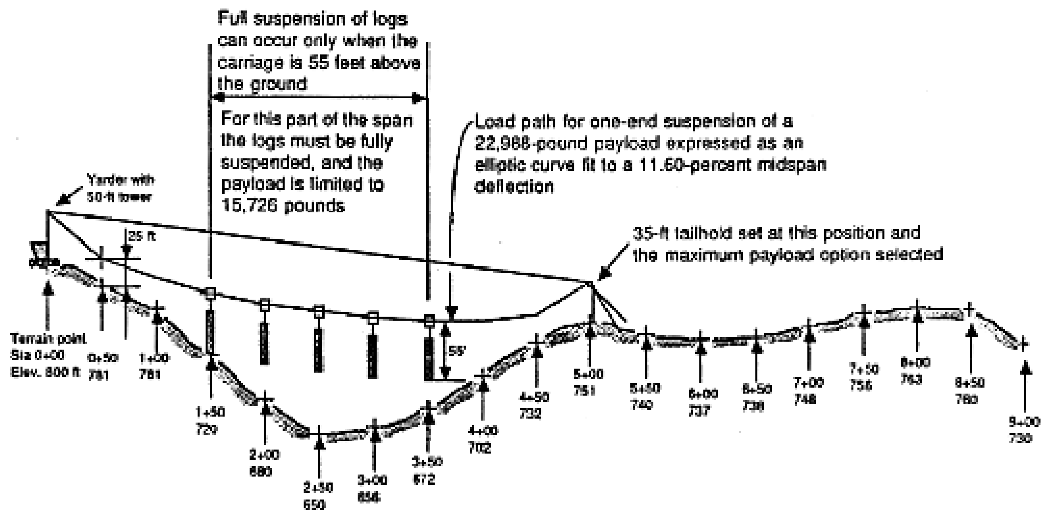

Figure 18—The maximum payload, load path, and full suspension limits, for the longest standing skyline span that can support at 10,000-pound payload.

Limitations

The limitations of the methods of skyline analysis in the SKYTOWER and SKYMOBILE programs reflect the extent that accuracy has been sacrificed for speed. Catenary equations describing skyline mechanics are the most accurate method for skyline analysis, but the results provided by catenary equations can be approximated with far less computational effort and computing time. Because the planning algorithms require exhaustive calculations of payload and load path for many spans on many profiles, using simpler approximations is better. The effect of approximations on the accuracy of skyline analysis should be understood, however, by the planner. Three approximations were used in the SKYTOWER and SKYMOBILE programs:

1. Treating skylines as straight-line segments, not as curved catenaries, in the iterative solution for midspan carriage position with a given load or for the payload for a given carriage position.

2. Using parabolic equations to describe the load path for the running and live skylines, instead of an iterative catenary or straight-line solution of each carriage position within the span.

3. Using elliptic equations to describe the load path for the standing skyline, instead of an iterative catenary or straight-line solution for each carriage position within the span.

Straight-Line Approximations of Skylines

When skylines are fully tensioned, their length and alignment can be closely approximated by straight-line segments. This fact has been used to develop algorithms that solve the load-path geometry by using desk-top computers with limited memory. Carson and Mann (1971) compared the difference between the load-path geometry solutions based on a straight-line (rigid link) approximation algorithm with the geometry based on a catenary solution. They report the percentage of error due to the straight-line approximation to be always within 1-2 percent of the exact catenary solution for the range of practical running skyline problems. The straight-line approximation approach is equally valid for single-line skylines.

The straight-line approximation method has been widely accepted for skyline analysis. It is generally agreed that the accuracy of the ground-profile data on which skyline analysis is based holds a far greater potential for error than does the straight-line approximation method. We believe that the use of the straight-line approximation method easily meets the accuracy requirements for broad-scale planning of harvesting units.

Parabolic Curve for the Running and Live Skyline Load Path

The average error for nine interior points in the skyline span (at one-tenth of a span, two-tenths of a span, and so on to nine-tenths of a span) has been calculated by comparing the deflection from the parabolic load path with the deflection calculated from an iterative solution (similar to that used to calculate midspan deflection shown in equation group I, which uses the straight-line approximation method) for a representative range of skyline load paths. These errors, listed in table 1, are somewhat greater when yarding is uphill rather than downhill and increase as the midspan deflection increases.

Use of the parabolic approximation would not be justified if timber-harvest planning of skyline systems depended primarily on accurate load-path projections for high deflections and large payloads (the error of the approximation increases considerably in that range). Midspan deflections of this magnitude tend to provide payloads that far exceed what is needed for good skyline production. The magnitude of the payloads (based on a 600-pound carriage and partial suspension of the turn at a chord slope of 0 percent) for the four different deflections shown in table 1 are 9,067 pounds for 5-percent deflection, 20,356 pounds for 1 a-percent deflection, 30,969 pounds for 15-percent deflection, and 40,698 pounds for 20-percent deflection. Deflections most often observed in skyline planning are in the range of 5-10 percent. Deflections in excess of that provide payloads beyond adequate; their exact magnitude may be of academic interest, but taking full advantage of them is difficult in a typical logging operation. The error that occurs when the parabolic approximation is used to solve for deflections in this range therefore does not appear significant from a practical viewpoint .

Table 1—Comparing differences at various skyline slopes between the vertical distance from the skyline chord to the loaded carriage as modeled by the parabolic curve vs. Carson's iterative method for calculating the load path curve for a running skyline.

	Average deflections[a] calculated at 100 foot intervals inside the 1,000 foot span											
	Skyline deflection 5%			Skyline deflection 10%			Skyline deflection 15%			Skyline deflection 20%		
Slope of the skyline chord	Error	Chord to carriage distance	Error	Error	Chord to carriage distance	Error	Error	Chord to carriage distance	Error	Error	Chord to carriage distance	Error
percent	percent	feet	feet	percent	feet	feet	percent	feet	feet	percent	feet	feet
-50	2.50	36.70	.92	4.71	73.62	3.47	7.62	111.09	8.47	11.03	149.65	16.51
-40	2.30	36.70	.84	4.44	73.63	3.27	7.34	111.16	8.16	10.85	149.90	16.51
-30	2.06	36.70	.76	4.03	73.63	2.97	6.89	111.20	7.66	10.46	150.10	15.70
-20	1.75	36.70	.64	3.51	73.63	2.58	6.24	111.22	6.94	9.60	150.23	14.72
-10	1.39	36.69	.51	2.85	73.62	2.10	5.37	111.20	5.97	8.86	150.25	13.31
0	1.02	36.69	.37	2.09	73.60	1.54	4.30	111.14	4.78	7.61	150.15	11.43
10	.63	36.69	.23	1.26	73.59	0.93	3.08	111.06	3.42	6.07	149.92	9.10
20	.25	36.68	.09	0.48	73.56	0.35	1.77	110.97	1.96	4.33	149.60	6.48
30	.07	36.68	.03	0.45	73.54	0.33	1.08	110.86	1.20	2.65	149.24	3.95
40	.33	36.68	.12	1.11	73.52	0.82	1.04	110.77	1.15	2.04	148.88	3.04
50	.53	36.67	.19	1.71	73.50	1.26	1.89	110.69	2.09	1.83	148.58	2.72
Average	1.17	36.63	0.43	2.42	73.59	1.78	4.24	111.03	4.71	6.87	149.68	10.28

a/ The load path curve calculated for the iterative method is based on a haulback line that weighs 1.04 lbs per foot with an allowable tension of 19,600 lbs, and a combined slackpulling plus mainline weight of 1.44 lbs per foot. Both the parabolic and the iterative curve pass through the same midspan point.

The effect that the average error in feet, when applied to the midspan deflection, has on the payload may be a more significant way for the planner to evaluate the adequacy of the parabolic approximation. The skyline inputs from table 1 show that the payloads could be expected to vary as follows: the 9,067-pound payload at 5-percent deflection ±0.43 feet would vary by ±99 pounds; the 20,356-pound payload at 10-percent deflection ±1.78 feet would vary by ±391 pounds; the 30,969-pound payload at 15 percent deflection ±4.71 feet would vary by +960 pounds; and the 40,698-pound payload at 20-percent deflection ±10.28 feet would vary by ±1,900 pounds.

The point to be made from this relation is that where the magnitude of the payload is critical, the error due to the parabolic approximation is small. The error increases as the importance of the exact size of the payload decreases.

Elliptic Curve for the Standing Skyline Load Path

The elliptic curve would correctly describe the load path of a standing skyline if the stretched skyline remained at one length and the straightline approximation of the skyline held true; neither of these suppositions are exactly true, however. The tension in a standing skyline will roughly double as the loaded carriage passes from the end to the middle of the span. This change in tension will change the stretched length of the skyline. This change is small, about 0.3 percent of the total length, but it has the effect of shortening the skyline when the carriage is at the end of the span. Another factor influences the load path when the tension is reduced; the skyline cannot be as accurately approximated by the straight-line method, and the catenary effect—or curvature of the skyline—becomes more influential.

The extent to which these factors affect the load path is shown in table 2. The load-path comparisons, which are projected from the yarder to midspan, are almost symmetric around midspan. The extent of the difference depends, in this case, on the weight of the mainline.

The error from the elliptic approximation of load path is consistently conservative. The error may reject skyline spans that, in fact, meet carriage clearance requirements, but the error will not validate a skyline span that is inoperable. We did not feel this error was large enough to justify using a more complex algorithm. The error, near the yarder, tends to be counteracted by the lift provided by the height of a tower. Errors occurring near shorter tailholds can be counteracted by using prudent yarding limits (see fig. 12).

Table 2—Comparing differences at various points In a skyline span between the vertical distance from the skyline chord to the loaded carriage as modeled by the elliptic curve vs. a catenary solution where the unstretched line length is held constant and the stretched length is varied with skyline tension

Horizontal distance from tower to the carriage	Vertical distance from the top of the tower to the carriage established by the elliptic curve [a]	Vertical distance from the top of the tower to the carriage established by the true load path [b]	Error in the elliptic curve		Length of skyline stretched	Length of skyline unstretched
feet	feet	feet	feet	percent	feet	feet
50	47.03	42.06	4.97	11.82	1016.82	1014.47
100	62.02	57.98	4.04	6.97	1017.70	1014.47
200	80.86	78.39	2.47	3.15	1018.75	1014.47
300	91.98	90.78	1.20	1.32	1019.35	1014.47
400	98.06	97.69	0.37	0.04	1019.69	1014.47
500	100.00	100.00	0.00	0.00	1019.83	1014.47

a/ This curve is established with a horizontal span of 1,000 feet and an elevation difference between the head and tail spar of 0 feet, and a fixed line length of 1,014.47 feet.

b/ The true load path is based on a catenary curve, and skyline stretch is accounted for.

Another consideration for the skyline algorithm errors involves the accuracy of the profiles extracted from the PLANS DTMs. When terrain breaks (points where the slope of the ground changes) are extrapolated from contour lines, some of the breaks are between the contour lines. If the terrain break is convex, then the true ground line, at the terrain break, will be higher than the profile indicates. The same type of error can occur when the profile, initially extrapolated from contour lines, is extrapolated from the DTM and divided into uniformly spaced terrain points. This source of ground-profile error is best constrained by using accurate topographic maps with reasonably close contour intervals (20 feet or less) and DTMs established with tight grid spacings. The error cannot be completely eliminated, and the effect it has on skyline analysis at convex terrain breaks is not conservative; some skyline spans analyzed through these profiles may be included on the plan even though they are inadequate.

Conclusions

The PLANS programs for skyline analyses are designed to provide the necessary convenience and efficiency for broad-scale planning while maintaining sufficient accuracy to ensure integrity of the harvesting design. Although the resulting harvest-unit designs often require field adjustment during layout they, nevertheless, provide a well-balanced initial plan for harvesting. Harvest plans developed with the attention to topographic detail and payload required by these programs provide a valid foundation for area analysis. The detail provided includes specific location of harvest-unit boundaries, cable spans, and payload. Production and yarding cost for the units can be determined by the simulation procedure in PLANS. This, in turn, can provide cost information that is sufficiently accurate to be useful for valid economic modeling and scheduling of management activities.

Metric Equivalents

1 inch = 2.54 centimeters

1 foot = 0.3048 meter

1 pound = 0.4536 kilogram

1 kip = 453.59 kilograms

References

Burke, Doyle. 1974. Skyline logging profiles from a digital terrain model. In: Proceedings of the 1974 Skyline Logging Symposium; 1974 January 23-24; Seattle. Seattle: College of Engineering-University of Washington: 52-55.

Carson, Ward W. 1975a. Analysis of running .skyline with drag. Res. Pap. PNW-193. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 8 p.

Carson, Ward W. 1975b. Programs for skyline planning. Gen. Tech. Rep. PNW-31. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 40 p.

Carson, Ward W. 1976. Determination of skyline load capability with a programmable pocket calculator. Res. Pap. PNW-205. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 11 p.

Carson, Ward W.; Mann, Charles N. 1971. An analysis of running skyline load path. Res. Pap. PNW-120. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 9 p.

Carson, Ward W.; Studier, Donald; Lysons, Hilton H. 1971. Running skyline design with a desk-top computer/plotter. Res. Note PNW-153. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 21 p.

Jones, J. Greg; Hyde, James F.C., III; Meacham, Mary L. 1986. Four analytical approaches for integrating land. management and transportation planning on forest lands. Res. Pap. INT-361. Odgen, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 33 p.

Lysons, Hilton H.; Mann, Charles N. 1967. Skyline tension and deflection handbook. Res. Pap. PNW-39. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 41 p.

McGaughey, Robert J.; Twito, Roger H. 1987. SIMYAR: a cable-yarding simulation model Gen. Tech. Rep. PNW-GTR-205. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 28 p.

McGaughey, Robert J.; Twito, Roger H. 1988. VISUAL and SLOPE: perspective and quantitative representation of digital terrain models. Gen. Tech. Rep. PNW-GTR-214. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 26 p.

Mills, Russell. 1932. Tension in logging skylines. Bull. 66. University of Washington Engineering Experiment Station. 30p.

Prince, M. David. 1971. Interactive graphics for computer-aided design. Reading, MA: Addison-Wesley Publishing Co. 301 p.

Reimer, Donald R. 1979. An operational computer assisted forest engineering system. In: Proceedings of the International Union of Forest Research Organizations symposium on mountain logging; 1979 September 10-14; Seattle. Seattle: College of Forest Resources-University of Washington: 17-19.

Reutebuch, Stephen E.; Evison, David C. 1984. The cable hauler planning package: user's guide. FRI Bull. 46. Rotorua, New Zealand: New Zealand Forest Service Forest Research Institute. 81 p.

Reutebuch, Stephen E. 1988. ROUTES—a computer program for preliminary route location. Gen. Tech. Rep. PNW-GTR-216. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 19 p.

Twito, Roger H.; McGaughey, Robert J. 1984. Computer aided timber harvest planning: an example. In: Proceedings of the mountain logging symposium; 1984 June 4-6; Morgantown, WV. Morgantown, WV: West Virginia University Press: 150-159.

Twito, Roger H.; Mifflin, Ronald W. 1982a. PLANS a preliminary logging analysis system. On file at: Forestry Sciences Laboratory, 4043 Roosevelt Way N.E., Seattle, WA 98105.222 p.

Twito, Roger H.; Mifflin, Ronald W. 1982b. Computer assisted evaluation of skyline thinning opportunities. In: Proceedings 7306, The small tree resource: a materials handling challenge; 1982 April 19-21; Portland, OR. Madison, WI: Forest Products Research Society: 73-79.

Twito, Roger H.; Mifflin, Ronald W.; McGaughey, Robert J. 19878. The MAP program: building the digital terrain model. Gen. Tech. Rep. PNW-GTR-200. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 22 p.

Twito, Roger H.; Reutebuch, Stephen E.; McGaughey, Robert J. 1987b. The HIGHLEAD program: locating and designing highlead harvest units using digital terrain models. Gen. Tech. Rep. PNW-GTR-206. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 22 p.

Twito, Roger H.; Reutebuch, Stephen E.; McGaughey, Robert J.; Mann, Charles N. 1987c. Preliminary logging analysis system (PLANS): overview. Gen. Tech. Rep. PNW-GTR-199. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 24 p.

U.S. Laws, Statutes, etc.; Public Law 94-588. National Forest Management Act of 1976. 16 U.S.C. 1600 (1976).

Young, G.G.; Lemkow, Daniel Z. 1976. Digital terrain simulators and their application to forest development planning. In: Proceedings of the 1976 skyline logging symposium; 1976 December 8-10; Vancouver, BC. Vancouver, BC: University of British Columbia Press: 81-99.

Appendices to this report containing step-by-step operating instructions for the SKYTOWER and SKYMOBILE programs are available from the Pacific Northwest Research Station. Copies of these appendices can be obtained by photocopying this page, filling in the necessary information, and sending it to:

USDA Forest Service
Pacific Northwest Research Station
Forestry Sciences Lab
Forest Engineering Systems
4043 Roosevelt Way N E
Seattle, WA 98105

These appendices include examples of designing skyline-harvest units and demonstrate many of the options and manipulations available.

If you wish to receive the PLANS program set—which includes SKYTOWER and SKYMOBILE—stored on diskettes, send five 5-1/4-inch double-sided, double-density, flexible minidisks.

Please send supplementary material for the SKYTOWER and SKYMOBILE programs to:

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Twito, Roger H.; McGaughey, Robert J.; Reutebuch, Stephen E. 1988. The SKYTOWER and SKYMOBILE programs for locating and designing skyline harvest units. Gen. Tech. Rep. PNWGTR-215. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 35 p.

PLANS, a software package for integrated timber-harvest planning, uses digital terrain models to provide the topographic data needed to fit harvest and transportation designs to specific terrain. SKYTOWER and SKYMOBILE are integral programs in the PLANS package and are used to design the timber-harvest units for skyline systems. SKYTOWER determines skyline payloads and spans for towers operating in fan-shaped settings from large central landings. The maximum yarding limit for each profile in groups of 18 circularly arranged yarding corridors is displayed after a landing is digitized on the digital terrain model. This unit can be modified to meet the planning needs. SKYMOBILE is similar except it is used for mobile yarders operating in parallel settings and permits several adjoining skyline spans to be designed on the same profile. Both use similar algorithms that permit quick solutions for either the longest span a designated payload can be yarded over or the largest payload that can be yarded over a designated span. Both program algorithms provide convenient ways to adjust the design and to locate and mark the final design on the topographic map. The algorithms :or these skyline solutions, which are approximations of exact catenary solutions for cables, are explained as are limitations of the methods used. Guides giving detailed operating instructions for the programs are available from the authors.

Keywords: Computer programs/programing, logging operations analysis/design, timber harvest planning, road building (forest/logging).

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