

A CASE STUDY OF THE KOLLER K300 YARDER ON A
NATIONAL FOREST TIMBER SALE IN THE APPALACHIAN REGION

by

Michael Kevin Rossie

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APPROVED:

Thomas A. Walbridge Jr., Chairman

William B. Stuart

Richard G. Oderwald

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INTRODUCTION

Projections of a continuously increasing demand for wood products in the future have spurred investigative efforts to improve the utilization of our timber resources. In the eastern United States, one area of effort toward achievement of this objective has been to increase the acquisition of timber heretofore considered economically inaccessible due to the high cost of logging steep and broken terrain.

Harvesting of timber from steep and broken terrain may be accomplished by conventional ground skidding methods with extensive skid road construction or by cable logging methods commonly practiced in the northwestern United States. Cable logging was originally developed in the South for harvesting of old-growth timber on poorly-drained soils. Since the depletion of the old-growth resource in the eastern United States, however, the application of cable logging methods has been primarily limited to highlead harvesting of the most valuable timber on difficult terrain. To date, the more sophisticated techniques of skyline rigging commonly practiced in the Northwest have seen little commercial application in the Appalachian region.

A concern for the environment, a desire to extend the forest resource base, and the increased volume of timber to be made available on steep slopes in eastern National Forests have renewed interest in the application of skyline harvesting techniques on these areas. The advent of light and relatively inexpensive skyline yarders from Western and European equipment companies offer a potentially cost-effective method for cable logging. Many factors, however, contribute to the reluctance of the eastern logging industry to accept skyline logging.

First, the growth/drain ratio for hardwood timber in Virginia is nearly two to one (Knight and McClure, 1978). Knowledgeable logging contractors are reluctant to invest in cable yarding equipment when little competition exists for an abundant supply of timber on terrain favorable to conventional harvesting methods.

Second, forest products markets in the Appalachian region are not sufficiently developed to support high-capital mechanized harvesting (Stuart, 1981). Wood buyers, equipment dealers, trained mechanics, and a trained labor pool are deficient in many of the areas of timber suitable for the application of cable logging. Access to these stands is still another problem. Often, the existing road system is not capable of supporting travel by fully-loaded log trucks, forc-

ing the contractor to under-utilize his transportation capabilities at an inflated cost.

Finally, cable operations typically experience low productivity and a higher delivered cost per unit than conventional ground skidding operations on similar sites. Thus, there is little incentive for contractors to invest in yarding equipment.

Despite the attendant problems associated with cable logging, the technique may have potential for future application in the Appalachian region. On the Jefferson National Forest in Virginia, approximately twenty-five to thirty percent of the total land area is on sustained slopes of greater than thirty-five percent. In the whole of Virginia, approximately ten percent of the total commercial forest land is located on slopes of greater than thirty-five percent and suitable for harvest through cable logging methods (Sloan, 1983). In the next five years, Region 8 of the United States Forest Service will offer sufficient sales on steep ground to support at least twenty-five cable harvesting operations.

Several light European and western yarders have been developed for harvesting of small timber on steep and difficult terrain but, to date, little information on machines of this type operating in Appalachia has been published. At

best, the information available offers a weak basis for harvest planning and comparison of the many available machine types.

The United States Forest Service Northeastern Forest Experiment Station in Morgantown, West Virginia is interested in improving knowledge and understanding of cable harvesting applications in the Appalachian region and provided the funds for this research. The Austrian Koller K300 yarder owned by Owens-Illinois of Big Island, Virginia was chosen for study because of its immediate availability and the company's two-year experience with yarding. This two-drum yarder rigged as a standing skyline was originally designed for use in thinning and smallwood clear-cutting operations and was introduced to western Virginia harvesting conditions by Owens-Illinois.

Burgeoning interest in the application of cable logging techniques in Appalachia makes machine production studies a timely subject. The Koller K300 skyline yarder is one machine that may have potential for cost-effective application in the eastern United States. To date, no detailed study and analysis of the Koller's productivity and cost has been made. Thus, the objectives of this research are:

1. To document the performance of the Koller K300 yarder in several yarding corridors

2. To identify variables which impact on machine productivity and use them to develop performance prediction equations
3. To evaluate the impact of yarding distance and corridor width on the productivity of the Koller K300 using a generalized machine simulator
4. To estimate the cost of harvesting with the Koller K300 yarder

LITERATURE REVIEW

Chappel and Schillings (1973) set forth four criteria necessary to the effective application of eastern harvesting systems:

1. Low capital investment. Capital outlay in any harvesting system must be no more than can be justified by the value of its realized production. In addition, the cyclical nature of timber harvesting mandates minimal fixed cost expenditures.
2. The system should be cost effective in a variety of stands and timber types. Cutting boundaries in the Appalachian region are often quite small and stocked with low-value hardwood timber or poorly stocked with high-quality saw timber. A logger should be able to operate economically in these stands as well as in the best timber available.
3. Equipment should be easy and quick to set up, take down, and move. This criteria is especially important for small cutting boundaries often encountered in the Appalachian region where frequent equipment relocation may be a major determinant of harvesting productivity.

4. Requirements for labor should be minimal. This criteria might better be stated by saying that the labor requirement should be optimized within the economic and engineering constraints of system design. Labor represents a variable system cost that can be adjusted. As such, the labor input to a system should be analyzed in the interest of efficiency and cost-effectiveness and adjusted accordingly.

Adaptation of light European skyline cranes to American thinning and harvesting applications has met with some success though the generally lower line-pull capabilities and shorter head spars limit the economical use of these machines to relatively uniform stands of small timber (Kellogg, 1981) such as stands commonly found in the western regions of the United States. A critical factor to be evaluated in the operation of these small systems is the labor requirement and its cost. With low-investment yarders, the fixed machine cost is roughly equivalent to the cost of an additional crew member (Kellogg, 1981). Consequently, the addition of men to a relatively low-production operation may exert a strong influence on the system's cost. Olsen (1981), in a 1980 yarder study using the Koller K300 yarder, reported a production increase with the addition of crew and a swing skidder, but a two-man crew (one machine operator

and one rigging slinger) decking logs was found to be the most cost-effective configuration.

Another critical aspect of the yarding operation is crew experience. Aulerich, in a presentation before the Cable Harvesting Applications Workshop at the University of Southern Mississippi in August, 1980 reported that expertise of the yarding crew may account for up to forty percent of the operation's production variance (Walbridge, 1980).

In 1972, the Department of Forest Engineering at Oregon State University in Corvallis embarked on a program of smallwood harvesting research. One of their first undertakings investigated the differences between tractors and skyline systems in thinning of douglas-fir. It was found that skyline systems outproduced the tractors but at a cost 1.5 to 1.6 times greater (Aulerich, 1975). Attention then turned to identification of the factors contributing to the higher cost of the skyline cable systems. Lateral yarding, consuming up to fifty per cent of the total cycle proved to be the key component. Reduction in the idle time of the skyline through reduction of lateral yarding time, then, could increase productivity and provide substantial savings in the unit cost of harvesting.

Several opportunities for the reduction of the lateral yarding element were investigated. First was an attempt to

maximize the lateral inhaul speed by adopting a policy of directional felling. Aulerich (1975) reported that in partial cuts, falling the trees away from the direction of skidding (falling away from the lead) is preferable where possible to minimize snags and lateral inhaul time. A study conducted by the Forest Engineering Research Institute of Canada (FERIC) found that falling trees out of lead caused an increase in the breakage of product and machine cables (McMorland, 1982) resulting in increased downtime and higher unit cost of the product.

A second method for reducing the lateral yarding element was found in the adoption of a gravity outhaul carriage using a skyline stop or lock to maintain position as opposed to a haulback line (Aulerich, 1975). Research conducted at Oregon State University found that use of a skyline stop reduced machine cycle time through the tendency of the carriage's momentum to "throw" the slack and the relative ease of slackpulling due to the free-spooling mainline drum (Aulerich, 1975).

Another advantage of the gravity outhaul or shotgun carriage is that the need for a haulback line is eliminated, thus enhancing the simplicity of the system. Dykstra (1976) found that the simpler skyline systems experienced fewer operating and repair delays, resulting in lower cost per unit

productivity. The highlead system, despite its even greater simplicity, however, was found to experience more frequent operating delays due to a greater number of snags: a consequence of less vertical lift exerted on the load.

Prebunching of logs has been shown in some cases to increase skyline productivity and may potentially reduce harvesting costs in skyline operations by reducing lateral yarding time. A thinning study conducted in 1980 by LeDoux and Butler (1981) found that

...For all machines involved in prebunching and swinging, the cost per unit produced apparently favors some form of prebunching. Although these preliminary costs are based only on direct costs, move-in, move-out, and the additional rigging required with the prebunching machine must be considered. The increased lead time needed for prebunching also must be considered in light of mill or contract requirements.

Similar results were reported by Kellogg and Aulerich (1977) who reported a reduction in total harvesting costs when prebunching was used in a skyline thinning operation. The technique appears to be most successful when used in conjunction with high-cost yarders (Kellogg, 1981).

Other methods that might potentially reduce lateral yarding time include bunch-felling, pre-setting chokers, or use of tongs under certain circumstances (Aulerich, 1978).

Determinants of logging productivity and cost have long been of concern to loggers and woodlands managers. Several

methods of investigating logging productivity have been attempted with mixed results. Tennas (1955) felt that:

Of the several techniques used in industrial performance analysis, the production study is probably the most applicable to the logging industry.

The majority of yarding machine production studies have been performed using a detailed timing approach, resulting in linear equations intended to model the machine's operational characteristics. In most cases, however, the models' ability to predict production has been weak due to wide variation in the yarding cycle. Cottell, McMorland, and Wellburn (1976) in a comparison of several yarding machines operating in British Columbia suggested that increased detail in timing or measurement of the site would do little to improve the resulting regression equations. For this reason, FERIC dropped the detailed timing approach in 1975 in favor of the work sampling method for estimating element times.

Despite a large margin of unexplained variance in yarding machine production models, various studies of light yarders have resulted in consistently similar results for defining the major determinants of yarder productivity. Brandstrom (1933) reported that for most logging machinery including yarders, piece size is the most important variable affecting machine cost and production. Cottell, McMorland, and Wellburn (1976) found that it was unusual for any yarding ma-

chine to produce an average of more than 220 pieces per shift, so piece size is critical. The operation's bucking policy should attempt to maximize piece size within the physical limitations of the machine and the landing.

In most studies, yarding distance is reported to be the most important variable influencing total cycle time. Gardner (1980), in a study of the Skagit GT3, found that other measurable determinants of the cycle time were lateral yarding distance, slope, number of logs, volume, and yarding distance. In his study of skyline productivity under alternative harvesting prescriptions and levels of utilization in larch-fir stands in Montana, he concluded that prior knowledge of yarding distance, lateral distance, and number of logs (chokers) on the mainline could be used to provide a reasonable estimate of system productivity.

As noted earlier, the hesitancy on the part of eastern loggers to adopt cable technology is due in part to low product volume and value per acre. Lysons (1977) noted that the small log harvesting problem is primarily one of economics: more logs must be moved to produce a given volume. An attendant problem to the low piece and per acre volumes is the widespread distribution of logs within the cutting area. LeDoux and Butler (1981) found that piece distribution within a cutting area is an important determinant of crew productivity in yarding operations.

Literature concerning the economics of cable logging in Appalachia is scarce at best. Gibson and Phillips, at the Cable Logging Conference held at Virginia Tech in 1973, stated: Of the cable systems available, we believe the lighter, less costly systems would be effective in Appalachia. Fisher, Gibson, and Phillips (1980) enumerated five reasons for the potential effectiveness of light cable yarders:

1. Slopes are predominantly convex in Appalachia. Smaller cable systems with a reach of 1000 feet or less would minimize the problems associated with convex slopes.
2. More than 75 percent of the forest land in West Virginia (typical of Appalachia in this regard) is owned by private individuals and has a limited tract size. Small cable systems are highly mobile and can easily be moved into small tracts. In addition, these machines can usually be moved on state highways without violating vehicle standards on height, weight, and width.
3. The smaller cable systems have a lower initial cost and can be better matched to small and low value timber than their larger counterparts.

4. The transportation of small cable systems do not require the wide roads necessary for the transport of their large western counterparts. Road building and maintenance cost may be reduced and less forest land is removed from production.

METHODS AND PROCEDURES

The purpose of this chapter is to present the methods and procedures used to accomplish the research objectives. Included are physical descriptions of the harvesting corridors, yarding crew, and the Koller K300 yarder. Field procedures are summarized and a description of data analysis techniques is given. The steps used to conduct the research are set forth below:

1. Project design and scheduling
2. Data collection
3. Gross data analysis
4. Machine performance prediction
5. Computerized machine simulation
6. Economic analysis

Project Design and Scheduling

Prior to commencing the production study, a meeting including representatives of Owens-Illinois, the Forest Service Research Station at Morgantown, and the Virginia Tech Department of Forestry was scheduled to reach agreement on research objectives, methods, and procedures. It was decid-

ed that the production analysis would be accomplished using the time study method and would result in performance prediction models based on data from several yarding corridors. If possible, videotaped records of machine operation would be made to facilitate intensive study of the machine/situation relationships.

Independent variables to be measured would include yarding distance, lateral yarding distance, corridor width, number of pieces per turn, volume per turn, and corridor slope. Stand characteristics on the study site would be recorded through the establishment of Forest Models¹ which would later provide a stand data base for harvesting machine simulation. An inspection of the site in which the K300 was then operating resulted in approval of the area for the production study. A review of similar production studies was made and field work commenced on Monday, July 26, 1982 on the Fletcher Mountain timber sale.

The first three days of field work were spent in observing machine operation so that a plan of study consistent with machine and crew operation could be designed. Specifically, the application of the time study method of production analysis required definition of machine cycle elements and variables to be investigated. Cycle elements had to be

¹ Installed according to American Pulpwood Association Harvesting Research Project (APA-HRP) guidelines

meaningful in terms of machine function and be easily and consistently timed over a day's work.

Seven elements were chosen for inclusion in the time study. They were:

1. Outhaul- The time required for the empty carriage to travel from the deck to the carriage stop on the skyline.
2. Mainline drop- The time required for the yarding hook to reach the ground after outhaul.
3. Walkout and set chokers- The time required to secure a turn to the mainline.
4. Winch slack- The time required to winch in mainline slack before winching the turn laterally.
5. Winch laterally- The time required for the turn to be winched from the yarding hook lock in the carriage.
6. Inhaul- The time required to winch the turn uphill to the landing.
7. Unhook- The time required to unhook the chokers at the landing.

Other variables measured for each cycle were yarding distance (from the tower to the carriage lock) and lateral yarding distance (horizontal distance from the carriage stop to the farthest log hooked in the turn). Specific instructions for the field study are included in the Appendix.

Gross information measured for each corridor included length and width of the yarding corridor, corridor profile, and rigging height in the tail tree.

As the machine cycle seemed relatively insensitive to small changes in distance, it was felt that measurement of distances to the nearest ten feet would be sufficiently precise. Thus, distance from the yarder was flagged at 50 foot intervals along the corridor and used as a guide in visually estimating the distance from the tower to the clamped carriage. Yarding distance was estimated to the nearest ten feet. Similarly, lateral yarding distance was visually estimated to the nearest ten feet using the known corridor width as a guide.

On the landing, incoming pieces were measured for cubic foot volume determination using Smalian's cubic volume formula:

$$\text{Cubic Foot Volume} = (B + b)/2 * L$$

Where B = large end cross-sectional area in square feet
 b = small end cross-sectional area in square feet
 L = total length of the piece in feet

Cross-sectional area is derived by assuming that the log ends are circular and using their diameter measurements in the area formula for a circle:

$$\text{Cross-sectional area (ft}^2\text{)} = 0.005454 \times (\text{diameter})^2$$

Where diameter is given in inches

The Harvest Area

The harvesting areas on which the Koller K300 were observed were included in a timber sale located in the Pedlar Ranger District of the George Washington National Forest in Amherst County, Virginia. The Fletcher Mountain area was accessed by traveling ten miles east of Buena Vista on U.S. Route 60 to a left turn on National Forest Road 2649 behind the Long Mountain Wayside. The timber sale area was approximately 1.3 miles up Forest Road 2649 from the highway. Elevations of the sale boundaries range from 2600 to 2900 feet.

Three yarding corridors were observed during the time studies of the K300. All were designated by the Forest Service to be harvested only by cable operations and required access by contractor-built branch roads and landings (see Figure 1). The harvesting prescription for all boundaries was clearcut.

Corridor 1.

Corridor 1 was characterized by a convex slope measuring approximately 400 feet (horizontal distance) in length with a maximum slope of 80 percent. The skyline corridor was set perpendicular to the slope and crossed a creek in a hollow, thereafter rising at a rate of 30 percent. Total horizontal length of the yarding road was 490 feet.

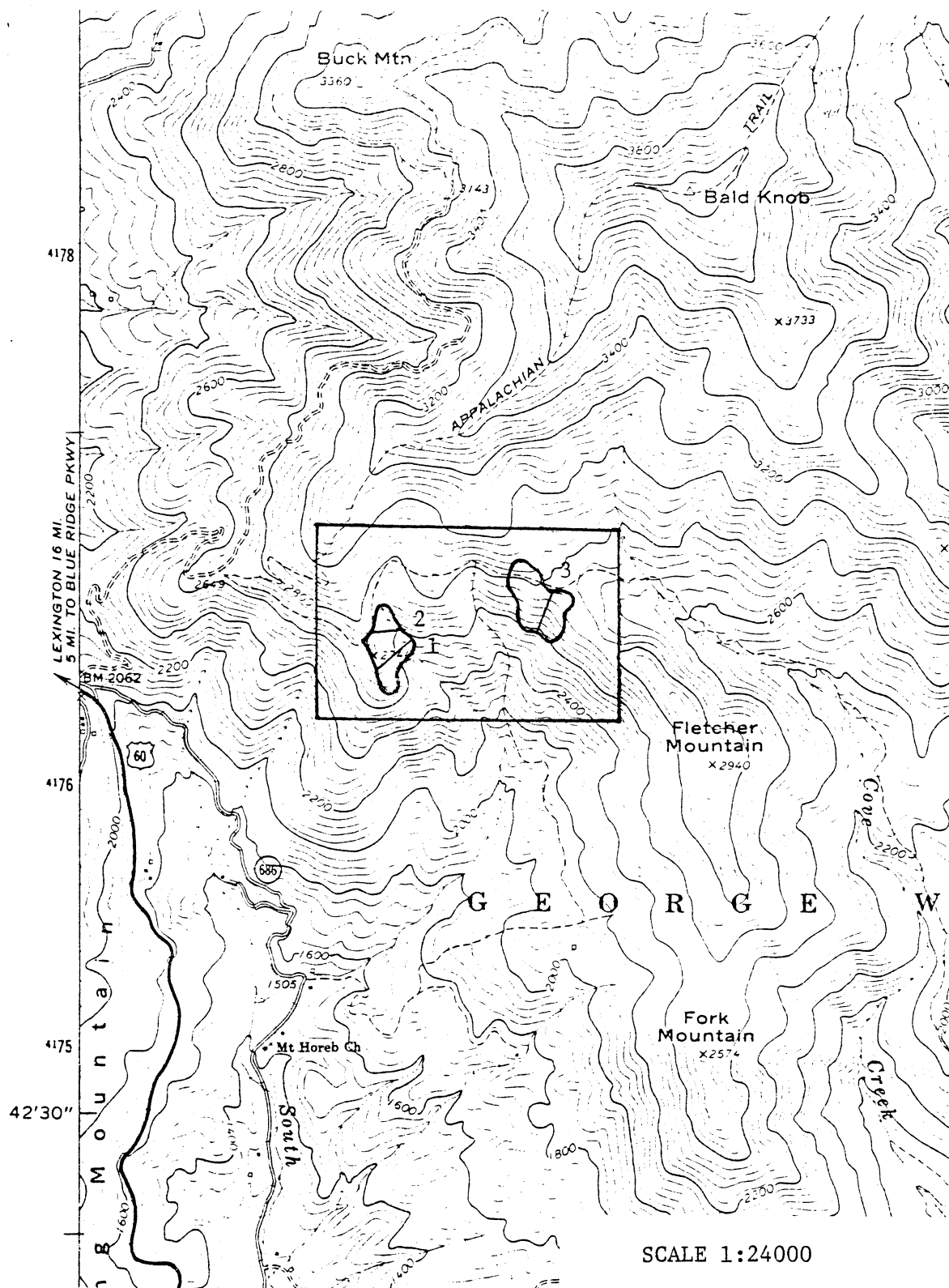


Figure 1: Location of the study area

The stand on Corridor 1 was typified by upland hardwood species (predominantly chestnut oak) approximately 80 years old. The average diameter at breast height (DBH) of the merchantable trees on the site was 10.6 inches (standard deviation=6.8 inches) and the average total height was 46 feet (standard deviation=14 feet). The distribution of tree diameters is given in Figure 2. Volume per acre is 1976 cubic feet (22 cords).

The skyline was rigged between the K300's tower and a red oak tree located at the edge of the cutting boundary. The skyline was suspended 40 feet in the tail tree. A vertical height of more than 100 feet from the creek to the skyline was provided to satisfy the contract stipulation of full log suspension over the creek. The skyline profiles for all three corridors are included in the appendix.

Logs were yarded laterally from distances of up to 120 feet from the skyline. Trees were felled, limbed, topped, and bucked at the stump prior to yarding. Bucking lengths ranged from 8 feet to tree length, depending on the quality of the log and the sawyer's perception of the K300's capabilities.

DISTRIBUTION OF TREE DIAMETERS ON CORRIDOR 1

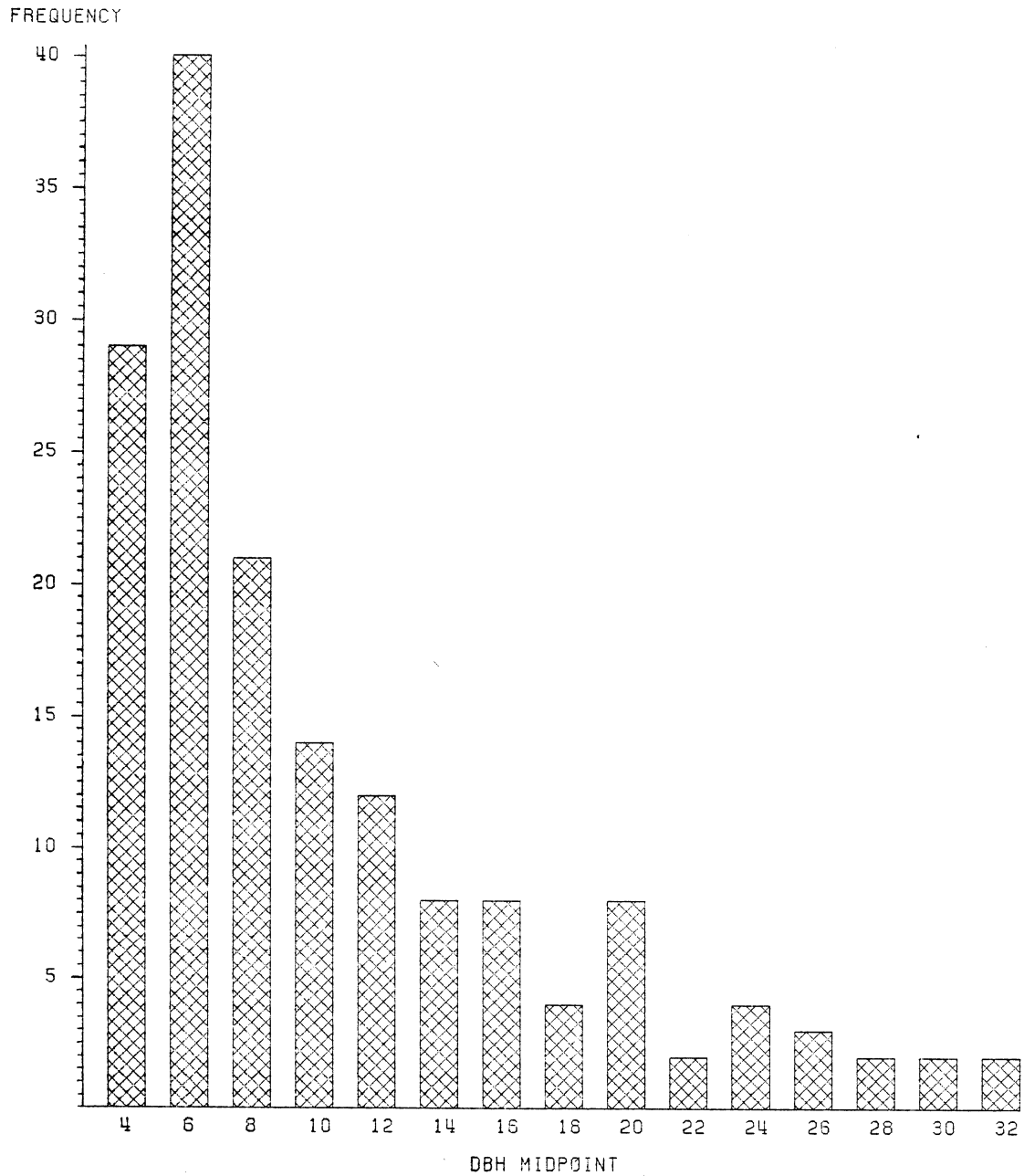


Figure 2: Distribution of tree diameters on Corridor 1

An intermediate support was rigged 50 feet from the tower at the brow of the hill so that the operator could take advantage of a large decking area. Landed logs were bucked if necessary by the operator/chaser or loader operator and immediately sorted and moved from beneath the skyline by a Prentice 210 loader. Pulpwood was loaded directly onto straight-frame trucks at this point for transport to the Owens-Illinois semi-chemical pulp mill at Big Island, Virginia. Saw logs were decked until a full load had been yarded and then loaded and transported to the Owens-Illinois sawmill at Buena Vista, Virginia. Figure 3 shows the log handling from site 1 to the mill.

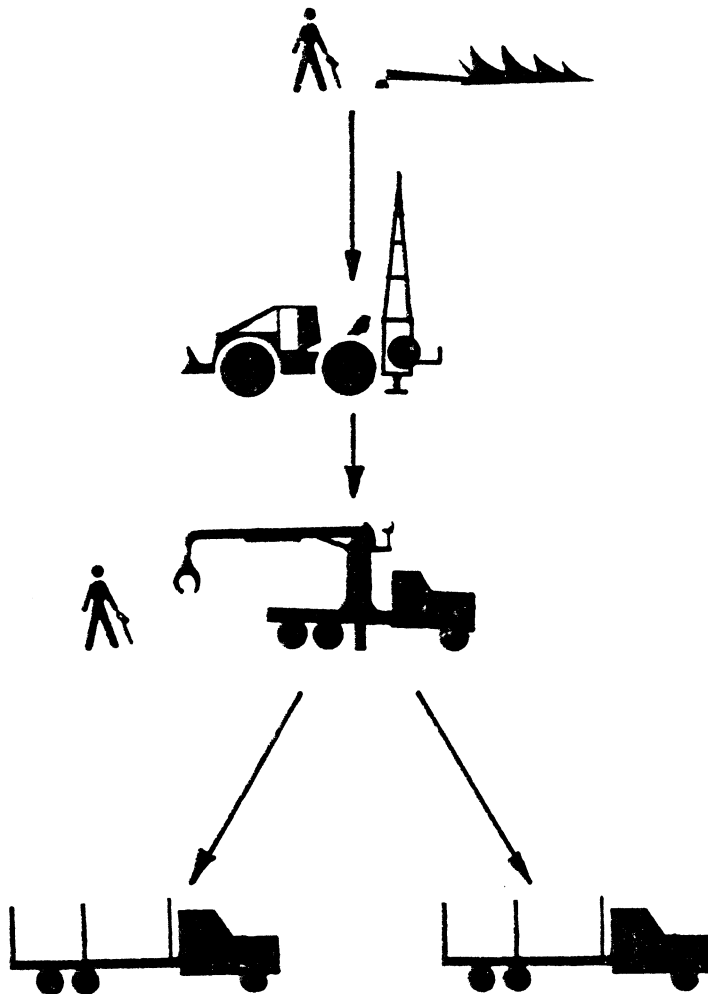


Figure 3: Wood handling on Corridor 1

Corridor 2.

The stand on Corridor 2 was comprised of upland hardwoods with some cove hardwood species in the hollow. The average diameter of the merchantable trees on the site was 10.1 inches (standard deviation=6.0 inches) and average total height was 46.5 feet (standard deviation=18 feet). The distribution of tree diameters is given in Figure 4. Volume per acre was 1536 cubic feet (17.1 cords).

Machine set-up consisted of a 410 foot skyline corridor located in the same cutting boundary as Corridor 1. The layout of the road was similar, passing over the same creek approximately 150 feet up from the first skyline road. The main slope averaged 60 percent and was slightly concave in shape. The skyline was set perpendicular to the slope and extended 100 feet beyond the edge of the boundary to a large red oak tree where it was anchored at ground level. No block or spar was used.

The K300 was set up on the permanent road by special permission of the Forest Service sale officer to provide lateral yarding access to the far corner of the sale boundary. In this set-up, no room for a landing was provided, making it necessary to use a swing skidder to move logs to a load-

DISTRIBUTION OF TREE DIAMETERS ON CORRIDOR 2

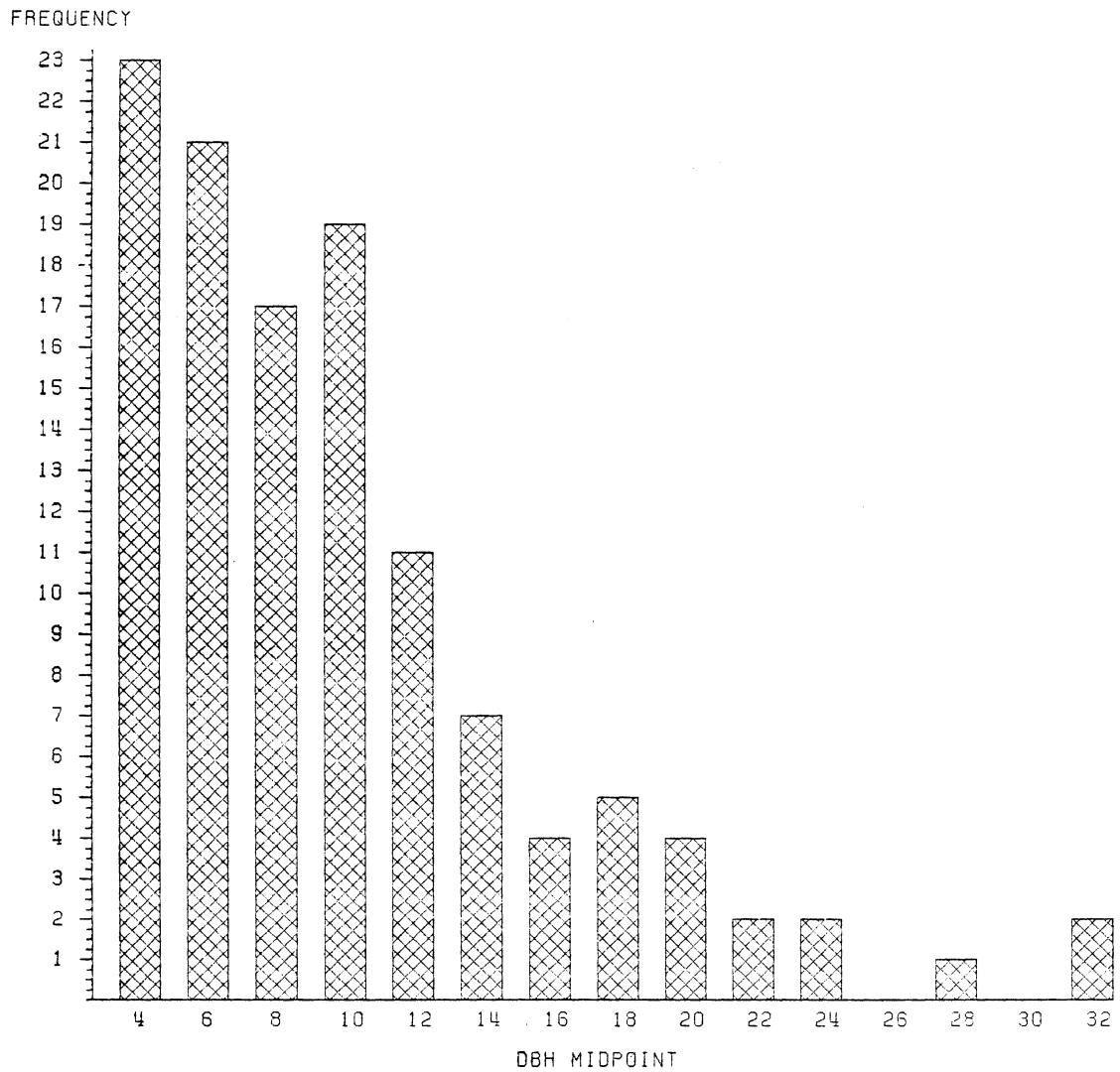


Figure 4: Distribution of tree diameters on Corridor 2

ing deck. As logs were landed, they were held by the main-line until the chokers on the Cat 518 skidder could be hooked to swing the turn. Two to three of the yarder's turns were combined for skidding to the landing 100 yards down the road. The Prentice 210 sorted and loaded as on Corridor 1. Figure 5 shows the handling of the logs.

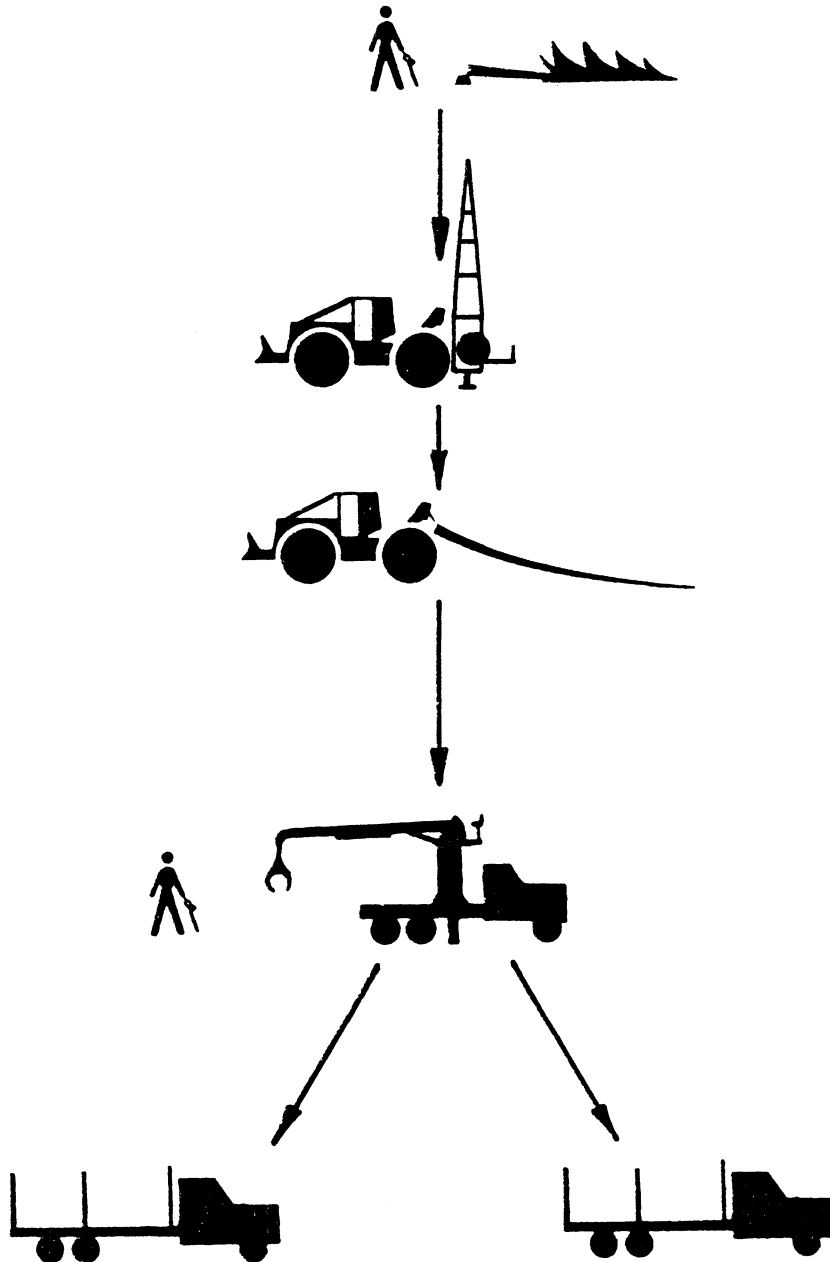


Figure 5: Wood handling for corridors 2 and 3

Corridor 3.

Corridor 3 was comprised of a skyline corridor 450 feet long with a nearly constant slope of 40 percent. The corridor followed a ridge in the terrain resulting in uphill lateral winching. The terrain was rocky and stocked primarily with low-quality hardwood pulpwood trees although some sawlogs were yarded from the low end. Time did not permit measurement of stand characteristics prior to felling of the corridor. Consequently, no specific stand information is available for this area.

The K300 was set on the brow of the hill providing just enough flat space to land the incoming logs. The skyline spanned a distance of 460 feet and was rigged 40 feet up in the tail tree at the edge of the cutting boundary. Due to a low skyline height on the uniform slope, lift on the yarded logs was minimal, resulting in 'plowing' of the skyline corridor.

One choker setter (as opposed to two on sites 1 and 2) hooked the turn at lateral distances of up to 100 feet from the skyline. The turn was then yarded to the base of the tower and unhooked by the operator who immediately returned the carriage to the woods. The swing skidder operator then

hooked his chokers to the drag for removal to the loader landing 75 yards away. Two to three turns were combined to form one skidder turn. Sorting and loading was accomplished as before (see Figure 7) .

The Koller K300 Yarder

The Koller K300 yarder is manufactured in Kufstein, Austria by J. Koller and consists of a 23 foot (7 meter) tower and two-winch drumset. The unit may be mounted on a carrier equipped with a three-point hitch and driven by the carrier's power take-off (PTO) shaft or mounted on the Koller trailer with integral engine. The minimum driving output requirement is 40 hp (30 kw).

The Owens-Illinois yarder is a slight modification of the three-point hitch design (See Figure 6). The yarder is mounted on the rear of a refurbished Timberjack 230D skidder. The drumset is driven by a Sundstrand fixed-displacement hydraulic motor and variable-displacement pump. Power to the pump is supplied by a link to the crankshaft of the Timberjack's GMC 3-53 diesel engine.

Power transmission to the mainline and skyline winches is accomplished by individual hydraulically-assisted single plate dry clutches. Skyline tension is maintained by a manually operated overband brake. The mainline drum is braked by a hydraulically-assisted band.

The mainline drum has a spool capacity of 1150 feet (350 meters) of 3/8 inch (9.5 mm) wire rope and develops an average line pull of 3950 pounds (1790 dN). Line speed varies from 0 to 16 feet per second (5 meters per second) depending

on the input shaft speed. The skyline drum has a spool capacity of 1150 feet (350 meters) of 5/8 inch (16 mm) wire rope. The skyline is tensioned on a section of bare drum adjacent to the storage drum. The average linepull in this section is 9920 pounds (4500 dN).

The yarder is equipped with two 100 foot (30 meter) wire rope guylines spooled on manually operated winches. The guyline diameter is 9/16 inch (15 mm).

The system employs a Koller self-clamping carriage (Model SKA1) with multispan capabilities. The carriage weighs 330 pounds (150 kg) and has a load capacity of 1.1 tons (1 metric tonne). A skyline slope of at least 15 percent is required for effective gravity outhaul.

Two clamping mechanisms are contained within the carriage and activated by hydraulic pressure derived from a sheave-driven pump and accumulator. The first clamping device controls the carriage brake on the skyline while the second device controls the cams which hold and release the yarding hook attached to the end of the mainline. The self-clamping design permits remote operation of the carriage by the yarder operator.

The carriage is lowered down the hill until the choker setter signals the stop and then pulled back at least 1 meter. When the mainline is slackened, the carriage clamps it-

self to the skyline and simultaneously releases the yarding hook and chokers, lowering them to the ground. Once the turn is hooked, the choker setter signals the operator to begin winching. As the hook joins with the carriage, the yarding hook is locked and the skyline brake released, allowing uphill winching of the load.

Further information on the Koller yarder and carriage is included in the appendix.



Figure 6: The Owens-Illinois yarder

The Yarding Crew

The yarding crew for the Owens-Illinois yarding operation consists of seven men including the system supervisor whose time is divided between two company harvesting operations. Yarding is accomplished by an operator/foreman and two choker setters. Two truck drivers and a feller comprise the remainder of the crew.

There is some rotation of labor within the system but the crew foreman operates the Koller ninety percent of the productive time and the two truck drivers are permanently assigned to their own trucks. The sawyer and one of the choker setters trade responsibilities at approximately two-week intervals.

All members of the yarding crew are between the ages of 26 and 44 and have at least eight years of logging experience and five years employment experience with Owens-Illinois. Only the system supervisor is college-educated. At the time the Koller yarder was purchased, a representative of Western Equipment Company from Eugene, Oregon provided a one-day workshop on the operation of the yarder. No other special yarding training was provided.

Data Collection

Data collection for this research was extended over a sixty-day period beginning July 26, 1983 and was comprised of numerous two and three day periods on the Fletcher Mountain site. Several factors including numerous machine breakdowns, addition of variables to the study plan, scarcity of manpower for the research crew, and temporary reallocation of the yarding crew to a ground skidding job prevented data collection in one contiguous time period.

The first step in data collection was to establish Forest Models in the areas to be subsequently harvested and time studied. The Forest Models later provided stand description information and "stands" to be harvested by a Generalized Machine Simulator (GENMAC) originally developed under the auspices of the American Pulpwood Association Harvesting Research Project (APA HRP).

Forest Models are one-acre plots representing typical harvesting conditions for a specific region and are comprised of detailed individual tree description including diameter at ground line and breast height, double bark thickness at ground line and breast height, total and merchantable heights, clear bole length, crown width, form (one of ten categories), species, and cut/leave category for each tree within the model. Two models were established within

the boundaries of the harvesting area and subsequently logged during the time study phase of the research. A model was harvested during the time study for each of the first two corridors.

Time study data was collected using the continuous timing method in which the ending time, to hundredths of a minute, was recorded for each element. Each element was defined as beginning at the end of the preceding element. Thus, there were no gaps in timing between the elements. The continuous timing method has the additional advantage of preserving gross time information despite lost or missed observations. For example, If the ending time of the outhaul element for a particular turn is missed, the total cycle time may still be calculated by subtracting the ending time of the preceding cycle from the ending time of the current cycle. Similarly, over any continuously timed period, the gross time may be divided by the number of cycles observed to arrive at the average total cycle time. On the three corridors studied, 216 total cycle times were obtained and comprise the data base for the analyses performed.

Approximately five and one-half hours of yarding activity on Corridor 2 was videotaped. This visual record of the operation provided a basis for intensive study of machine/crew interaction. The tapes were subsequently time-studied for inclusion in the data set.

Data Analysis

Field data collected during the time studies of the K300 was recorded by corridor and entered into a data storage file in the computer system at Virginia Tech. Statistical analyses were then performed on the data set by reading the appropriate variables from the central file and entering them into a statistical analysis package entitled Statistical Analysis System (SAS).

Analysis of the field data was accomplished in four steps. Where applicable, tables and figures are included to enhance understanding of the machine and system operating characteristics.

Gross Data Analysis

The gross data analysis consists of computation of cycle and element means and investigation of the type and frequency of operating delays. The purpose of these analyses are threefold; First, productivity estimates may be generated through knowledge of average cycle time and projections of machine utilization. Second, the contribution of each element to the total cycle and the element variability may be comprehended through representations of element sample distributions. Finally, investigation of delays may provide insight into the effects of delays on yarding activity.

Performance Prediction Models

The next priority was to assess the effect of potential performance predictors on the total cycle and its component elements. The STEPWISE procedure in SAS was used to determine the significance of predictor variables and their transformations to the linear prediction models. The procedure examines all variable combinations in a least squares regression analysis and reports the best model found using a single predictor, then two predictors, and so on until all variables given as independent have been fitted to the model for predicting the outcome of the dependent variable. "Best" is defined for the purpose of the analysis by the maximum coefficient of determination (R^2) obtained for each n-predictor model. The type II sum of squares is provided as a basis for significance testing of each variable entered into the model. An analysis of variance table provides the basis for testing of the overall regression.

The type II sum of squares is the sum of the squares (SS) of errors for each variable given all other variables in the model. The significance of each independent variable may be tested by comparing the type II SS against the mean square of the residuals in a partial f-test. For this report, the 95 percent significance level was chosen for testing the models and variables.

Each performance prediction model was developed on the basis of all data collected and then tested for its applicability to the individual yarding corridors through a coincidence and parallelism analysis as discussed by Swindel (1970). The effectiveness of the coincidence and parallelism analysis is predicated on the reassignment of model variance to the residual term for a complete model. The complete model is comprised of intercepts and coefficients for each situation to be tested. The sum of squares of error (SSE) for the complete model is identical to the sum of the SSE's for the individual situations.

Next, a reduced model is constructed by combining all observations of the predictor variable and fitting the linear model again. For example, if the intercept of the model is to be tested, then the reduced model will be constructed with a single intercept to replace the three given in the complete model. Any decrease in the model's predictability is reflected in a larger SSE for the reduced model. The SSE for the reduced model is then compared to that of the complete model in a partial f-test as shown in Table 1.

Several variables were measured during the field study for subsequent testing of their predictive capabilities. The first variable examined is the average slope of the yarding corridor. Presumably, as slope increases with all

TABLE 1

The Form of the Coincidence and Parallelism Tests

$$f = [(SSE - SSE*) / (df - df*)] / MSE$$

where SSE = The sum of squares of error for the reduced model

df = The degrees of freedom of error for the reduced model

SSE* = The sum of squares of error for the complete model

df* = The degrees of freedom of error for the complete model

MSE = The mean square of errors for the complete model

other factors held constant, the skidding force must also increase against the effects of gravity. Thus, on steeper slopes, the inhaul element would be slow relative to flatter areas. In addition, the increased difficulty of mobility on steeper sideslopes would tend to lengthen the time required for the choker setters to hook a turn and move to a safe observation point.

Increasing slope was expected to reduce cycle time. As carriage outhaul is accomplished through gravity, it is expected that outhaul rate will increase on steeper slopes. The time required for the chokers to reach the choker setters after the carriage locks on the skyline may also decrease.

The second potential predictor variable investigated was yarding distance. Most yarder production studies have found yarding distance to be the single most important production variable and significant in a variety of prediction models. Intuitively, as yarding distance increases (with all other factors held constant), one would expect the inhaul and outhaul elements to consume more time, thereby increasing the duration of the yarding cycle with corresponding negative impact on productivity. The cycle time increase will be small at close distances where the inhaul and outhaul elements comprise a relatively small proportion of the total

cycle. Both slope and horizontal yarding distances were investigated for an expected positive relationship with cycle and element time.

The third variable tested for its predictive capabilities was lateral yarding distance. All other factors held constant, an increase in yarding corridor width follows with an associated increase in lateral yarding time.

The final variable tested for its predictive capabilities is number of pieces produced per turn. As additional pieces are hooked, lateral yarding, unhooking, and total cycle time may be expected to increase. A narrow range of observations (one to four pieces) and wide cycle variability inhibits statistical significance of the variable as a predictor in all prediction models except lateral yarding.

Simulation Analysis

A computerized machine simulation package developed specifically for timber harvesting applications was used to evaluate the impact of corridor width and length on the hourly productivity of the Koller K300 yarder. Time study data provided the basis for the simulation of machine operation and the Forest Model constructed on Corridor 1 (number 94 in the Forest Model files at Virginia Tech) provided a "stand" to be harvested.

The Generalized Machine Simulator (GENMAC) used to simulate yarding activity treats the skyline carriage as a limited area machine such as a cable skidder. The carriage travels down the center of a simulated corridor stopping at the first tree or piece encountered. A turn is then accumulated by acquiring consecutive pieces in the search pattern until either all of the "chokers" have been filled or the maximum diameter limit has been reached. The load is then "winched laterally" to the center of the corridor and the inhaul element begins. The cycle is repeated, searching an area the width of the specified corridor and up to ten feet² feet in front of the carriage location until the entire corridor has been harvested. At this point, the yarder "moves" to the head of the next swath and continues as before. The operation is repeated until the entire "tract" has been harvested.

The machine cycle is modeled stochastically in GENMAC through a series of five machine functions whose duration is defined by linear regression models in conjunction with the Gauss subroutine or distribution functions derived from the time study data. The Gauss subroutine is used to generate a random Normal variate about the predicted value of the regression using the regression standard deviation (Farrar,

² Ten feet was chosen to simulate actual yarding activity observed on the Fletcher Mountain study

1981). A description of each element with its input function for the simulation is given below.

1. Outhaul is modeled in GENMAC in the travel unloaded (TRAVU) function. The outhaul time in minutes is given as a linear function of the distance from the deck or landing to the location of the carriage.
2. Walk and set chokers. These two elements are modeled together through the use of two consecutive acquire (ACQR) functions. The first ACQR card (time = 0) is a dummy card used to accumulate a turn. It is followed by a second ACQR function which specifies the sample distribution of hooking times observed within the specified corridor width. GENMAC randomly samples the distribution to generate a hooking time for each cycle in the simulation.
3. Lateral winching time is modeled in the process (PROC) function and is given as a distribution derived in the same manner as the ACQR distribution. PROC occurs only once per cycle.
4. Inhaul time is modeled in the travel loaded (TRAVL) function, where time in minutes is given as a linear function of the distance from the carriage location to the landing.

5. Unhooking time is modeled through random sampling of the unhooking time distribution observed in the time study. The value is input on the disposition (DISP) card in GENMAC.

Road changes are modeled in GENMAC through the use of the TURN function. In practice, the road change includes take down of the current machine set-up, machine relocation to the top of the next harvesting corridor, and rigging of the skyline and guys. The gross rigging time is highly variable and appears to be primarily a function of the amount of rigging required. Hanging the skyline in a block on a tail tree for example requires up to thirty minutes longer than simply anchoring to a stump on the backslope. If intermediate supports are rigged, the rigging time is further increased. Two sets of simulations were run for the analyses performed here. The first set assumes road changing time of two hours, and the second set assumes one hour.

The "stand" harvested by GENMAC is described by a Forest Model (number 94 in the Forest Model files) constructed from data collected on Corridor 1 in the study area. When an area larger than the Forest Model itself is desired for a simulation, the model is duplicated until an area of the desired size has been built. Each simulation harvested an area of six acres whose horizontal dimension (along the sky-

line corridor) is determined by the desired corridor length. More corridors were required to harvest the 208 foot corridors than were required to harvest the 416 foot and 624 foot corridors. Figure 7 shows the harvesting area layout used to simulate the harvest for each corridor length.

GENMAC was originally developed to model machine operation beginning with standing trees or, at least, trees felled at the stump and left whole. Consequently, the Forest Model stand input file had to be modified to simulate a stand that had been felled and bucked in preparation for yarding. This was accomplished by plotting the stump locations of the merchantable trees in the model, then tipping the merchantable height of the tree downhill and "bucking" it into merchantable lengths according to the product code given in the model. The bucked pieces were then assigned a unique identification number and recorded with the coordinate location of the end nearest the landing in the modified tree file.

The output generated by GENMAC includes a standardized report summarizing machine performance and productivity under the prescribed harvesting conditions. The distributions of volume produced for each simulated hour were used as the input to a two-way analysis of variance for determining the effect of corridor dimension on hourly productivity. The

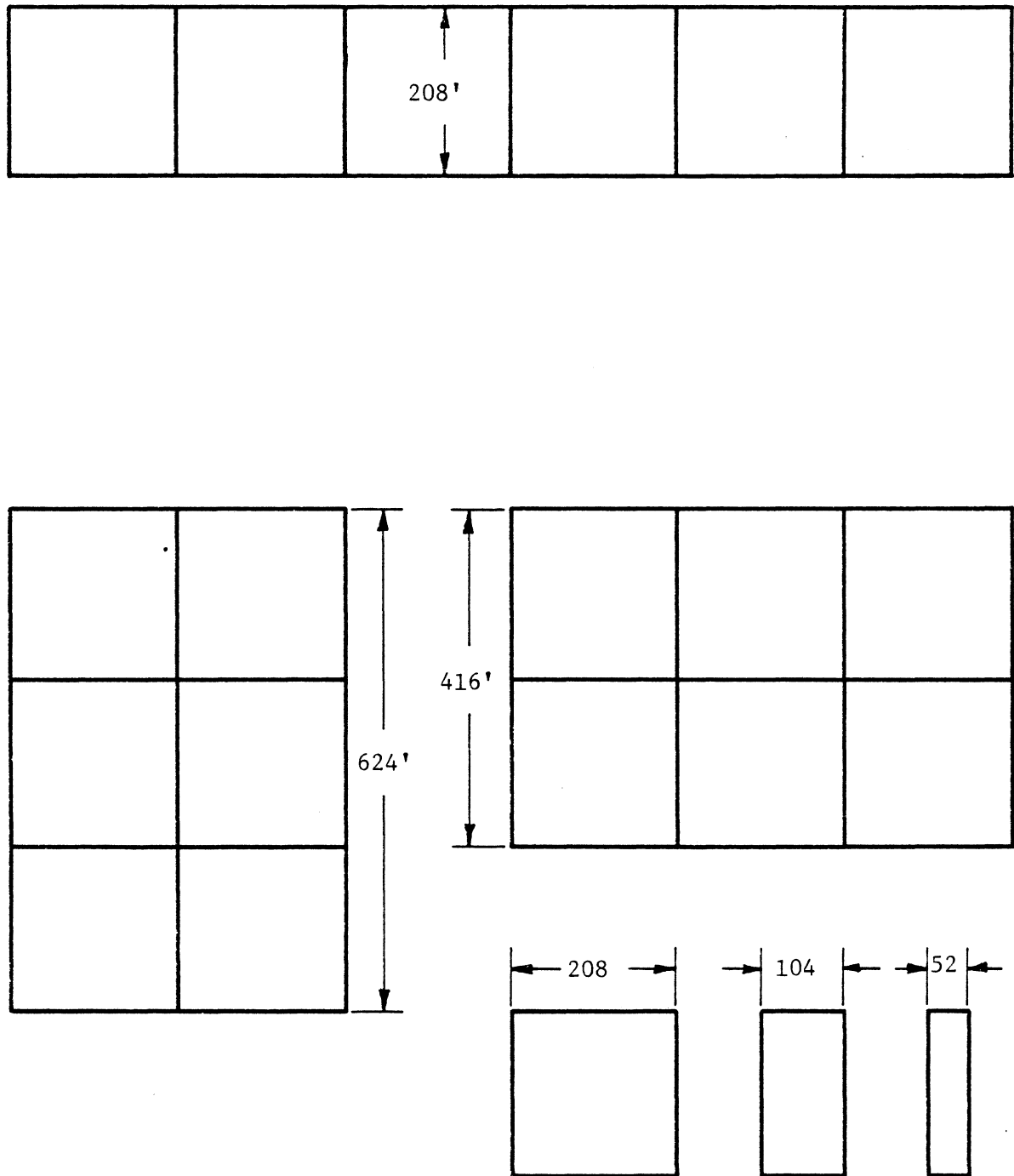


Figure 7: Simulated harvesting areas for each corridor length

Duncan's multiple range test was performed on corridor width and length means to test for differences in productivity due to changes in corridor dimensions. The 95 percent significance level was used. Because of the dangers associated with extrapolating real data beyond its range, corridor lengths are limited to 624 feet (The length of three square acres placed end to end) and corridor widths to 208 feet (the width of one square acre).

Economic Analysis

A matter of importance to harvesting supervisors, wood buyers, and wood sellers alike is the cost of timber harvest. Generally, costs are estimated for a given system by grouping costs into three categories: fixed or ownership costs, variable or operating costs, and labor costs, which have properties of both fixed and variable costs.

The estimation of fixed costs was accomplished by assuming the system was to be used by a private logging contractor who purchased his equipment new and financed through the equipment dealer. Equipment prices and terms of the financing were obtained from Mr. Chuck Lieber of McIntyre Equipment Company of Salem, Virginia. The add-on financing rate

used in the calculations includes creditor life insurance. Fire, theft, and vandalism insurance is added to the weekly equipment payment and was derived from insurance premium quotes obtained from Aetna Insurance Company's "quick-quote" service for construction machinery. Taxes given are based on current Montgomery County, Virginia property tax rates for construction equipment.

Machine operating costs were obtained from "Machine Rate Calculations and Productivity Rate Tables for Harvesting Southern Pine" (Cubbage, 1981). Since no cost experience with the Koller K300 in the East has been recorded, the operating costs are assumed to equal the operating costs of a Prentice 110 loader by virtue of machine similarities. Specifically, both machines are stationary and have similar engine sizes.

Labor costs are computed from assumed hourly wages plus thirty percent fringes. Each crew member is assumed to work eight hours each day and five days each week.

Finally, yarding production rates are computed based on the average cycle time and volume produced per turn during the time study at Fletcher Mountain. The weekly costs are summed and divided by the weekly production in cords to arrive at an estimated "on-board truck" cost for various levels of yarder utilization. Hauling costs are excluded from the calculations.

RESULTS AND DISCUSSION

Gross Data Analysis

The sample mean and standard deviation for each element and element delays are given in Table 2. The sample means and standard deviations for each yarding variable are given in table 3. The mean total cycle time and volume produced per turn are used in Table 4 to derive an estimate of hourly productivity in the absence of delays.

Figure 8 shows the average percent contribution of each element to the total cycle time and the percent of the total number of delays observed in each yarding element. Delays that prevent the completion of a cycle are noted as "total cycle delays". Lateral yarding is the most time-consuming element in the yarding cycle and subject to more frequent delays.

Table 5 shows the frequency and mean time of delays for each corridor. The Duncan's multiple range test performed on the mean delay times for each corridor concluded no significant difference between corridors 1 and 2 ($p > .05$) but delays were significantly longer on Corridor 3.

TABLE 2

Sample Means and Standard Deviations for All Element and
Cycle Observations

Times in Minutes	n	mean	standard deviation
Outhaul	236	0.49	0.15
Outhaul delays	0	--	--
Lateral yarding	220	2.92	1.06
Lateral yarding delays	36	2.46	2.62
Inhaul	238	1.18	0.49
Inhaul delays	5	4.83	1.91
Unhook	229	0.56	0.33
Unhook delays	2	0.64	0.13
Total cycle	216	5.10	1.30
Total cycle delays	8	24.49	9.73
All delays	51	6.08	9.13

TABLE 3

Sample Means and Standard Deviations for All Yarding
Variable Observations

Variable	Mean	Standard Deviation
Yarding distance	328 ft	137 ft
Lateral Yarding Distance	45 ft	35 ft
Number of Pieces Hooked	1.64	0.63
Cubic Foot Volume Produced	36.07	17.69

TABLE 4

Projection of Yarding Productivity from Mean Cycle Time

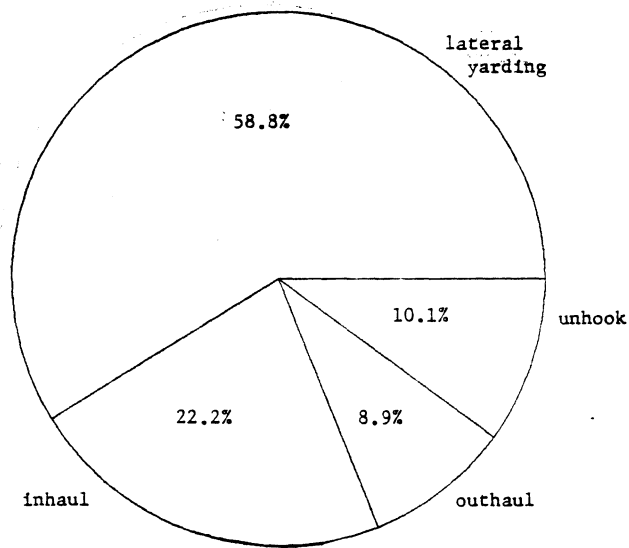
Average Cycle Time	5.10 minutes
Number of Cycles per Hour	11.76 cycles/hour
Average volume produced per turn	36.1 ft ³
Total hourly productivity	424.7 ft ³

TABLE 5

Frequency and Duration of Delays by Corridor

Corridor	Frequency of occurrence per one hundred cycles	Mean duration (minutes)
1	17.0	4.94
2	24.4	3.16
3	18.8	11.18

PERCENT OF CYCLE TIME SPENT IN EACH ELEMENT



PERCENT OF DELAYS OCCURRING IN EACH ELEMENT

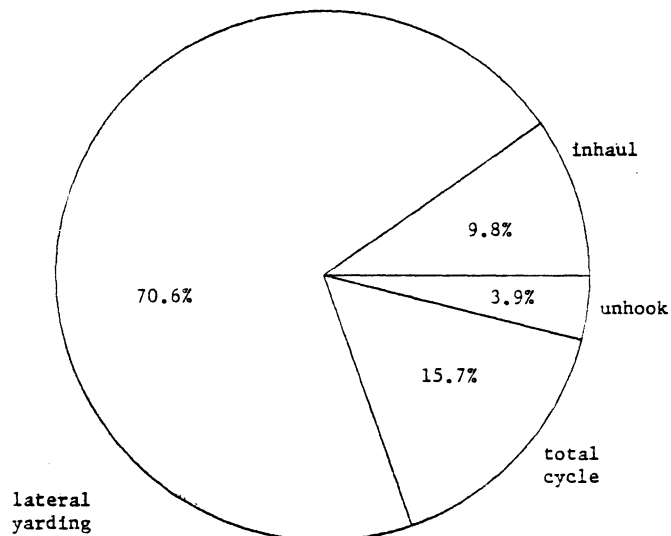


Figure 3: The percent contribution of each element to the total cycle and the percent of delays in each element

The single most time-consuming delays observed were mainline breaks which, in all cases, occurred after the yarding hook locked into the carriage prior to inhaul. When the yarding hook rejoins the carriage following lateral yarding, a moment of slack is required for the carriage brake on the skyline to release. When the operator's line of sight to the carriage stop is obstructed, he must rely on a signal from the choker setter or the feel of the controls to know when to give slack to the mainline. If the operator remains unaware that the hook has mated with the carriage, he continues to tension the mainline against the carriage brake which may result in the mainline breaking. The average time required to repair a mainline break was 27.34 minutes.

Four of the five mainline breaks observed during the time study occurred on Corridor 3 within a two day period. As no personnel changes were made between sites, it appeared that the breaks were precipitated by some difference in the yarder set-up on this Corridor 3. One possibility which seems likely is that an area of approximately one acre at the top of the corridor was not felled prior to moving in the yarder in order to provide a selection of intermediate support trees should a multispan layout have been required. The ef-

fect of the unfelled trees was to obscure the operator's view of the carriage which resulted in repeated tensioning of the mainline against the carriage brake prior to inhaul. The resulting overload may have weakened the mainline cable, thereby increasing its chances of failure.

By far the most frequently observed delay occurred during the breakout of the pieces hooked for a turn; The K300 was not able to pull the load to which it had been hooked. When a delay of this type occurred, the choker setter would signal the yarder operator to stop and then attempt to resolve the hangup by rehooking the turn, loosing a part of the load, or bucking the pieces shorter. In many cases, the cause of the hangup appeared to be limbs that were not cut off the stem at the time of felling. The average time spent in delays of this type was 2.39 minutes.

Of the delays that occurred on Corridor 2, sixty-five percent were lateral yarding hangups. A possible explanation for the high occurrence of this type of delay might be the position in the yarding corridor where the majority of Corridor 2 data was collected. As trees were felled downhill, limbs and tops tended to accumulate at the bottom of the corridor reducing the visibility and mobility of the crew in that area. Limbing and bucking appeared to have been done less carefully in those areas resulting in pieces

too large or too limby for the K300 to break out. Nearly all of Corridor 2 data was collected from the bottom while observations from corridors 1 and 3 were distributed more uniformly throughout the yarding corridor.

All delays observed for this study may be classified as operating delays inasmuch as the occurrence of a delay interrupts machine operation in the middle of an ongoing cycle. The nine categories of delays observed during the study period are ordered in Table 6 by frequency of occurrence. The "miscellaneous" delays given in the table include three unusual delays. The first was caused by a choker slipping off the hooked log while the mainline was under tension. The sudden release caused the carriage to roll over the skyline twice which required slacking of the skyline to untangle the cables. The delay lasted 22.12 minutes.

The second unusual delay occurred on corridor three when the winch speed adjustment cable broke halting inhaul of the current turn. A repair was improvised until a new part could be obtained. The delay lasted 32.11 minutes.

The third unusual delay was the result of a short downpour that hampered visibility of the yarding crew. The rain shower lasted five minutes.

TABLE 6
Operating Delays

Delay Description	Average duration (minutes)	Frequency of occurrence (per 100 cycles)
<u>Lateral yarding delays</u>		
Load won't breakout. Interrupts lateral yarding element	2.39	13.9
Chokers required adjustment	6.00	1.0
Chokers or mainline tangled downslope	1.84	1.0
Operator away from controls	1.07	0.5
<u>Inhaul delays</u>		
Inhaul grounded and stopped	4.83	2.3
<u>Unhook delays</u>		
Mainline tangled at landing	0.64	1.0
<u>Total cycle delays</u>		
Mainline break	27.34	2.3
Miscellaneous	19.74	1.4

Performance Prediction Models

Results of the stepwise procedure for predicting total cycle time are given in Table 7. Of the four variables tested for their predictive capability, only slope distance and lateral distance proved to have any significant influence on the outcome of the model. The number of pieces produced was the third variable entered into the model but was not significant at the requisite 95 percent level ($p=.084$). Percent slope of the skyline corridor was the least significant variable ($p=.35$) and increased the coefficient of determination by only .003. The single most powerful predictor of cycle time is slope distance. Its relationship to total cycle time is shown in Figure 9.

An analysis substituting horizontal distance for slope distance in the stepwise procedure was performed and found to result in slightly less predictability of the total cycle time. Results of the analysis are shown in Table 8.

The tendency of horizontal distance to underestimate the carriage travel distance is reflected in the larger yarding distance coefficient. More of the variation in the predictor model is allocated to the intercept resulting in a larger residual variance. The lateral distance coefficient changes very little in the horizontal distance model as do the effects of number of pieces produced and slope of the skyline corridor.

TABLE 7

Prediction Models for Total Cycle Time

Total Time (minutes) = $3.375 + 0.0052 * (\text{Slope Distance})$
 $R^2 = 0.305$
 $s = 1.094$
 $n = 185$

Total Time (minutes) = $2.868 + 0.0052 * (\text{Slope Distance})$
 $+ 0.0114 * (\text{Lateral Distance})$
 $R^2 = 0.395$
 $s = 1.023$
 $n = 185$

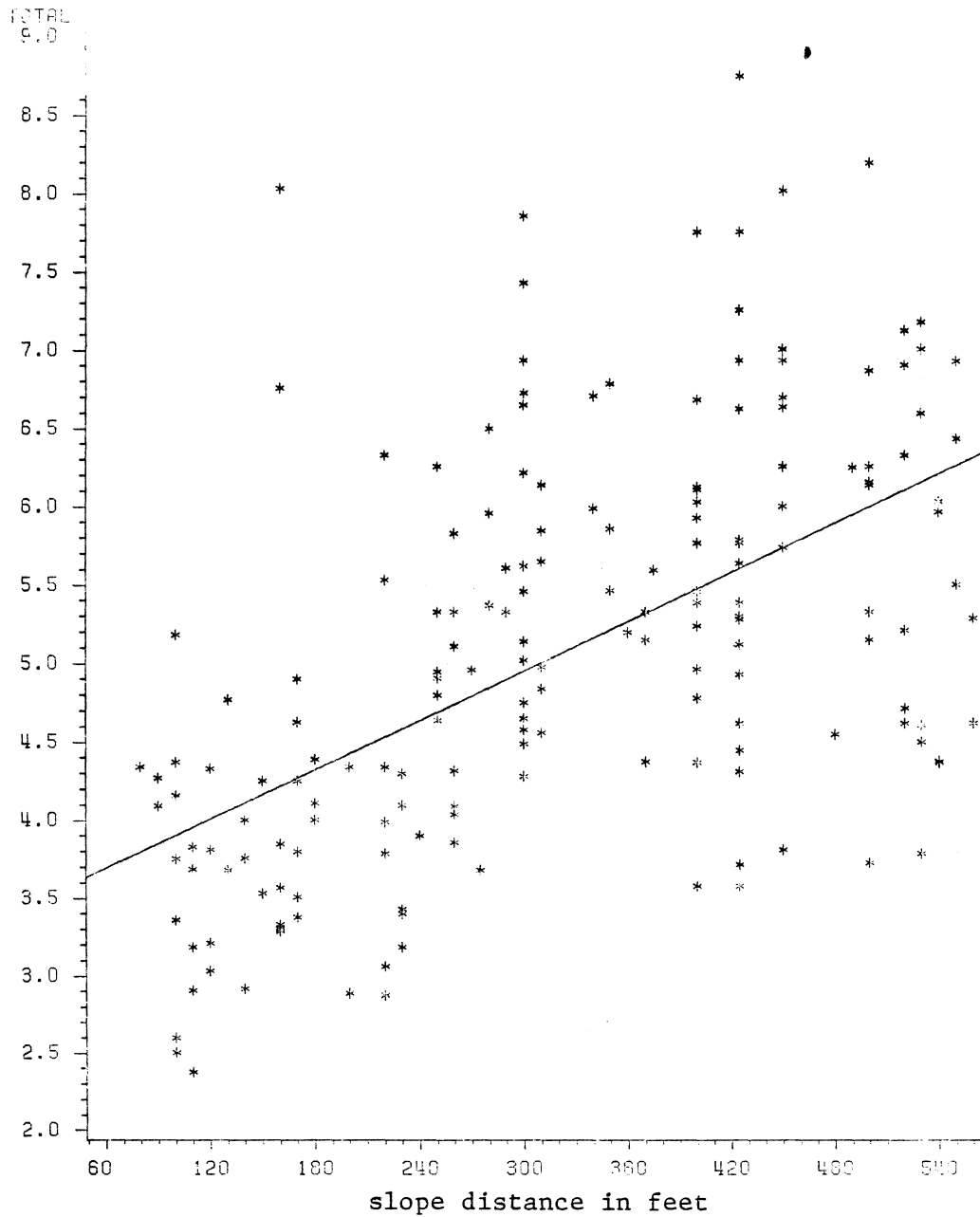


Figure 9: The effect of slope distance on total cycle time

TABLE 8

Prediction of the Total Cycle Using Horizontal Distance

Total time (minutes) = $3.453 + 0.0056 * (\text{Horizontal Distance})$
 $R^2 = 0.299$
 $S = 1.099$
 $n = 185$

Total Time (minutes) = $2.925 + 0.0055 * (\text{Horizontal Distance})$
+ $0.0114 * (\text{Lateral Distance})$
 $R^2 = 0.388$
 $S = 1.030$
 $n = 185$

The prediction model given for total cycle time was developed using data from all yarding corridors studied. To investigate the possibility of variation in the model between yarding corridors, a coincidence and parallelism analysis was performed on the total time prediction models developed for each corridor individually. Results of the analysis are shown in Table 9.

Failure to reject the null hypothesis in all cases suggest that for the Fletcher Mountain study, there are no significant differences between corridors for the effects of yarding distance, lateral distance, or any factors which may be hidden in the intercept of the regression. The implication, then, is that for the three yarding corridors studied, either no variables which impact on pure yarding time are different, or else differences that do exist are not statistically significant.

The stepwise procedure for prediction of the lateral yarding time yielded the prediction models given in Table 10. Of the four variables tested for prediction, only slope did not enter the model as a significant variable. The models given should be interpreted cautiously in light of their low R^2 values. A maximum of 22.4 percent of the vari-

TABLE 9

Coincidence and Parallelism Tests for the Total Cycle
Prediction Model

H0: $A_i = A$ for all i . The intercept of the regression is similar on all corridors.

Ha: $A_i \neq A$ for at least one i . The intercept of the regression is different on at least one corridor.

$f = .0572 \quad f(2,176)$

$p > .05$

Conclusion: Fail to reject H0. The evidence indicates that the effect of the regression is similar for all corridors.

H0: $B1_i = B1$ for all i . The effect of slope distance is similar for all corridors.

Ha: $B1_i \neq B1$ for at least one i . The effect of slope distance is different for at least one corridor.

$f = .6803 \quad f(2,176)$

$p > .05$

Conclusion: Fail to reject H0. The evidence indicates that the effect of slope distance is similar for all corridors.

H0: $B2_i = B2$ for all i . The effect of lateral distance is similar for all corridors.

Ha: $B2_i \neq B2$ for at least one i . The effect of lateral distance is different for at least one corridor.

$f = 1.1913 \quad f(2,176)$

$p > .05$

Conclusion: Fail to reject H0. The evidence indicates that the effect of lateral distance is similar for all corridors.

ation in lateral yarding time is explained by the three-variable model.

The source of the remaining variability in lateral yarding time appears to be attributable to factors not easily quantified. For example: the ease of setting chokers on any given piece, the ability of the choker setter to move at a consistent rate over slash, and the ease with which a turn will begin movement toward the carriage.

In an effort to further isolate sources of unexplained variation, lateral yarding was broken down into two parts: walk out and set chokers, and lateral winching. The first part represents the manual portion of lateral yarding while the second represents the mechanical portion. The stepwise procedure using the same predictors found to be significant for lateral yarding time was performed for the two component parts of lateral yarding. The results are shown in Table 11. The mechanical portion of the lateral yarding cycle is somewhat more predictable than the labor portion suggesting that at least a majority of the variation in lateral yarding is due to the manual operations performed. Surprisingly, the significance of number of pieces in the first model is very low ($p > .15$). Apparently, other sources of variability in the choker setting time outweigh the predictability of number of pieces hooked.

TABLE 10

Prediction of Lateral Yarding Time

Lateral Yarding Time (minutes) = $2.278 + 0.0135 * (\text{Lateral Distance})$

$R^2 = 0.188$

$s = 0.962$

$n = 188$

Lateral Yarding Time (minutes) = $1.936 + 0.0134 * (\text{Lateral Distance}) + 0.0011 * (\text{Slope Distance})$

$R^2 = 0.207$

$s = 0.953$

$n = 188$

Lateral Yarding Time (minutes) = $1.627 + 0.0126 * (\text{Lateral Distance}) + 0.0010 * (\text{Slope Distance}) + 0.2116 * (\text{Number of Pieces})$

$R^2 = 0.224$

$s = 0.945$

$n = 188$

TABLE 11

Prediction of Lateral Yarding Elements

Walk & Set Chokers (minutes) = $1.181 + 0.0187 * (\text{Lateral Distance})$
 $R^2 = 0.325$
 $s = 0.887$
 $n = 188$

Lateral Winching time (minutes) = $0.361 + 0.0046 * (\text{Lateral Distance})$
 $R^2 = .310$
 $s = 0.213$
 $n = 188$

Results of the coincidence and parallelism analysis for the lateral yarding time models (Table 12) show no significant differences across corridors with the exception of slope distance. The reasons for the difference are not immediately clear, but it should be noted that the effect of slope distance on lateral yarding time is quite small (0.10 minutes per 100 feet of slope distance) relative to the standard deviation of the estimate. It is possible that differences between corridors may be attributed to random phenomena alone and not the independent variables used to construct the model.

Prediction of the inhaul element provided a basis for making two inferences as to machine operation. First, the relatively high predictability of the inhaul element suggests consistent operation of the machine. Second, since inhaul time is consistent irrespective of number of pieces, slope of the skyline corridor, and volume produced, maximum productivity is achieved when the machine capacity is reached. Variable loading within the machine's capabilities has no effect on the inhaul time.

The only significant variable found for the prediction of inhaul time is yarding distance. Distance is a logical estimator as it is a measure of distance traveled and the inhaul element is a pure travel function. Again, substitution

TABLE 12

Results of the Coincidence and Parallelism Analysis for the
Lateral Yarding Model

H0: $A_i = A$ for all i . The intercept of the regression is
similar for all corridors.

Ha: $A_i \neq A$ for at least one i . The intercept of the regression
is different on at least one corridor.

$f = 1.748 \quad f(2,176)$

$p > .05$

Conclusion: Fail to reject H0. The evidence
indicates that the effect of the regression
is similar for all corridors.

H0: $B_i = B$ for all i . The effect of slope distance is similar
for all corridors.

Ha: $B_i \neq B$ for at least one i . The effect of slope is different
for at least one corridor.

$f = 2.627 \quad f(2,176)$

$p > .05$

Conclusion: Fail to reject H0. The evidence
indicates that the effect of slope distance
is similar for all corridors.

of horizontal distance for slope distance in the model resulted in a predictability loss. The results of the stepwise procedure for predicting inhaul time are shown in Table 13.

The inhaul time prediction model constructed using all data was tested for coincidence and parallelism across yarding corridors. The procedure was the same used for the coincidence and parallelism analysis performed for the total cycle model, the results were not. Both the effect (intercept) and the slope of the regression were found to be different on at least one corridor. In order to identify which of the corridors provided similar prediction results in the model, the models for each corridor were individually compared with each of the other corridors in a coincidence and parallelism analysis. The results of the analysis are shown in Table 14. Visual representations of the slope/inhaul time relationships for each corridor are given in the appendix. Only Corridor 3 was found to be significantly different. Further, the difference in the model coefficients for the three corridors suggested that the average inhaul rate on corridor three was slower than the rate for corridors 1 and 2.

A possible explanation for the lower rate on Corridor 3 may be the machine set-up in relation to the terrain condi-

TABLE 13

Prediction of the Inhaul Element

INHAUL TIME (minutes) = $0.26 + 0.0028$ (SLOPE DISTANCE IN FEET)
R² = 0.638
s = 0.299
n = 199

TABLE 14

Coincidence and Parallelism Analysis for the Inhaul
Prediction Models

H0: $A_i = A$ for all i . The intercept of the regression is similar for all corridors.

Ha: $A_i \neq A$ for at least one i . The intercept of the regression is different on at least one corridor.

$f = 5.404 \quad f(2, 193)$

$p < .05$

Conclusion: Fail to accept H0. The evidence indicates that the effect of the regression is different for at least one corridor.

H0: $B_i = B$ for all i . The effect of slope distance is similar for all corridors.

Ha: $B_i \neq B$ for at least one i . The effect of slope distance is different for at least one corridor.

$f = 7.908 \quad f(2, 193)$

$p < .05$

Conclusion: Fail to accept H0. The evidence indicates that the effect of slope distance is different for at least one corridor.

Ordered Alternatives

H0: $A_{12} = A_3$. The intercept of the regression is similar for all corridors.

Ha: $A_{12} \neq A_3$. The intercept of the regression on Corridor 3 is different than that for corridors 1 and 2.

$f = 15.52 \quad f(1, 195)$

$p < .01$

Conclusion: Fail to accept H0. The evidence indicates that the intercept of the regression is different on Corridor 3.

H0: $B_{12} = B_3$. The effect of slope distance is similar for all corridors.

Ha: $B_{12} \neq B_3$. The effect of slope distance is on Corridor 3 is different than that for corridors 1 and 2.

$f = 33.21 \quad f(1, 195)$

Conclusion: Fail to accept H0. The evidence indicates that the effect of slope distance is different for corridor 3.

tions. The skyline on this corridor was rigged as a low single span with little deflection, resulting in a plowing effect as the turn was skidded up the hill. The resulting resistance effectively slowed the inhaul rate.

The stepwise procedure for the outhaul element was not performed since only two of the four predictors collected could exert any logical influence on the outcome of outhaul time. A model using slope distance and corridor slope as a predictor variables was tested in the stepwise procedure and resulted in the equation shown in Table 15. The coincidence and parallelism analysis performed across all corridors for the prediction of outhaul showed no significant differences in the model for any of the corridors observed (see Table 16).

As with outhaul, only one of the four potential predictors would logically impact on the outcome of unhooking time. A model using number of pieces was constructed and found to be insignificant in predicting the time required to unhook each turn at the landing.

The unhooking time means presented in the last section were compared using Duncan's multiple range test. The average unhooking time on Corridor 2 proved to be significantly

TABLE 15

Prediction of the Outhaul Element

$$\begin{aligned}\text{Outhaul time (minutes)} &= 0.216 + 0.0008 * (\text{Slope Distance}) \\ R^2 &= 0.556 \\ S &= 0.071 \\ n &= 191\end{aligned}$$

TABLE 16

Coincidence and Parallelism Analysis for Outhaul Prediction

H_0 : $A_i = A$ for all i . The intercept of the regression is similar for all corridors.

H_a : $A_i \neq A$ for at least one i . The intercept of the regression is different for at least one corridor.

$f = 2.887 \quad f(2, 184)$

$p > .05$

Conclusion: Fail to reject H_0 . The evidence indicates that the intercept of the regression is similar on all corridors.

H_0 : $B_i = B$ for all i . The effect of slope distance is similar for all corridors.

H_a : $B_i \neq B$ for at least one i . The effect of slope distance is different on at least one corridor.

$f = 1.636 \quad f(2, 184)$

$p > .05$

Conclusion: Fail to reject H_0 . The evidence indicates that the effect of slope distance is similar on all corridors.

longer ($p = .05$) probably due to the absence of a landing at which logs could be easily moved from beneath the skyline. In several cases, the skidding line of the yarder was used to retain the logs at the base of the tower until the swing skidder's chokers could be hooked. The addition of the abnormally high unhooking times to the sample distribution serve to increase the sample mean and standard deviation. The unhook mean times for each corridor are given in Table 17.

TABLE 17

Sample Means and Standard Deviations for the Unooking Times

	1	Corridor 2	3
mean	0.50	0.72	0.49
standard deviation	0.23	0.50	0.21

Sensitivity Analysis

The average hourly productivity for each corridor length and width combinations are presented in Table 18. Each block in the matrix shows the average hourly productivity including road change time, followed by the standard deviation of the hourly volume estimate, the average hourly volume produced assuming zero road change time, the number of corridors required to complete the six acre harvest, and finally, one or more letters indicating the results of the Duncan's multiple range test on cell means. The same letter is found in all cells whose average hourly productivity estimates are not significantly different. The simulated number of hours required to complete each harvest ranged from 45 hours on the 624 foot by 208 foot wide corridor to 77 hours on the 208 foot by 52 foot wide corridor.

The results of the two-way analysis of variance indicated significant effects of both corridor length ($p = 0.004$) and width ($p = 0.0001$) on yarding productivity. No significant interaction between length and width was found ($p = 0.54$).

Identical testing procedures were performed on the nine simulations assuming a one-hour road changing time. The results are presented in Table 19. The two-way analysis of variance indicated no significant effect of corridor length ($p = 0.39$), width ($p = 0.07$), or interaction between the two

($p = 0.50$). In both cases, yarding productivity is significantly lower in the 52 by 208 foot corridors due to the low volume available in each corridor. More set-up time was required to completely harvest the stand.

TABLE 18

Average Hourly Cubic Foot Volume Production with Two Hours
Road Change time

		CORRIDOR WIDTH		
		52'	104'	208'
CORRIDOR LENGTH	208'	230.72	310.16	383.86
		238.69	247.37	210.27
		564.68	500.43	488.30
		23	11	5
		B	AB	A
	416'	312.85	363.50	406.38
		244.29	217.08	159.21
		507.48	455.83	446.85
		11	5	2
		AB	A	A
	624'	338.97	366.99	393.59
		221.24	186.50	143.63
		460.84	418.32	411.65
		7	3	1
		A	A	A

- First entry = Average cubic foot volume production including road changes
- Second entry = Sample standard deviation for average hourly production
- Third entry = Average cubic foot volume production excluding road changes
- Fourth entry = Number of corridors required to complete the simulated six acre harvest
- Fifth entry = Results of the Duncan's multiple range test on cell average volume productivity. Cells with same letter are not significantly different

TABLE 19

Average Hourly Cubic Foot Volume Production with One Hour
Road Change Time

		CORRIDOR WIDTH		
		52'	104'	208'
CORRIDOR LENGTH	208'	326.15	386.56	431.38
		222.10	216.04	170.31
		564.68	500.43	488.30
		23	11	5
	416'	B	AB	A
		388.77	406.11	426.37
		210.83	188.10	134.61
		507.48	455.83	446.85
		11	5	2
	624'	AB	AB	A
		393.10	395.57	403.27
		188.30	164.78	131.96
		460.84	418.32	411.65
		7	3	1
		AB	AB	AB

- First entry = Average cubic foot volume production including road changes
- Second entry = Sample standard deviation for average hourly production
- Third entry = Average cubic foot volume production excluding road changes
- Fourth entry = Number of corridors required to complete the simulated six acre harvest
- Fifth entry = Results of the Duncan's multiple range test on cell average volume productivity. Cells with same letter are not significantly different

Economic Analysis

Estimates of "on-board truck" harvesting costs are given both with and without the inclusion of the Caterpillar 518 swing skidder in Tables 20 and 21. The intention of the estimates is to reflect the direct costs of a private logging contractor. Costs other than those directly attributable to harvesting are not considered. Equipment financing costs are based on a 20 percent down payment and a 9 percent add-on finance charge. Taxes are calculated from the current Montgomery County, Virginia tax rate of \$7.57 per \$100 of taxable value which is defined as: $20\% * (\text{Machine Cost} - \text{Depreciation})$. All machines are assumed to be new in the current year and depreciated according to the accelerated cost recovery (ACR) schedule.

Labor costs are calculated assuming a base rate of \$6.00 per hour plus 30 percent fringes. The contractor is assumed to serve as the loader/skidder operator and draws a weekly salary of \$270.00. Each crew member is scheduled for five eight-hour work days per week. Machine utilization is calculated as a percent of 40 scheduled hours per week. Details of the cost calculations and assumptions used may be found in the appendix.

TABLE 20

Estimated Felling, Yarding, and Loading Costs Assuming No
Swing Skidder Necessary

Levels of Utilization			
	50 %	60 %	70 %
Fixed Costs			
Koller	\$251.42	\$251.42	\$251.42
Prentice	\$314.28	\$314.28	\$314.28
Saws (2)	\$40.00	\$40.00	\$40.00
Labor Costs	\$1599.00	\$1599.00	\$1599.00
Operating Costs			
Koller	\$240.00	\$288.00	\$336.00
Prentice	\$240.00	\$288.00	\$336.00
Saws	\$60.00	\$60.00	\$60.00
Total Weekly Cost	\$2744.70	\$2840.70	\$2936.70
Weekly cord Production	94.4	113.3	132.2
Total Cost/Cord	\$29.07	\$25.07	\$22.21

*Saws have 50 percent utilization

TABLE 21

Estimated Weekly Felling, Yarding, and Loading Costs
Assuming A Swing Skidder is Necessary

Levels of Utilization			
	50 %	60 %	70 %
Fixed Costs			
Koller	\$251.42	\$251.42	\$251.42
Prentice	\$314.28	\$314.28	\$314.28
Cat	\$454.76	\$454.76	\$454.76
Saws (2)	\$40.00	\$40.00	\$40.00
Labor Costs	\$1599.00	\$1599.00	\$1599.00
Operating Costs			
Koller	\$240.00	\$288.00	\$336.00
Prentice	\$240.00	\$288.00	\$336.00
Cat	\$307.20	\$307.20	\$307.20
Saws	\$60.00	\$60.00	\$60.00
Total Weekly Cost	\$3506.66	\$3664.10	\$3821.54
Weekly cord Production	94.4	113.3	132.2
Total Cost/Cord	\$37.14	\$32.34	\$28.91

*Saws have 50 percent utilization

SUMMARY AND CONCLUSIONS

A desire to extend the timber resource base in Appalachia has led to investigation of the cost and productivity of the relatively new light skyline yarders that are currently used in Europe and the western United States. To date, the need to harvest the hardwood timber growing on steep terrain has not been proven, nor has the cost of yarded timber proved competitive with conventionally harvested products. The basic purpose of this research was to document the performance of the Koller K300 yarder in Appalachia and identify determinants of productivity. The detailed time study method was used.

Gross analysis of the time study data showed wide variation in cycle times and frequently occurring operating delays. The majority of the operating delays observed occurred during lateral yarding (lateral yarding comprises more than 50 percent of the total cycle time). The estimated average hourly productivity in the absence of delays was 424.7 cubic feet.

The results of the regression analysis for predicting cycle and element times showed the best predictors to be yard-

ing and lateral yarding distances. The number of pieces hooked improved the prediction of lateral yarding time but was insignificant elsewhere. Slope of the skyline corridor was not a significant predictor in any of the prediction models tested.

A series of computerized harvesting simulations based on the time study data investigated the impact of narrowing the skyline corridor in light of more frequent skyline road changes. No difference in gross productivity was found between 104 and 208 foot wide corridors. The higher frequency of road changes associated with 52 foot wide corridors resulted in a significant productivity decrease. When road changes were assumed to require two hours, a significant productivity decrease was observed for 208 foot long corridors as compared to 416 and 624 foot long corridors. The only significant difference observed when road changes were assumed to last one hour was a reduction in productivity associated with corridor widths of 52 feet.

Felling, yarding, and loading costs for three levels of machine utilization were estimated for two yarding and loading systems. The first set of costs assumed that yarded logs were removed from beneath the skyline and loaded directly on to waiting trucks by a Prentice 210 loader. The estimated costs ranged from \$22.21 per cord with 70 percent

utilization to \$29.07 per cord with 50 percent utilization. The second set of calculations assumed the use of a swing skidder between the yarder landing and loading deck. Estimated costs ranged from \$28.91 per cord with 70 percent utilization of eight scheduled hours daily and \$37.14 per cord with 50 percent utilization.

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Appendix A

MANUFACTURER'S SPECIFICATIONS FOR THE KOLLER K300 YARDER

Koller Yarder K 300

for economic uphill logging

SYSTEM

The K 300 is a yarder for uphill logging. For the outhaul of the carriage a minimum slope of about 15 to 20 % is necessary. External yarding distance between 300 and 500 meters, depending on the cable diameter.

SPECIFICATIONS

1. General: Double-drum winch set with steel tower, to be attached to a carrier with three-point hitch. The winch set is driven from the carrier by means of a power take-off shaft.
2. Carrier: All carriers with three-point hitch and power take-off shaft are suitable, as well as the Koller Trailer (separately available) with own engine and automatic transmission.
Necessary rotational direction of the power shaft, looking on the winch, to the LEFT (i. e. Power take-off shaft of the carrier to the right).
Necessary lifting capacity of the hydraulics 1600 dN (1.6 t).
Minimum driving output 30 kw (40 hp).
3. Winches: A) Mainline drum with hydraulic remote-control.
Number: 1
Operation: freewheeling or under power
Cable capacity: 350 m 16 mm ø
Average line pull: 1790 dN (1.79 t)
Average line speed: 1.6 m/s at an input of 500 rpm
3.2 m/s at an input of 1000 rpm
varies from 0 to 5 m/s with Koller Trailer
Power transmission: hydraulically assisted single plate dry clutch.
Power limitation eliminates line cracking.
hydraulically assisted band brake.
Brake:
b) Skyline drum
Number: 1
Operation: freewheeling or under power
Cable capacity: 350 m 9.5 mm ø
Line pull in the tensioning section of the drum: 4500 dN (4.5 t)
The skyline is to be tensioned only in the tensioning section.
Power transmission: hydraulically assisted single plate dry clutch.
Power limitation eliminates line cracking. Important: max. pressure 110 bar at hydraulic operation — watch the gauge!
Brake: mechanically operated band brake.
Fasten the safety chain after tensioning procedure to prevent involuntary opening!
4. Tower: Steel tower
Height: 7 meters

Tower raising with three-point hitch.

For transport the tower is folded at its folding point by means of a Tirlor (supplied with tower). Depending on the carrier, a simple support of the folded part of the tower is to be provided.

Guylines: 2 x 30 m, 15 mm $\varnothing$ with steel core,
and 2 x 10 m extensions.

The guylines are kept on the tower on drums with catch and are equipped with thimbles and shackles to facilitate a quick fixing.

5. Weight: 1.6 t (cables included)

6. Cables recommended:

Skyline: 16 mm $\varnothing$, 114 Seal construction, fibrous core, cross or uniform lay, 180 dN/mm²
Mainline: 9.5 mm $\varnothing$, 42 wires, fibrous core, cross lay, 180 dN/mm²

7. Mounting: The tower is to be fixed to the three-point hitch by means of three bolts with locking pin. Power connection with power take-off shaft.
The tower is to be raised at the site of operation and lowered to the ground with the three-point hitch.

The two guylines are to be fastened on good anchors.

The vertical angle between tower and guylines must not be too small — guide value 75° or more.

In order to avoid slack guyline layers on the drum being jammed, they are to be tensioned on the bare diameter of the guyline drum. It is important that at least six turns of the guyline remain on the drum. Extensions are available.

The skyline is to be pulled out down to the lower anchorage and fastened there.

Before tensioning the skyline, hang up the carriage, fasten the mainline on the load hook of the carriage and pull the brake of the mainline drum. Do not pull out more slack skyline of the skyline corridor than is needed to lay the skyline in the tensioning section of the drum. The tensioning is to be effected only in the tensioning section of the drum. The skyline is tensioned at low engine speed by operation the clutch, and kept in tension by locking the brake.

Unhook the upper support of the three-point hitch before producing the basic tension in order to obtain an equal stress on the guylines — otherwise the upper support could be damaged.

The tower should be anchored with additional lines on both sides — especially in case of a longer lateral yarding distance.

The brake lever is to be blocked with the provided device to avoid involuntary opening. For carriage overhaul release the brake of the mainline drum.

The further operating procedure depends on the type of carriage (see operating instructions for the automatic carriage).

All specifications subject to change without notice.

Appendix B

MANUFACTURER'S SPECIFICATIONS FOR THE KOLLER SKA1 CARRIAGE

Applications:

The compact Koller carriages are used in logging, construction or wherever material transport is necessary. The hauling line can be used to move the load laterally or raise and lower it as desired at any point along the skyline. The carriage can pass intermediate supports.

Type SKA: Gravity outhaul system (slopes greater than 15 %). Compact mechanically-clamped carriage not requiring a separate stop.

Type ASKA: The SKA gravity carriage can be easily converted to work in any terrain uphill or downhill by adding a simple attachment, which has slackpulling capabilities.

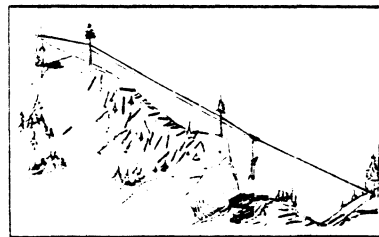
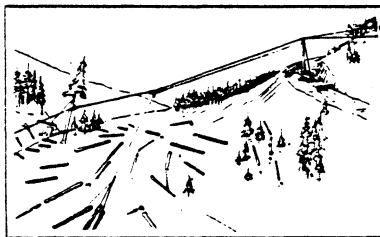
Special carriage with a spreader-bar configuration is designed for transport of long loads such as pipe and construction steel.

Techn. Specifications:

Type	SKA 1	SKA 2.5	SKA 5
Load capacity	1 ton 1000 daN	2.5 ton 2500 daN	5 ton 5000 daN
weight	330 lb 150 kg	550 lb 250 kg	925 lb 420 kg
number of sheaves	2	4	4

(1 daN = 1 Kp)

All specifications are subject to change without notice.



KOLLER USA CORPORATION

620 SW 4th Street
CORVALLIS, OREGON 97333
TELEPHONE (503) 758-9337
FAX: 510-596-0681

J. KOLLER

Forsttechnik — Kranseilbahnen
Kufsteiner Wald 25
A-5330 KUFSTEIN/AUSTRIA
Telefon 053 72/3257
Telex 5135525 kol a

Appendix C

EXPLANATION OF TIMING CODES AND FIELD INSTRUCTIONS

Slope Times

- OT -Outhaul from intermediate support to carriage lock on slope. Record begin time and slope distance to carriage stop.
- MD -Mainline drop. Time required for mainline to touch the ground after carriage lock on out haul. Record begin time.
- WC -Walkout and set chokers. time required to secure a turn to the mainline. Begins when the buzzard hook reaches the ground after outhaul. Record begin time and lateral distance.
- WS -Winch slack. Time required to winch in mainline catenary before inhaul. Record begin time.
- LAT -Winch laterally. Time required for the turn to be secured to the carriage. Begins when mainline slack has been spooled in. Record begin time.
- I -Inhaul from carriage release to intermediate support. Record begin time.
- U -Unhook chokers. Begins when carriage locks on skyline after inhaul. Record begin time.
- D -Delay. Record begin time and explanation for delay.

Log Volumes

For each turn, record both end diameters to the nearest inch and the total length to the nearest foot for each piece yarded.

Appendix D

FIELD STUDY TIMING SHEET

TURN NUMBER	ELEMENT, TIME & DISTANCES	NOTES OR COMMENTS

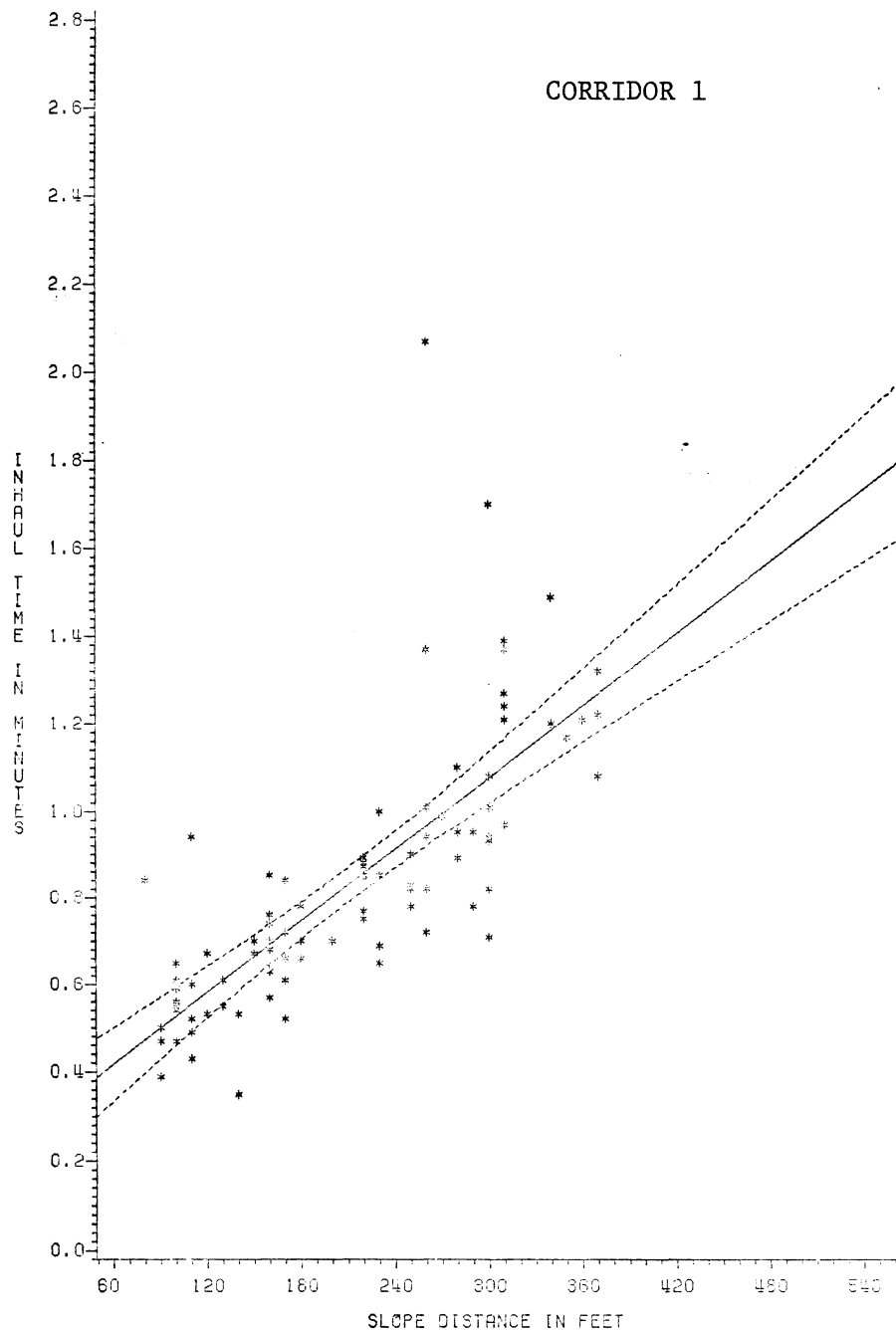
Appendix E

FIELD STUDY TALLY SHEET FOR RECORDING TURN VOLUME MEASUREMENTS ON THE LANDING

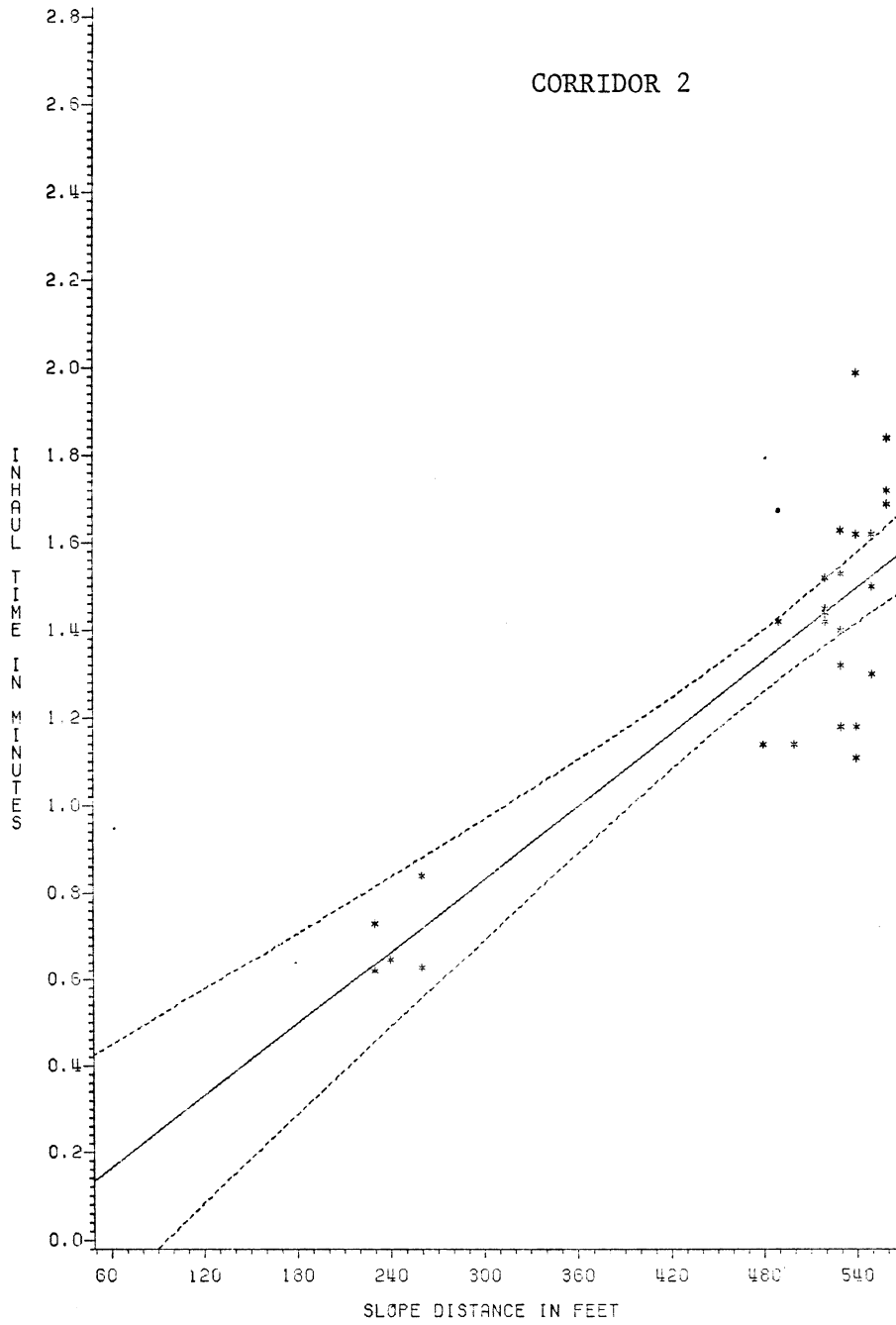
TURN NUMBER	SMALL END DIAMETER	LARGE END DIAMETER	LENGTH	NOTES OR COMMENTS

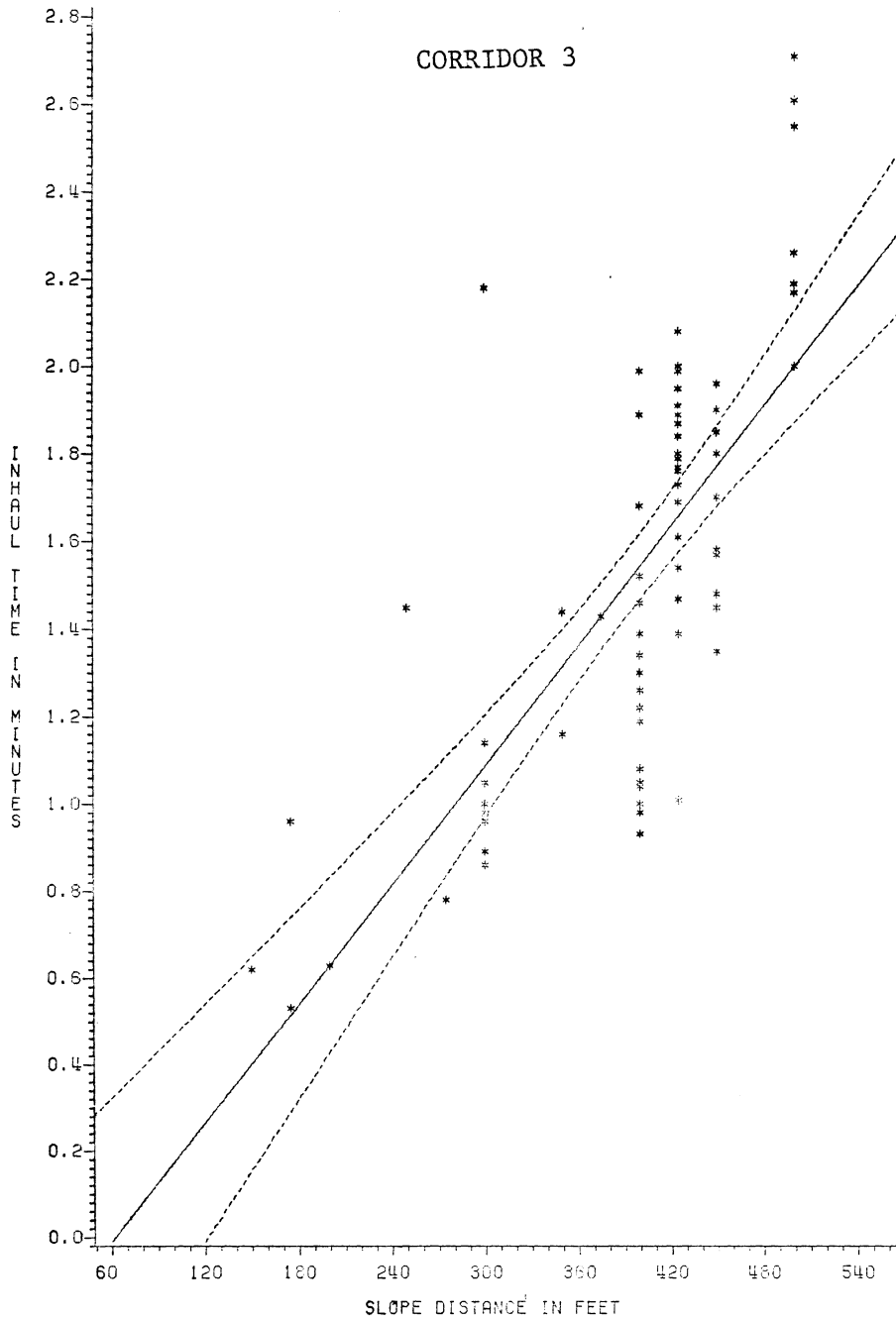
Appendix F

THE RELATIONSHIP BETWEEN SLOPE DISTANCE AND
INHAUL TIMES



CORRIDOR 2





Appendix G

INPUT FILE FOR GENMAC

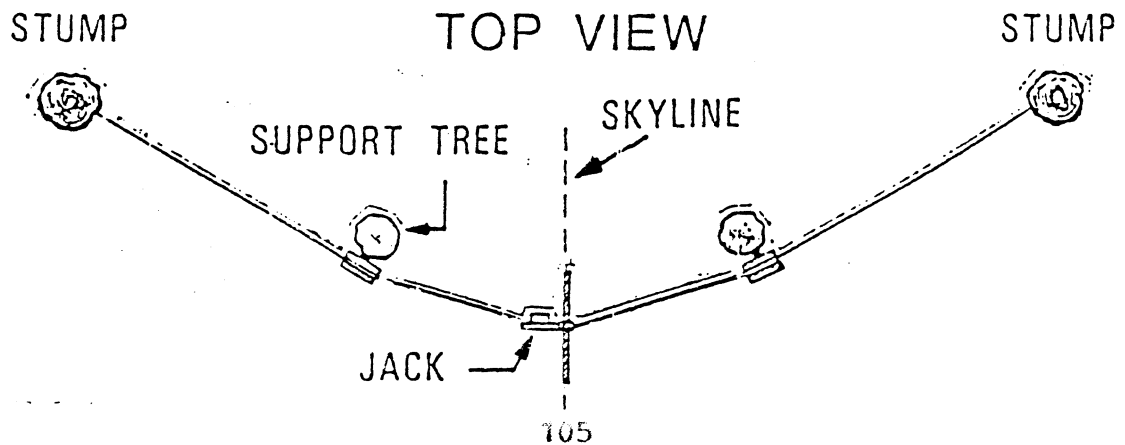
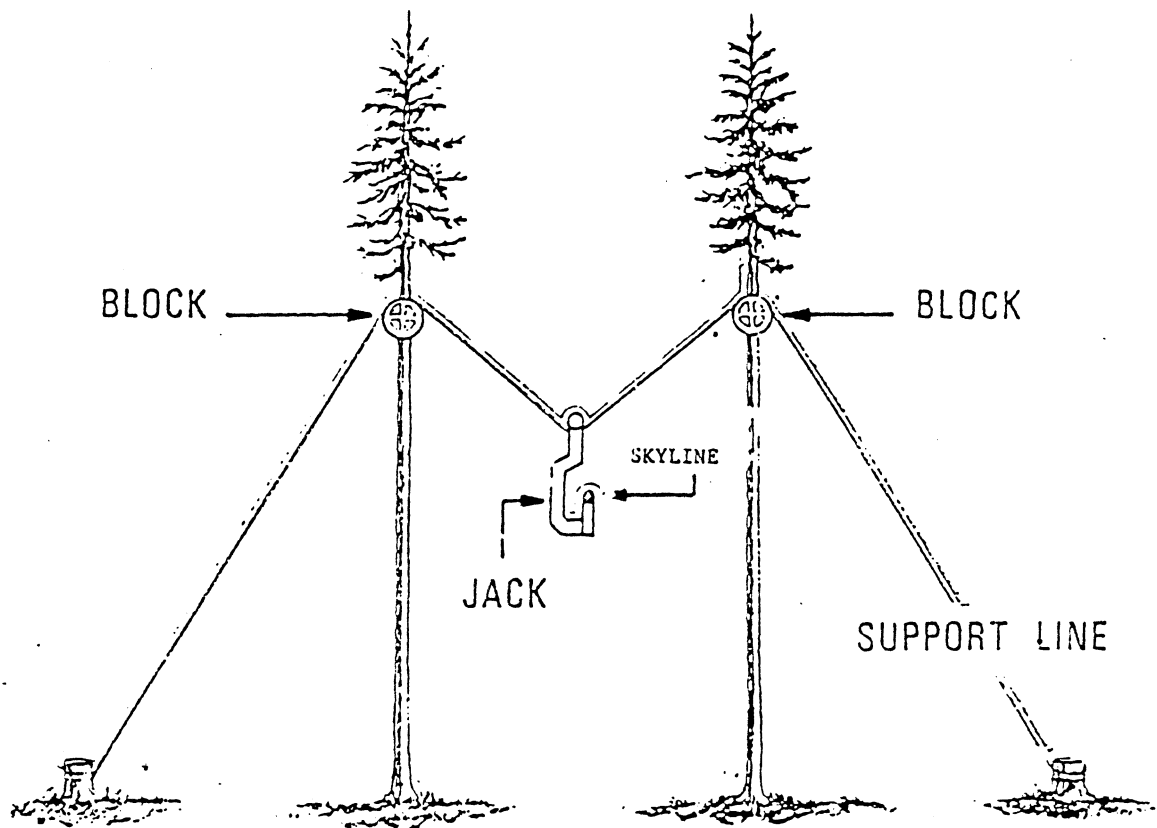
```

TITLE KOLLER SIMULATION. WIDTH = 52'. LENGTH = 208'.
INFOR LA TREES Y 1 0
STAND 101 INFO 009 12.0 20.00 0.00 N N 0094
STAND 101 PINE L L L L L L L L L L
STAND 101 HOWD L L L L L L L L L L
STAND 101 CEDR L L L L L L L L L L
STAND 101 NMR L L L L L L L L L L
STAND 101 VOL 01 4.0 1.0 M -0.3709700 0.0023300 N 0.0 99.9 0.0 99.9
STAND 101 VOL 11 4.0 1.0 M -0.3709700 0.0023300 N 0.0 99.9 0.0 99.9
STAND 101 VOL 00 4.0 1.0 M -0.3709700 0.0023300 N 0.0 99.9 0.0 99.9
STAND 101 VOL 03 4.0 1.0 M 0.0000000 0.0054540 N 0.0 99.9 0.0 99.9
STAND 101 VOL 13 4.0 1.0 M 0.0000000 0.0054540 N 0.0 99.9 0.0 99.9
STREE 102 1 6 10 52 N N 4
DECKS -50
SHEAR 99.9 99.9 4.0 .01 3 2 1 0 0 0 4.0 55
TRAVU 002 0.216375 0.000829 0.1009 1617
ACQR 000
ACQR 999
ACQR 999 4573 18 0.750000 0.25 1 4573
ACQR 999 0.62 0004
ACQR 999 0.87 0004
ACQR 999 1.12 0009
ACQR 999 1.37 0010
ACQR 999 1.62 0009
ACQR 999 1.87 0008
ACQR 999 2.12 0002
ACQR 999 2.37 0006
ACQR 999 2.62 0004
ACQR 999 2.87 0003
ACQR 999 3.12 0001
ACQR 999 3.37 0000
ACQR 999 3.62 0000
ACQR 999 3.87 0001
ACQR 999 4.12 0000
ACQR 999 4.37 0000
ACQR 999 4.62 0001
ACQR 999 4.87 0000
ACQR END
PROC 999 0553 7 0.050000 0.100000 1
PROC 999 0.05 0003
PROC 999 0.15 0016
PROC 999 0.25 0019
PROC 999 0.35 0036
PROC 999 0.45 0006
PROC 999 0.55 0007
PROC 999 0.65 0005
PROC END
TRAVL 002 0.229188 0.002918 0.2993 3719
DISP 999 2 99999.9 999 0.100000 1
DISP 999 9711 0009 0.200000 0.100000 1
DISP 999 0.15 0001
DISP 999 0.25 0023
DISP 999 0.35 0065
DISP 999 0.45 0053
DISP 999 0.55 0028
DISP 999 0.65 0013
DISP 999 0.75 0009
DISP 999 0.85 0008
DISP 999 0.95 0029
DISP END
TURN 001 120.00
END
STOP

```

Appendix H

DIAGRAM OF INTERMEDIATE SUPPORT
FRONT VIEW

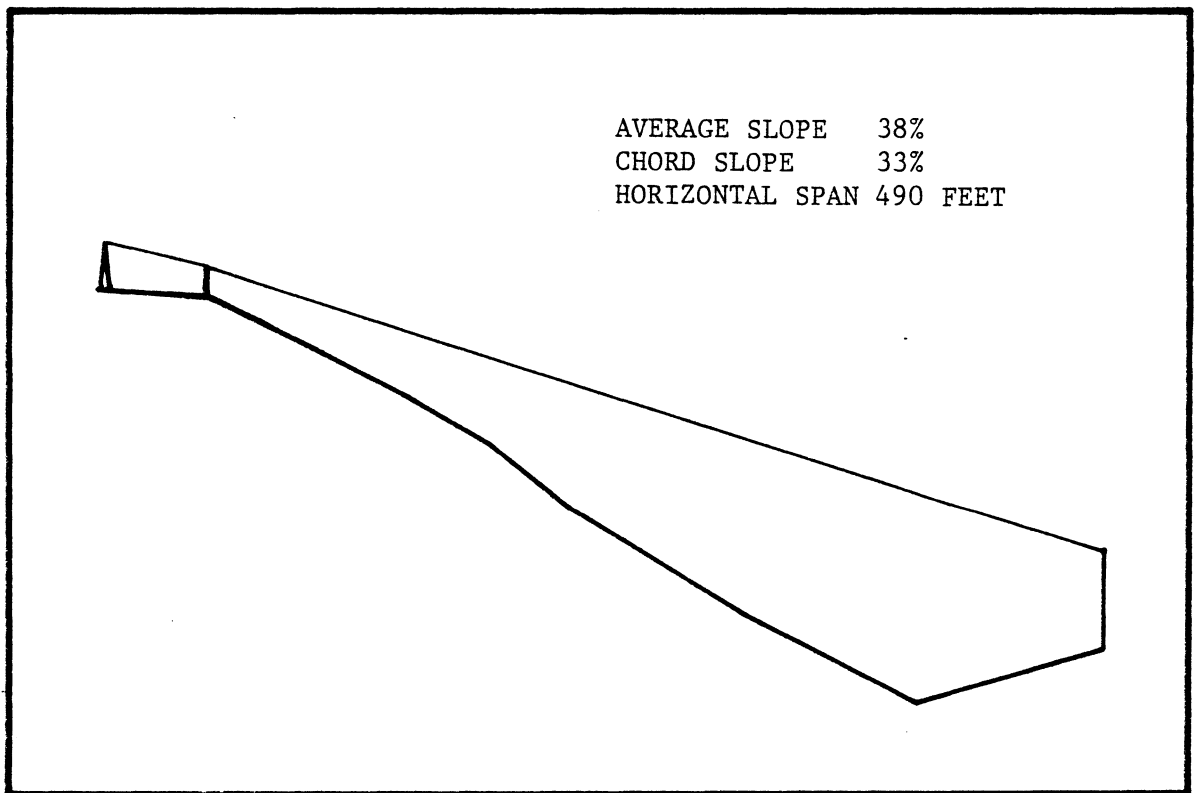


Appendix I
SKYLINE TAILHOLD

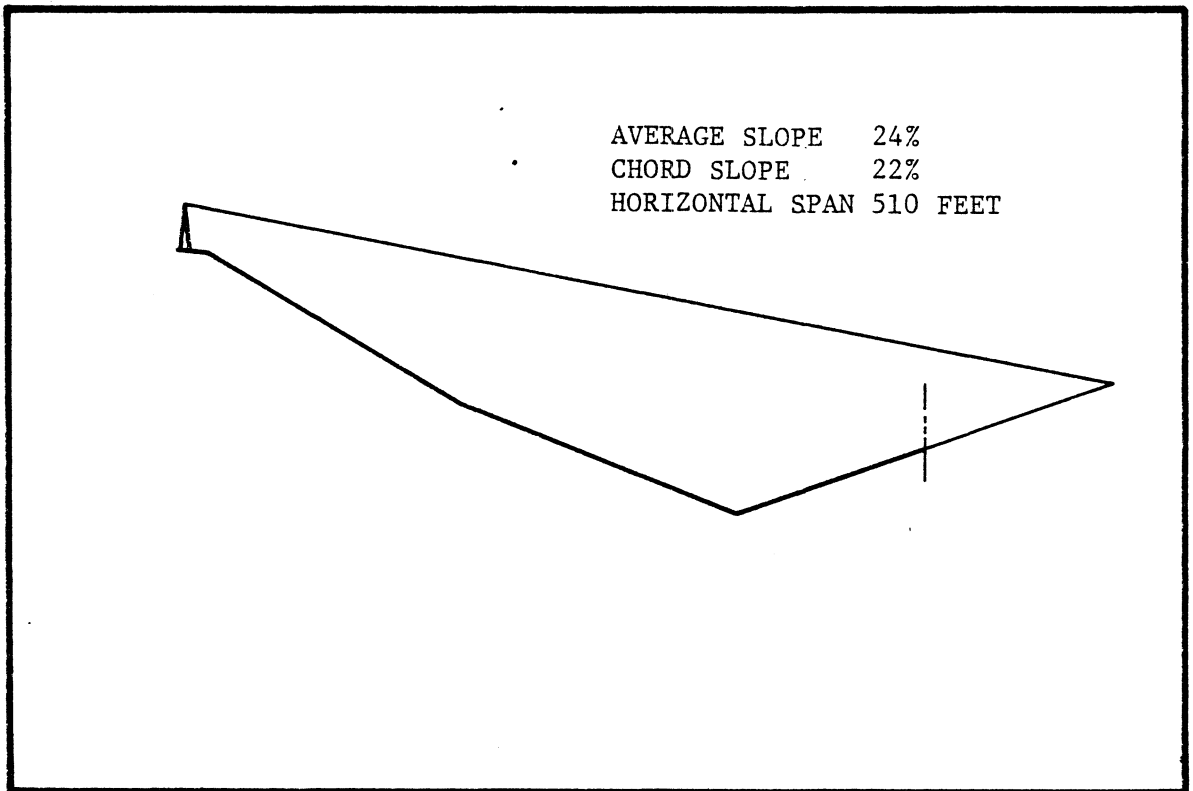


Appendix J

SKYLINE PROFILE OF CORRIDOR 1

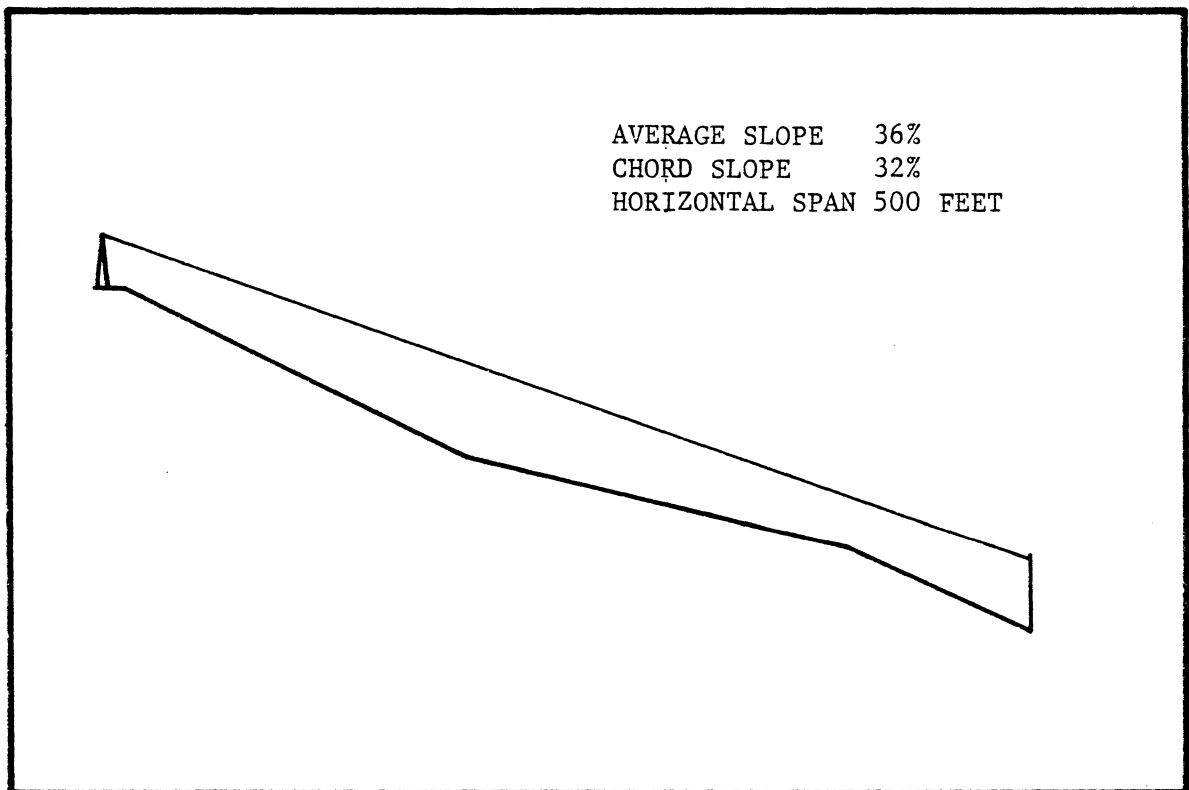


Appendix K
SKYLINE PROFILE OF CORRIDOR 2



Appendix L

SKYLINE PROFILE OF CORRIDOR 3



Appendix M

CALCULATION OF FIXED MACHINE COSTS

Koller K300 Trailer-Mounted Yarder and Carriage

purchase price	\$44000
less down payment (20%)	\$8800
financed amount	\$35200
terms: 9 % add-on (including creditor life insurance)	
period: 4 years	
weekly payment	
$([1 + (4 \times .09)] \times \$35200) / (4 \text{ yrs} \times 52 \text{ wks/yr})$	\$230.15 / week
insurance	
$(\$1 / \$100 \text{ of machine value}) / (52 \text{ weeks} / \text{yr})$	
$(\$440 / \text{yr}) / (52 \text{ wks} / \text{yr})$	\$8.46 / week
taxes	
$\$7.57 / \$100 \text{ of } .20 \times (\text{cost} - \text{depreciation})$	
year 1 depreciation = 0 (ACR method)	
$(.0757 \times [.20(44000 - 0)] / (52 \text{ wks/yr})$	\$12.81 / week
total	\$251.42 / week

Prentice 210 Loader

purchase price	\$55000
less down payment (20%)	\$11000
financed amount	\$44000
terms: 9 % add-on (including creditor life insurance)	
loan period: 4 years	
weekly payment	
$([1 + (4 \times .09)] \times \$44000) / (4 \text{ years} \times 52 \text{ wks/yr})$	\$287.69 / week
insurance	
$(\$550 / \text{yr}) / (52 \text{ wks} / \text{yr})$	\$10.58 / week
taxes	
$\$7.57 / \$100 \text{ of } .20 \times (\text{cost} - \text{depreciation})$	
year 1 depreciation = 0 (ACR method)	
$(.0757 \times [.20(55000 - 0)] / (52 \text{ wks/yr})$	\$16.01 / week
total	\$314.28 / week

Caterpillar 518 Skidder

purchase price	\$65000
less down payment (20%)	\$13000
financed amount	\$52000
terms: 9 % add-on (including creditor life insurance)	
loan period: 3 years	
weekly payment	
$((1 + (3 * .09)) * 52000) / (3 \text{ years} * 52 \text{ wks/yr})$	\$423.33 / week
insurance	
$(\$650 / \text{yr}) / (52 \text{ wks} / \text{yr})$	\$12.50 / week
taxes	
$\$7.57 / \$100 \text{ of } .20 * (\text{cost} - \text{depreciation})$	
year 1 depreciation = 0 (ACR method)	
$(.0757 * [.20(65000 - 0)] / (52 \text{ wks/yr})$	\$18.92 / week
total	\$454.76 / week

Chainsaws (2)

Total (Cubbage, 1981)	\$40.00 / week
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Appendix N

OPERATING COST ASSUMPTIONS (CUEBAGE, 1981)

Koller K300 Yarder

fuel & lube	\$2.50 / hr
repair & maintenance	\$8.40 / hr
skyline 1150' of 5/8 inch wire rope	
\$0.87 / foot	
expected life: 2000 hours	\$0.50 / hr
mainline 1150' of 3/8 inch wire rope	
\$0.52 / foot	
expected life: 1000 hours	\$0.60 / hr
total	\$12.00 / hr

Prentice 210 Loader

fuel & lube	\$3.50 / hr
repair & maintenance	\$8.50 / hr
total	\$12.00 / hr

Caterpillar 518 Skidder

fuel & lube	\$5.35 / hr
repair & maintenance	\$10.01 / hr
(including tires)	
total	\$15.36 / hr

Chainsaws (2)

fuel, lube, repair, & maintenance	\$3.00 / hr
total	\$3.00 / hr

Appendix O

LABOR COST ASSUMPTIONS AND CALCULATIONS

1 yarder operator

\$6.00 / hr + 30% fringes \$312.00 / week

2 choker setters

\$6.00 / hr + 30% fringes \$624.00 / week

loader/skidder operator and contractor

\$270 / week + 30 % fringes \$351.00 / week

1 feller

\$6.00 / hr + 30% fringes \$312.00 / week

total labor cost

\$1599.00 / week

Appendix P

HOURLY PRODUCTION CALCULATIONS

average cycle time 5.1 minutes	11.76 cycles / hr
average volume produced per cycle	36.1 ft ³
total hourly production	424.70 ft ³
90 ft ³ / cord	
total cord / worked hour production	4.72 cords / hr

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A CASE STUDY OF THE KOLLER K300 YARDER ON A NATIONAL
FOREST TIMBER SALE IN THE APPALACHIAN REGION

by

Michael K. Rossie

(ABSTRACT)

A production and cost study for the Koller K300 skyline yarder operating on an Appalachian timber sale was undertaken to document the yarder's performance, to identify predictors of yarder performance, to evaluate the impact of corridor dimension on machine productivity, and to estimate direct harvesting costs.

The average yarding cycle lasted 5.10 minutes and produced 36.1 cubic feet of timber. Lateral yarding consumed an average of 59 percent of the yarding cycle and included 71 percent of the operating delays observed. Log hangups account for 59 percent of the operating delays.

Reliable prediction of the yarding cycle time is difficult due to wide variability in the observed times. The best model found for predicting the duration of the yarding cycle uses yarding distance and lateral yarding distance as independent variables. The lateral yarding element is the least predictable element of the yarding cycle.

Simulation analyses were used to investigate the effects of changing corridor dimension on average hourly yarding productivity in light of machine setup time. Corridor widths of 52 feet resulted in significantly less production than widths of either 104 or 208 feet when yarding road changes were assumed to require two hours. Corridor lengths of 208 feet were significantly less productive than lengths of 416 or 624 feet. No significant difference in productivity was found for the three corridor lengths when road changing time was reduced to one hour. Again, the 52 foot corridor widths were less productive.

Estimated direct harvesting costs (on board truck) are given for two system configurations and three utilization levels. The estimates range from \$22.21 per cord to \$37.14 per cord.