SIMULATING CABLE YARDING COSTS AND PRODUCTION RATES: A CASE STUDY OF FIRST THINNING OPERATIONS WITHIN PINUS RADIATA PLANTATIONS ON STEEP SLOPES IN SOUTH EASTERN AUSTRALIA.

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AN ABSTRACT OF THE PAPER OF

Philip John Deamer for the degree of Master of Forestry in Forest Engineering presented on September 2nd, 1987.

Title: Simulating Cable Yarding Costs and Production Rates: A Case Study of First Thinning Operations within Pinus radiata Plantations on Steep Slopes in South Eastern Australia.

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Dr. Julian Sessions.

Cable yarding of first thinning size material from plantations of *Pinus radiata* in South Eastern Australia is simulated using a computer model. Production rates, expressed in cubic metres per hour and production cost, expressed in dollars per cubic metre were derived using the model to simulate cable yarding under set conditions.

Values for the production rate and cost were obtained from the simulation of three machines; a Koller K-300, a Timbermaster and a Madill 071, all rigged as standing skylines on uphill settings and using intermediate supports.

Results obtained by the simulation runs are presented showing the variation of total average costs per cubic metre, with slope distance of the setting and the variation of production per hour against slope distance. For each machine an optimal landing spacing and slope distance was identified for operations in forests of given average thinning piece size.

Management implications and alternative harvesting

strategies are discussed concerning the introduction and use of such machines to cable log this forest type.

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1. INTRODUCTION

The forest manager investigating the introduction of a cable yarding system into a new forest type and area faces a difficult task. The manager needs to specify a combination of yarder, rigging and labour which will result in an economic operation. To do this the manager must consider all the variables likely to affect the total cost and hourly production of the operation. Using these variables, the relationship must be derived which link the cost of a unit of production to the on site conditions of the logging area. In this paper the introduction of a cable system to yard thinning material from first thinning steep areas of plantation grown exotic softwood within the Tumut Management Area in South Eastern Australia will be investigated.

Area Background and History

The Tumut Management Area is located 450 kilometres south west of Sydney, New South Wales, on the western fall of the Great Dividing Range. It is the centre for a large regionalised exotic softwood plantation and utilization industry. (Forestry Commission of New South Wales 1984).

The plantation is comprised almost entirely of the species **Pinus radiata** (D. Don), commonly known as radiata pine.

The earliest plantation of conifers in the area was in 1921 on Bago State Forest. Other plantations were established in the late 1920's at other locations in the area. Plantation establishment virtually ceased with a government inquiry in 1935 which continued until the outbreak of World War II. Plantation establishment resumed again in 1945 and increased annually on existing State Forests and land acquisitions. By the mid 1960's 1500 hectares per annum were being established and in 1966 the Commonwealth Softwood Agreement Act came into effect. Its stated purpose was to assist the States of Australia to expand their plantation program and to achieve national self sufficiency in wood production by the year 2000. The Tumut program peaked in 1969 with 4008 hectares being established in that year. The annual plantation rate has since stabilized at 2400 hectares per annum. Currently 85 percent of the area established annually is new plantation and the remaining 15 percent second rotation planting.

The large annual plantings of the late 1960's and early 1970's, brought about by the Softwood Agreement Act, were established on a wide range of soil and topographical conditions. Some plantation is established on slopes up to 70 percent. Available flat land suitable for planting is also diminishing, resulting in a continued addition of steep land to the plantation estate.

Management

Radiata pine grown in the Tumut Management Area is subject to an intensive management strategy aimed at maintaining a healthy, productive forest, capable of providing a reliable source of roundwood to the various utilization industries in the area.

Part of this management strategy is the successful first thinning of the forest between ages 13 and 16 years. The thinning is carried out for a number of reasons, including:

(i) To maintain a healthy and vigorous stand,

(ii) To meet pulpwood requirements of established industries in the area,

(iii) To ensure the stability of the forest,

(iv) To ensure suitable growth of the forest for future sawlog and veneer production.

Current Harvesting Practice

Current harvesting practice for first thinning operations is based on mechanical falling, mechanical processing (limbing and bucking) and mechanical log length extraction to a roadside cold deck.

The operation is based on a fifth row outrow system, where every fifth row is removed to allow machine access and thinning of the bays adjacent to the outrows. Initial planting of the forest is set out at 1320 stems per hectare, on a 2.5 X 3.0 metre grid. The actual strike rate or stocking of live trees just prior to thinning varies down from this value, typically falling in the range of 900 to 1300 stems per hectare. The basal area of the forest after thinning is typically 15 to 18 square metres per hectare.

Harvesting machinery currently in use is exclusively ground based. Typically a rubber-tyred Kockums 880 feller buncher, a rubber-tyred Logma stroke delimber/processor and an Osa, Volvo or Kockums 6 wheel drive forwarder. These machines are limited to a maximum grade of 45 percent, operating under ideal conditions.

High winter rainfall and low evapotranspiration rates occur during winter and early spring months. The resultant high soil moisture content in these months reduces the capacity of these machines to negotiate grades, limiting them to grades less than 15 percent on well drained soils. Consequently the amount of available timber that can be harvested is reduced during this season.

These two factors, limited winter harvesting and maximum gradeability of existing machines will shortly precipitate a need for a harvesting system capable of overcoming these problems. (Orman and Carter 1985). Such a harvesting system may involve the partial or full suspension of logs by a wire rope, rigged onto a man made tower, the logs being brought to a landing attached to a carriage running on a skyline. This method of timber extraction is widely used to harvest similar forest areas thoughout the world.

Objective

The objective of this paper is to predict the hourly production rate and cost per cubic metre of cable yarding first thinning material from plantation grown radiata pine within the Tumut Management Area under assumed logging conditions. A computer code written in **BASIC** and run on a microcomputer using an **MS-DOS** operating system will be written to predict cycle time and production rates of such an operation. Slope distances and lateral yarding distances will be varied to determine optimal settings.

Scope

This paper will consider the time and cost, in Australian Dollars, of yarding first thinning material from steep areas on radiata pine plantation using three machines.

(i) A Koller K-300 mobile yarder.

(ii) A Timbermaster mobile yarder.

(iii) A Madill 071 mobile yarder.

These machines represent the size and capital cost of machines currently in use to log similar forest and terrain in the Pacific Northwest of the United States of America and Europe.

A multispan rigging system will be assumed, operating under conditions typical for steeper areas of plantation in the Tumut Management Area. The range of slope distances over which yarding will be simulated will depend on the machine skyline drum capacity or the maximum distance for which payload can be obtained on lines sizes typical for the machines and using a safety factor of three.

Yarding costs will be expressed in terms of dollars per cubic metre and reflect road, landing, yarder and labour costs. Production rates computed by the simulation model will be expressed in cubic metres yarded per hour, not including road change times but including delays. These rates will be verified by comparison with actual results from published studies carried out in similar forest conditions using similar machines.

A simulation procedure will be used to predict these costs and production rates. Simulation is used over regression since it can take into account elements in the operation that are stochastic or non-linear. For example, the average cost of a function which is non-linear and involves a stochastic variable does not occur at the average value of the variable. Certain variables of the yarding cycle are non-linear, stochastic or both.

2. MODEL DESCRIPTION

The production rate of any cable yarder is a function of its payload capacity and cycle time. The payload capacity is a function of the topography, the yarder rigging arrangement and the line size. Cycle time is a function of the yarder power, the location of logs in the forest, rigging layout, rigging time and delay time. The model used in this paper recognizes these relationships and from them generates production rates for yarding thinning material for a given set of conditions.

Literature Review

The use of cable yarders to yard thinning material from forests similar to those considered in this paper is not a new concept. In the Pacific Northwest of the United States of Amercia research aimed at improving small wood yarding operations commenced in the early 1970's. Aulerich, Johnson and Froehlich (1974) compared skyline and tractor logging production rates and cost for thinning a 35 year old stand of Douglas Fir. They reported the skyline system to be more productive than the tractor system on steeper slopes. They also reported the hourly cost of the skyline system to be 1.5 to 1.6 times higher than the tractor system. Further, they identified the lateral yarding element of the yarding cycle to be the most time consuming. Aulerich (1975) suggested that carriage systems utilizing skyline stops may improve skyline efficiency for small wood harvesting. Carriage stops replace the need for a haulback line to hold the carriage in place during lateral yarding, thus reducing the power requirement of the yarder. Using a carriage and stop on a small yarder he found a 22 percent decrease in total turn time at an average yarding distance of 200 feet (61 metres) compared to a carriage held in place with a haulback line, operating in similar conditions.

Kellogg (1980) reported the use of multispan rigging and a Koller self-clamping carriage to yard thinning material from a 35 year old stand of Douglas Fir. The production rates were reported to match those of previous studies using single span systems, the increased payload made available by the increased deflection from the intermediate support offsetting the increased rigging time. The use of intermediate supports is of European origin and is used extensively to increase the payload capacity of small towers.

Other techniques have been suggested to increase the productivity of cable thinning. Kellogg and Aulerich (1977) demonstrated a 24 percent reduction in total yarding cost when a small, mobile, single drum prebuncher was used in conjunction with a Schield Bantam yarder to swing the logs to a central corridor. Other studies (Keller, 1979) have shown opposite results operating in different conditions. Prebunching however is still a viable logging method under some conditions.

The extraction direction for a majority of the studies published on thinning with skylines has been uphill. Some studies have compared extraction in both directions, uphill and downhill. Melmoth (1978) found uphill extraction to be the more productive direction for thinning extraction due in part to the added time required to rig downhill settings. Twaddle (1978) found the production rates of both extraction directions similar. Vypiel (1980) proposed that uphill extraction of thinning material was favourable for a number of reasons including reduced stand damage and greater control of the incoming load.

All studies cited have used a central corridor to move logs under the skyline to the landing. Logs are first inhauled laterally to a position underneath the carriage, either by the carriage mainline or a prebunching machine. When the logs are in place under the skyline the carriage and load are brought to the landing by inhauling the mainline. This is shown in Figure 1.

Simulation is a method that has been used by several researchers to determine the relationships between variables that affect the cost and production rates of logging operations, (Goulet et al 1979, LeDoux and Butler 1981, Sessions 1979). In most cases these models are written for a specific set of logging conditions, which does not easily allow for the model to be used outside of the purpose for which it was written. For this reason a simulation model was written to determine costs and production rates of cable logging in conditions specific to a plantation forest.

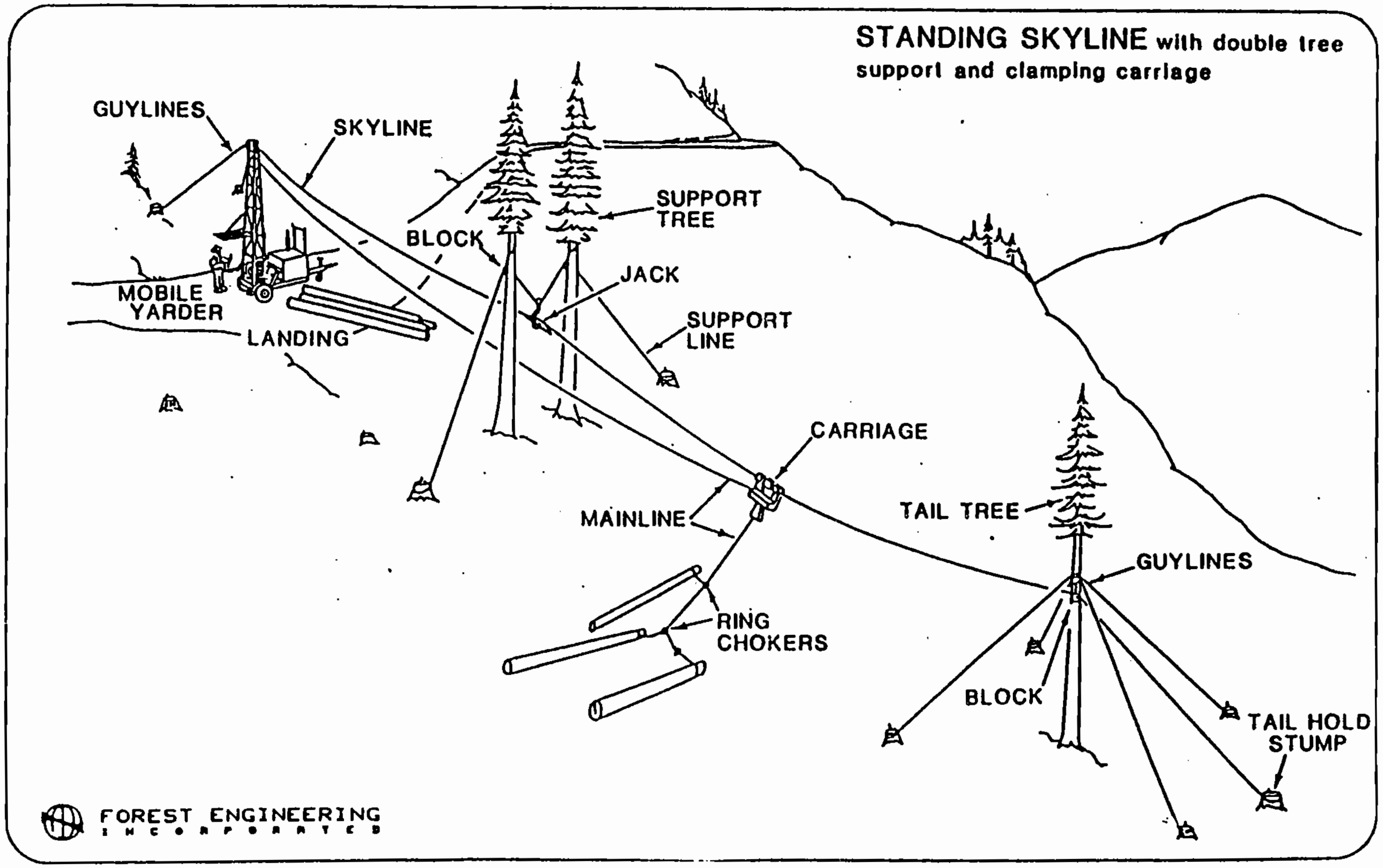

Figure 1. Reproduced coutesy of Forest Engineering Incorporated

Assumed Logging Conditions

The model in this paper assumes a similar logging system to that mentioned above. It will be assumed that a central skyline corridor carries the material from the bays adjacent to each corridor to the uphill road.

Conditions are set to be typical of the forest being considered. The ground slope of the area is set at 50 percent or 27 degrees and the initial stocking of the forest is set at 1100 stems per hectare, planted out on a 3.0 X 3.0 metre grid. Also thinning will remove 50 percent of the stems, resulting in a residual basal area similar to that currently prescribed in the management plan for the area.

It is also assumed that whole tree lengths will be yarded. The volume of these trees varies in the range of 0.2 to 0.35 cubic metres of pulpwood per tree. This average volume multiplied by the stems removed per hectare will give the total yield in cubic metres per hectare for a given piece size and yarding area.

Processing (limbing and bucking) and the removal of the processed material from the yarder landing to a roadside cold deck will be performed by additional machinery.

Road Costs

The cost of roads in the forest area considered is based on the assumption that the existing roads, constructed for plantation establishment will be reopened for transport of the thinning material. Based on previous road reconstruction costs in the area, each metre of road required for a yarding setting will add $2.00 to the total cost of the yarding operation. The length of road required for each setting is defined by the spacing of the landings, or the distance between outrows.

Landing Width and Cost

The width of each landing is designed to allow sufficient room for the yarder and clearance for the logs to be unhooked and stored between the yarder and the road edge. Landing widths are set at 16.7 metres for the Madill 071 and 15.0 metres for the Koller K-300 and the Timbermaster. The calculation of landing width for each machine is shown in Appendix A.

The cost of landing construction is assumed to be constant for all three machines. This is based on the assumption that construction time for the landing requirement of any machine considered here will be equal. The machine requirements for landing construction include a medium sized tractor and a grader. It is assumed that this equipment can construct four landings per day. Each of these landings would cost $340 each, based on current machine and labour rates. An example landing cost calculation is shown in Appendix A.

Support Height and Location

The location of the intermediate support relative to the road edge varies with each machine. This is to allow adequate clearance of the skyline at the road edge for the different tower heights as shown in Figure 2. The required clearance of the skyline at the road edge is set at 6.0 metres for the Koller K-300 and Timbermaster towers and 9.0 metres for the Madill 071. These clearances are assumed and allow for adequate skyline deflection during inhaul, clearance for the machines to pass under the skyline and for log storage on the landing.

The height of both the intermediate support and the tail block is set at an assumed height of 12.0 metres or one half of the total stem height above the ground. No published data is available concerning the suitability of plantation grown radiata pine for skyline support spars. It is known from previous studies (Melmoth 1978, Twaddle 1977, 1978) that trees of similar size to those in the forest model ed in this paper have been used successfully as support trees.

Sequence of Simulation Calculation

The model uses the physical ability of the yarder and previous regression studies to simulate cycle time. The series of computations are divided into separate subroutines in the program. These are:

(i) The input of assumed conditions as detailed above.

(ii) The input of machine type and associate variables.

(iii) Costing calculation.

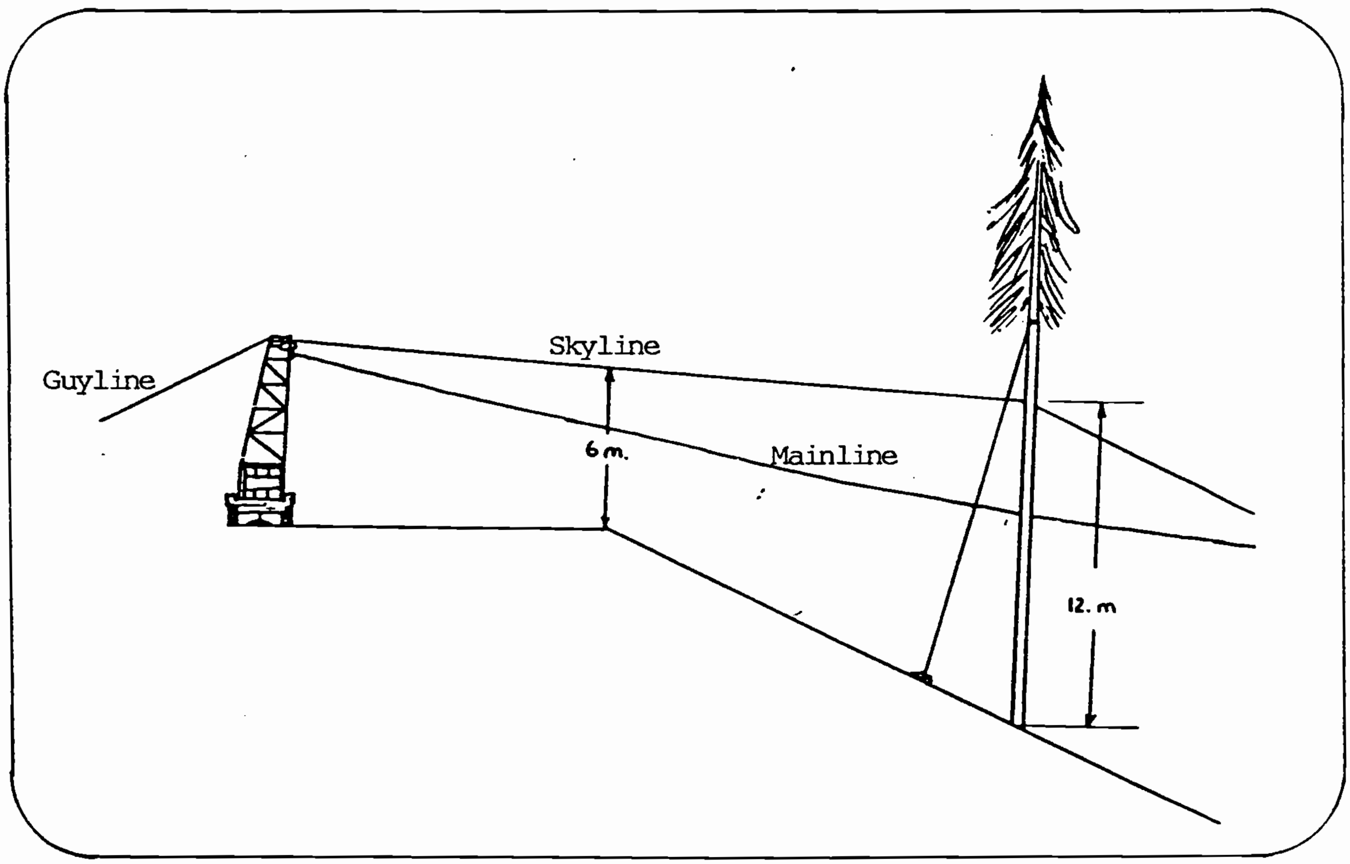

Figure 2. Intermediate support block location.

(iv) Payload calculation.

(v) Cycle time calculation.

(vi) Delay and rigging time adjustments and output.

Yarding or slope distance and lateral yarding distance are varied in a numerical sequence to determine yarding costs and production rates for each machine operating under conditions outlined above. Yarding distance is varied from 70 metres to the maximum skyline capacity of the yarder in steps of 30 metres. Lateral yarding distance is varied from 6 to 24 metres in steps of 3 metres. This is equivalent to outrow spacings from 5 to 17 outrows in steps to 2 outrows. A flow chart of the program is shown in Figure 3.

Machines

Three machines are available for use in the model.

(i) A Koller K-300 yarder and tower rigged as a multispan standing skyline. The crew size is set at three persons, one working as an engineer/chaser and two working as choker setters. A SKA-1 self clamping Koller carriage is used with the system.

(ii) A Timbermaster yarder and tower, rigged as a standing multispan skyline. The crew size is set

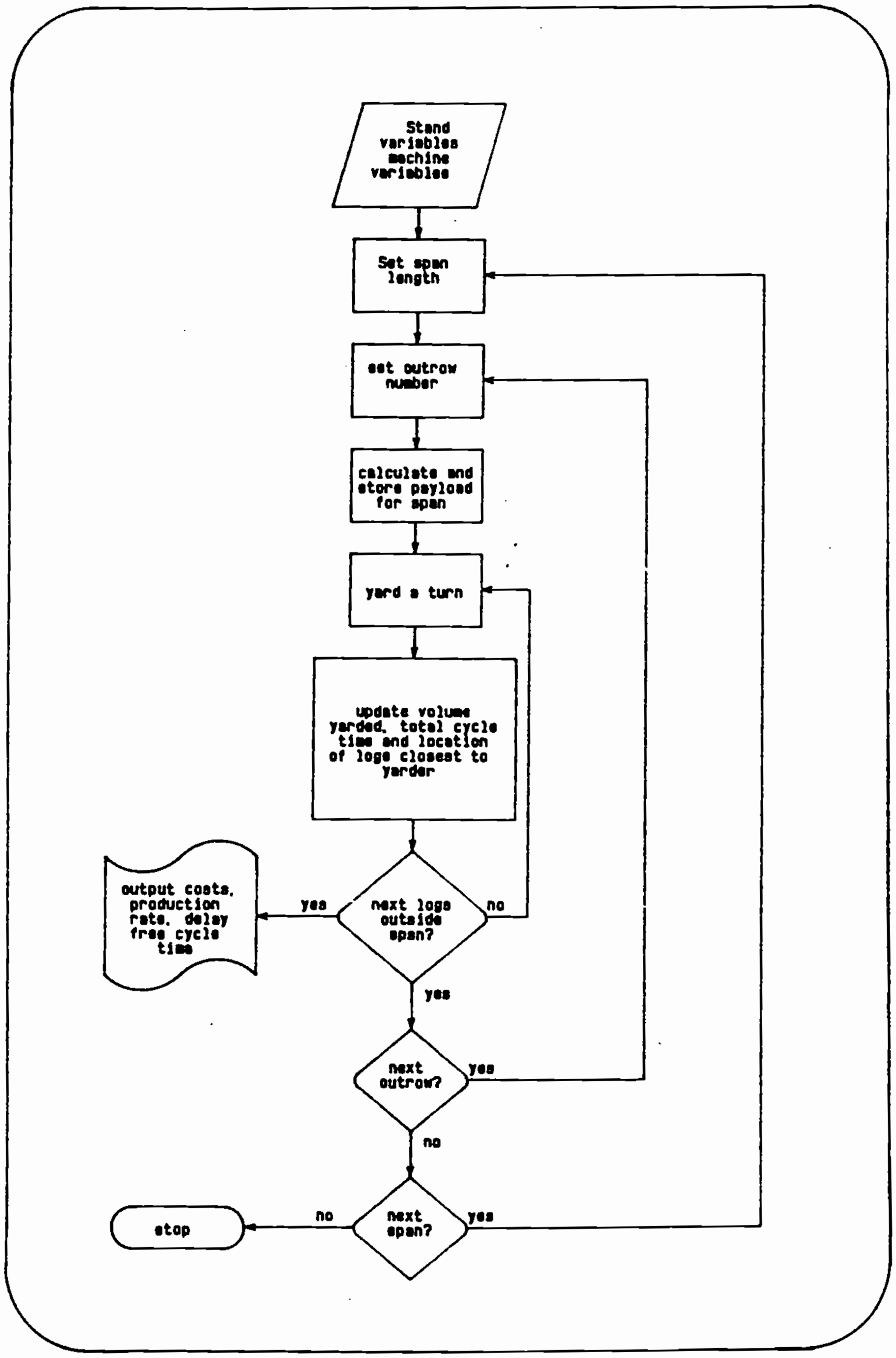

Figure 3. Flow chart of the simulation sequence.

at four persons, one working as an engineer, one working as a chaser and two working as choker setters. A SKA-1 self clamping Koller carriage is used with the system.

(iii) A Madill 071 yarder and tower rigged as a standing multispan skyline. The crew size is set at four persons, one working as an engineer, one working as a chaser and two working as choker setters. A Danebo mechanical slackpulling carriage (MSP), mounted on a truck able to pass intermediate supports is used with the system. Machine descriptions and specifications are shown in Appendix B.

These three machines are selected to represent the possible range of machines most likely to be adopted for operation in the area considered. This is based on several previous studies (Neilson 1977, Twaddle 1977, 1978, Melmoth 1978, Gabrielli 1980, Kellogg 1980). The crew size associated with each machine is set to represent the minimum number of men required. Two choker setters are considered minimum for safety reasons. For the Koller K-300 the engineer is able to double as a chaser, but the Timbermaster and Madill 071 require the engineer to be seated at controls, necessitating an additional crew man to act as a chaser. The carriage type selected with each machine is based on current industry practise in the

Pacific Northwest of America for similar machines operating under similar conditions.

Costing

Following the input of variables associated with a specific machine a subroutine calculates the hourly cost of running the yarder. The formula used is from Bushman (1987). Where possible the factors used in this calculation are actual costs, otherwise estimates are used. Actual costs include hourly wage rates for forest labourers, wage on-costs, fuel costs, wire rope costs and interest rates. Estimated costs are yarder, carriage and radio (talkie tooter) cost new on-site; the yarder, carriage and radio salvage value; and the yarder, carriage and wire rope life.

The Average Annual Investment (AAI) method of equipment costing is used. This method combines straight line depreciation with additional average annual costs to determine a total ownership cost (Bushman, 1987). Operating costs are calculated by estimating fuel, oil and maintenance costs then adding these to the ownership costs. An example of the costing calculation is set out in Appendix C for each machine.

Payload Calculation

Before the simulation of yarding commences the payload capacity of the system is calculated. This is expressed as the maximum number of whole tree lengths that can be yarded to the landing from each of 9 points spaced equally along the downhill span of the skyline and an additional point at the midspan of the uphill span (Figure 4).

A ring and toggle choker system, shown in Figure 5 is used in conjunction with each carriage. The ring and toggle system is suited for choking several logs spread over an area, since the maximum allowable distance between the logs is the length of the available mainline pulled from the carriage. A maximum of 6 ring and toggle chokers are available for loading, depending on the payload capacity. Six logs per turn is below the payload capacity of the machines at shorter spans, particularly the Madill 071. Gabrielli (1980) found 6 to be the maximum number of ring and toggle chokers that can be managed effectively under similar operating conditions to those considered in this paper.

The calculation used is adapted from Sessions (1986). The skyline segments and mainline are assumed to act as rigid links. The rigid log model is used to determine the normal ground force of the log load. Perumpral et al (1977) presented an expression for the normal ground force exerted by a non-rigid tree length log load supported at the butt end by a choker cable and dragged behind a skidder. The expression was derived from anaylsis of a free body diagram and experimental observations of <u>**Pinus taeda**</u> tree lengths. The rigid log model was used in preference to the tree length model here since the tree length model was derived for an individual species of timber, acting on level ground and with butt clearances of 0.75 metres or less, considerably less than the 2.0 metre minimum butt clearance specified in this analysis.

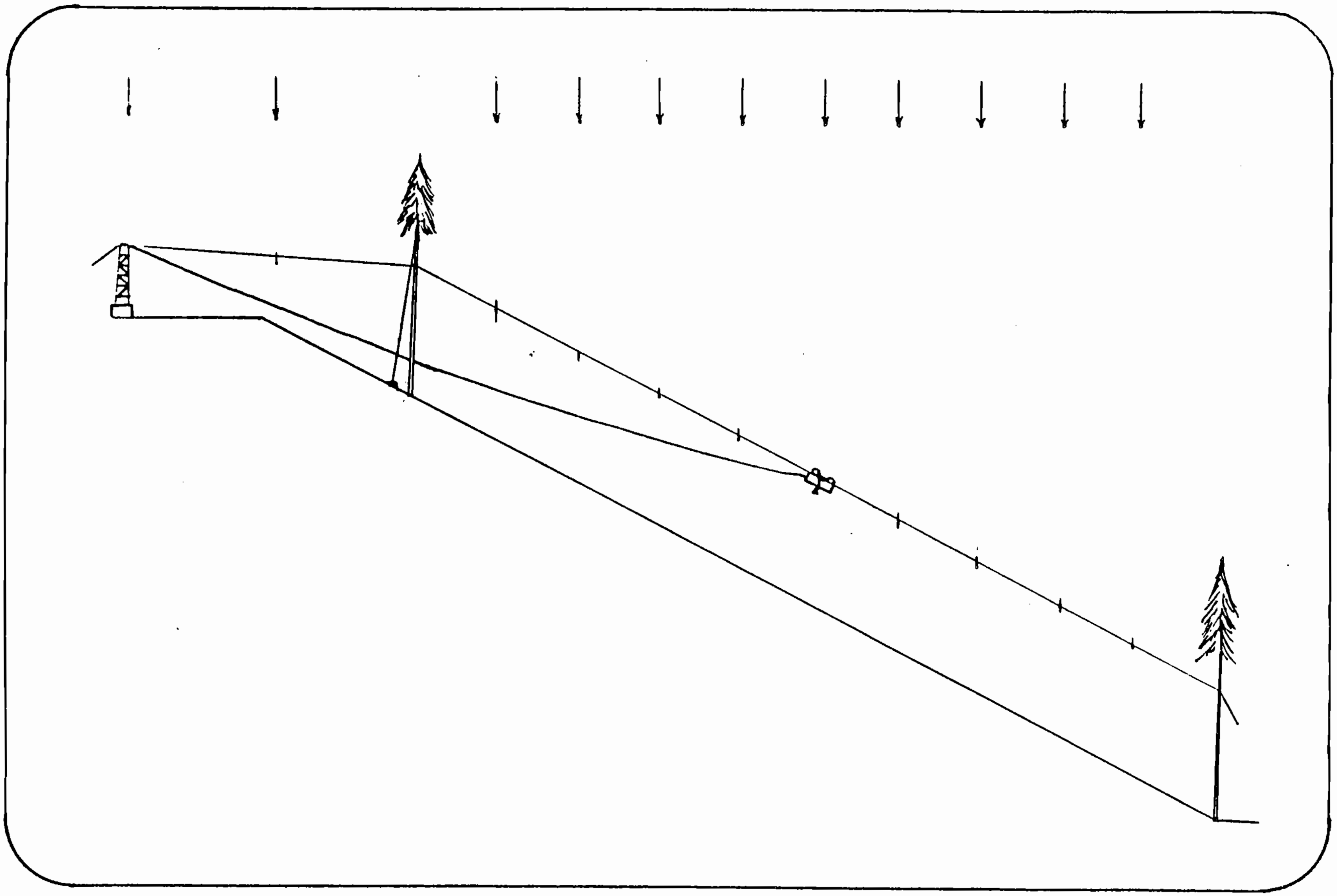

Figure 4. Payload capacity calculation points.

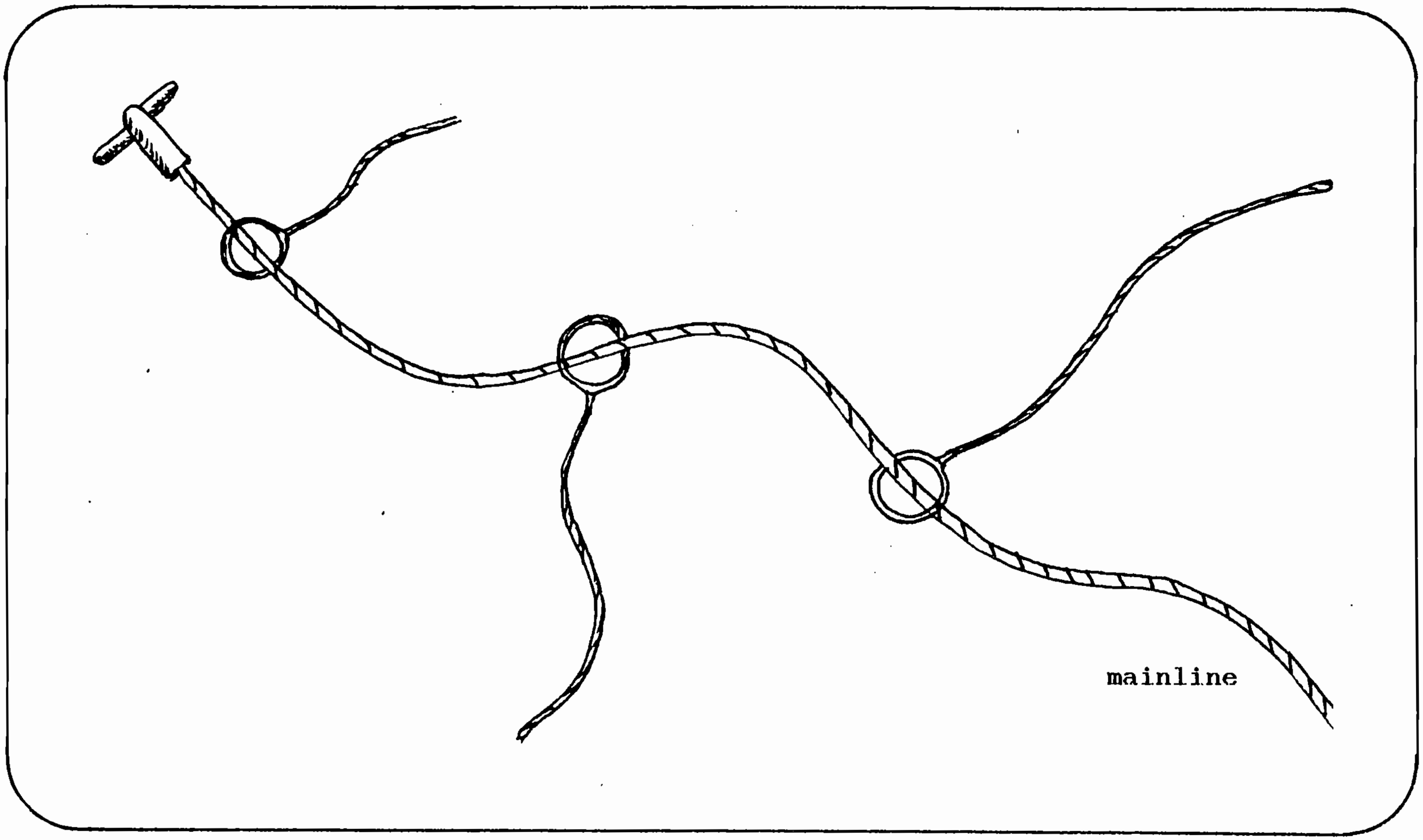

Figure 5. Ring and toggle choker system.

The calculation commences by computing the longest stretched line length that can maintain a front end log clearance of at least 2.0 metres during inhaul for the entire skyline span. The line length is calculated at each of the ten points identified earlier and the appropriate value is saved. The incoming carriage is then assumed to follow an elliptical load path, the segment geometry of which is calculated for each point along the skyline span previously used to calculate the minimum line length. Once the load path is defined the payload capacity is determined for the first point away from the yarder by calculating the vertical component of the skyline and mainline tension and matching this to the vertical force required to support a load of 6 logs in contact with the ground. The process is repeated by adjusting the tension in the skyline by a secant step size until the calculated vertical component of the lines equal that required to support the load. If this tension is below the maximum safe working tension then the payload for that point is set at 6 trees. If it is above the maximum then the payload is reduced by 1 tree and the procedure repeated. The highest number of whole trees which can be supported by a skyline and mainline tension within the respective safe working limits is the load. The calculation is repeated for each point along the skyline span shown Figure 4 and a log load, log position matrix is generated. This defines the number of logs that can be yarded to the landing from each point on the span. This matrix is stored and used to determine the payload at each point during yarding simulation. A flow chart of the calculation is shown in Figure 6. A detailed description of the calculation is shown in Appendix D.

Cycle Time Calculation. Outhaul.

Simulation of the yarding procedure begins with the setting of initial values. The location of the carriage on the skyline above the landing is set at the return position. The position the carriage must travel to on the skyline in order to pick up the first turn of logs is also calculated and stored. It is assumed that the empty carriage travels the same path as the skyline chord slope (weightless line assumption). Simulation commences with the carriage moving from its return position down the skyline under the force of gravity. The gravitational force acting on the carriage produces a force component parallel to the skyline, proportional to the sine of the angle between the skyline and the horizon (Figure 7). As the carriage moves between the first and second sections the component of gravitational acceleration increases according to the increase in the skyline angle. The carriage is simulated to accelerate under these forces to a maximum velocity of 4 metres per second, the operator preventing the carriage from running out faster by use of the mainline brake. For the Madill 071 operating with a Danebo MSP carriage, the outhaul speed of the carriage is held constant at 4 metres per second, equivalent to the published maximum line speed of the haulback line going onto a bare drum. When the carriage reaches the

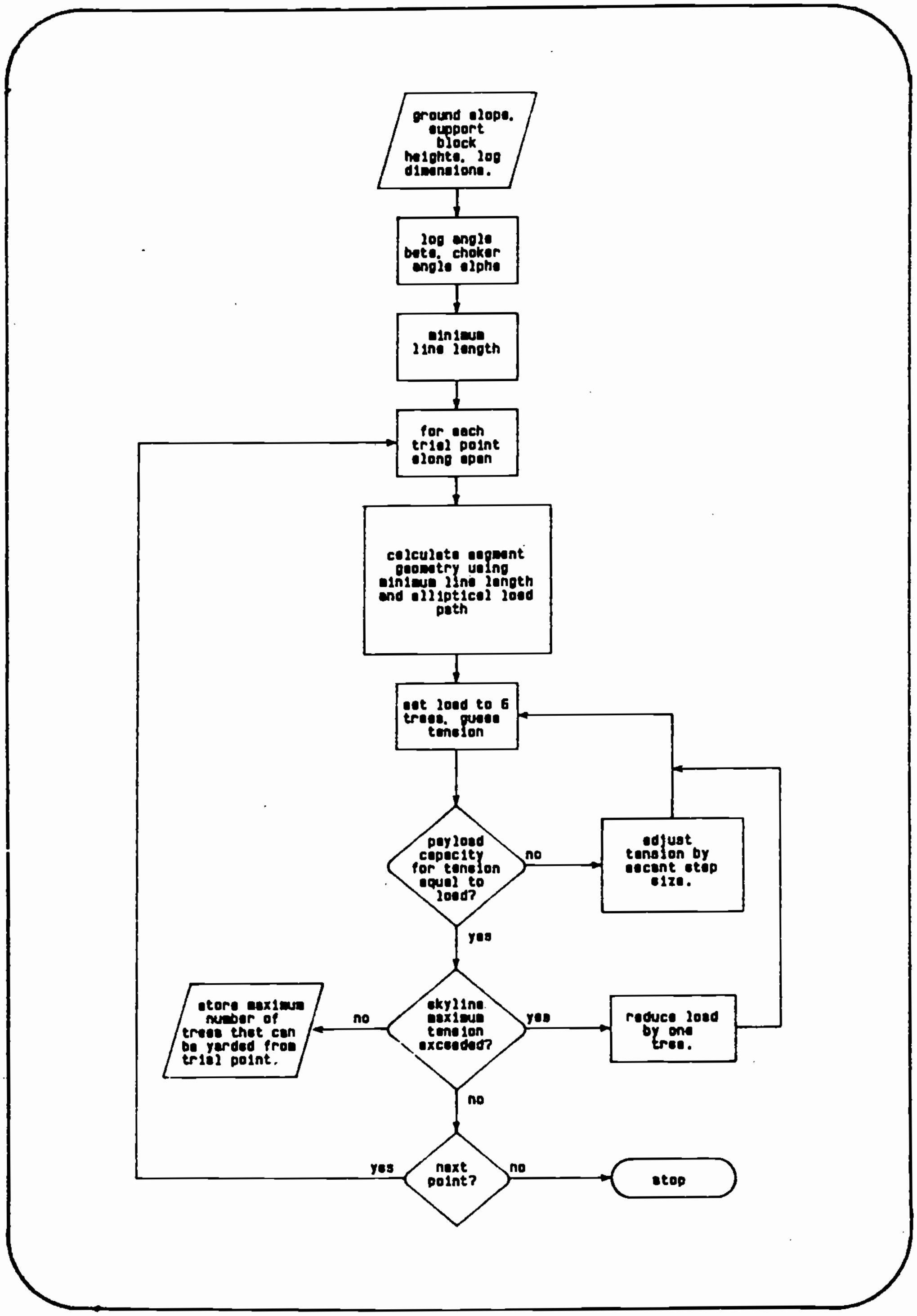

Figure 6. Flow chart for payload calculation.

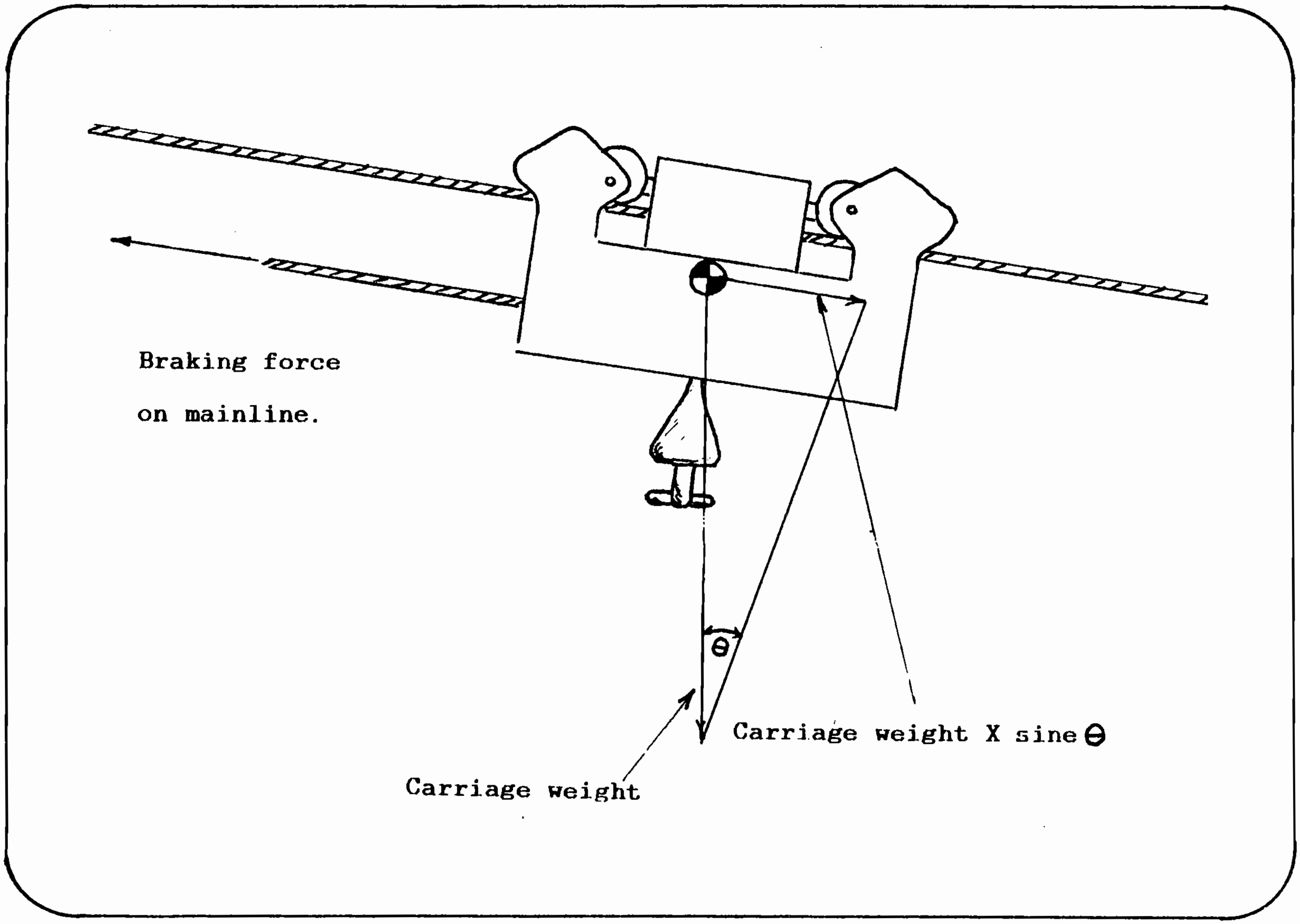

Figure 7. Forces acting on a gravity return carriage.

position above the logs closest to the yarder, it is assumed to stop instantly. An elapsed time of 5 seconds is then added to the outhaul time to account for the reaction time of the operators, the carriage to stop and the mainline to drop or be pulled out of the carriage.

Lateral Outhaul

Several studies (Aulerich 1975, Neilson 1977, Gabrielli 1980, Putman 1983, Kellogg and Olsen 1984, Kellogg, Olsen and Hargrave 1986) have reported coefficients for lateral outhaul distance in cycle time regression models. These are shown in Table 1. All but one (Kellogg, Olsen and Hargrave 1986) use a linear relationship. Gabrielli (1980) derived a regression equation for the lateral outhaul element of the yarding cycle. It is expressed as;

> Lateral outhaul time (minutes) = .47 minutes + .019minutes per metre of lateral outhaul line + .00444 minutes per lead angle degree.

This expression was adapted for use in this model by assuming a lead angle of 90 degrees and collapsing this term into the constant to give the equation;

> Lateral outhaul time (minutes) = .872 + .019 minutes per metre of lateral outhaul line.

TABLE 1.

Regression Coefficients for Lateral Yarding.

REF #.	REPORTED COEFFICIENT Minutes per Foot	Minutes per Metre
2.	0.15	.0492
10.	0.0134	.044
16.	0.017	.056
11.	0.00021 Minutes/Foot^2	-
13.	0.0257	.084
6.	0.00363	.019

The actual distance of lateral outhaul for each cycle used in the above equation is considered a function of the corridor spacing and the log location within each row, Figure 8. The corridor spacing directly defines the maximum distance of lateral outhaul since a planting grid of 3.0 X 3.0 metres is assumed. The maximum outhaul distance is equal to the outrow spacing number minus 1 plus **m**, where **m** is equal to 2 for an outrow spacing of 5 rows and increases by 1 for every possible outrow spacing between 5 and 17 rows. For example, an outrow spacing of 9 rows has a maximum lateral yarding distance of (9-1) + 4 = 12 metres. The actual lateral yarding distance for each cycle is assumed to be a random fraction of this maximum distance, beyond a minimum value of 3 metres. This is simulated in the model by multiplying the maximum lateral yarding distance for a given outrow spacing by a random number to determine the actual lateral yarding distance for each cycle.

Hook Time

The next element of the cycle time sequence is the hooking of logs. Gabrielli (1980) attempted to regress hook time against the number of logs but found the result not significant for a system using 6 ring and toggle chokers. Instead he reported hook time as the means of observation of 1.94 minutes, which is the value used in this model.

Lateral Inhaul

Time for lateral inhaul is estimated using a regression model from Gabrielli (1980). The model is;

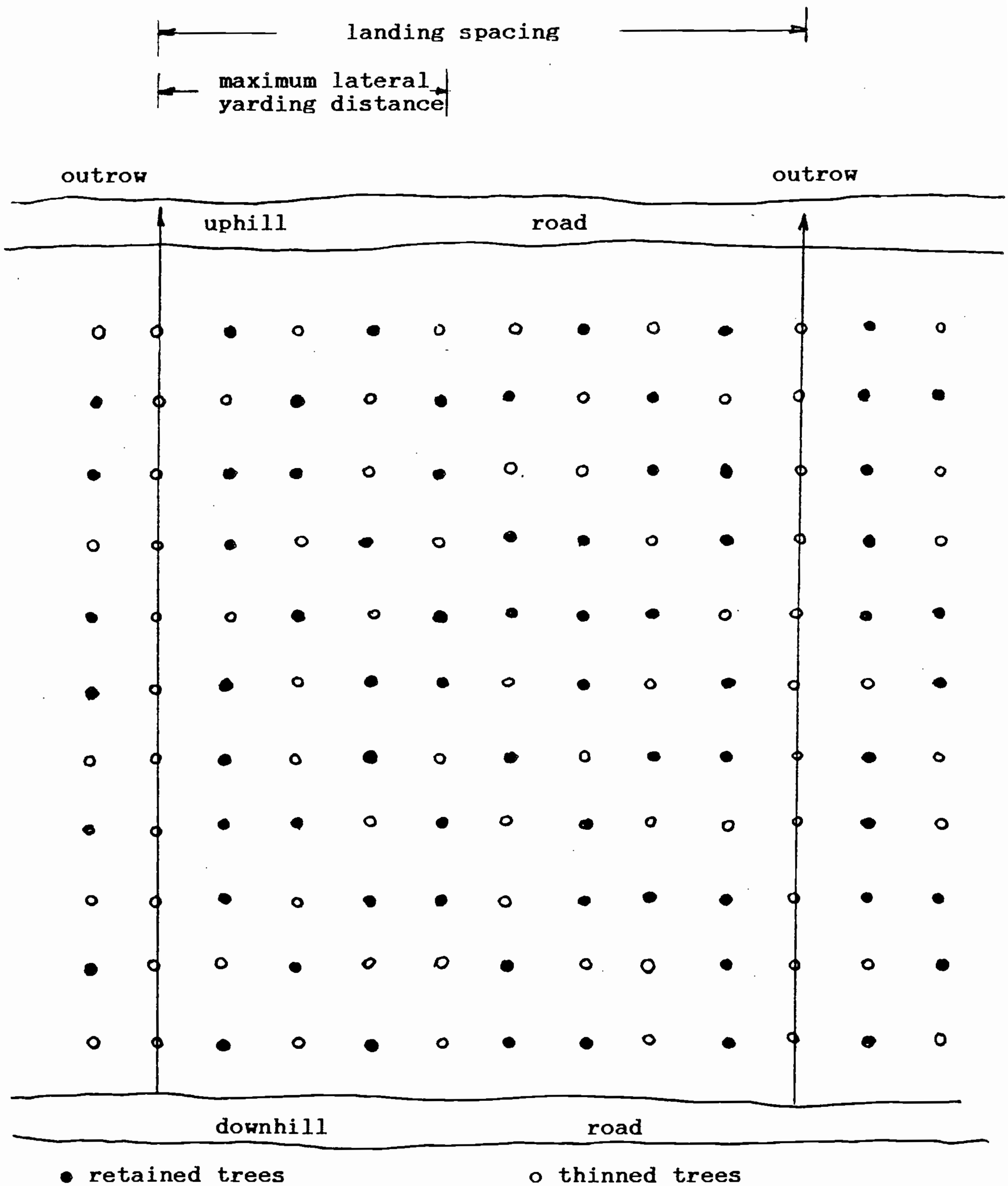

Figure 8. Relationship between outrow spacing, maximum lateral outhaul distance and the stems removed per hectare.

Lateral inhaul time (minutes) = .15 + .0054 minutes per metre of lateral inhaul + .00371 minutes per metre of lead angle + .03596 minutes per number of logs.

The coefficient for the lead angle is collapsed into the constant by assuming a lead angle of 90 degrees to give the following model used in this paper.

Lateral inhaul time (minutes) = .48 + .018 minutes per metre of lateral distance + .036 minutes per number of logs.

Inhaul

Carriage inhaul starts with the load locked into the carriage at the end of lateral inhaul. Inhaul time is calculated as a direct function of the yarder power at the drum and the static force on the mainline, calculated in the payload subroutine. The power at the drum is estimated as 0.63 of the total yarder power. This is based on the assumption that 10 percent of the flywheel engine power will be lost to transmision inefficiencies and a further 30 percent is lost to operator restraint and non optimal performance of the engine.

Unhook Time

The time required to unhook the log load is set at an average value of 34 seconds regardless of the number of trees in the load. Although this may not be the case in all situations, Gabrielli (1980) found no significant correlation between unhook time and log number for a ring and toggle choker system.

Yarded Volume Simulation

With the completion of a yarding cycle the volume yarded in that cycle is calculated as the product of the mean tree size and the number of pieces yarded. This value is added to previous total and stored.

Before the carriage returns for the next cycle the location of the logs closest to the yarder is updated. This calculation is based on the assumption that 50 percent of the stems from the unthinned forest are removed. The number of trees that are availabe from each row is therefore a function of outrow spacing. Since the outrow clearfalls one row the trees required to make up the thinning from the bays increases with each increase in outrow spacing. An infinite outrow spacing would result in the removal of every second stem in the bays. An outrow spacing of every third row results in 1/2 of the trees being removed from each row in addition to the outrow tree. For an outrow spacing of 17 rows, 7 1/2 trees are removed from each row in addition to the outrow tree. This is shown in Figure 8. The formula used to calculate trees removed from each row is;

$$(\text{Outrow spacing} - 2)/2.$$

As the carriage moves to the first available trees it loads the number of trees calculated previously to make a turn. After the carriage loads this turn the number of rows required to supply this number of tree is calculated using the formula above. The location of the row closest to the yarder still containing trees is calculated and this is where the carriage returns. Fractional logs are considered. This cycle continues until the next required row for logs is outside the slope distance set at the commencement of the run. Values for outrow spacing, maximum lateral distance and trees removed per row are shown in Table 2.

Delays

Cycle time delays are accounted for by using a representative percentage value obtained from published studies operating similar equipment under similar conditions (Table 3). A value of 30 percent is used in this paper to represent the percentage of total yarding time lost to delays. These delays represent total delays including log hang-ups during yarding, mechanical and personal delays.

Rigging Times

Published studies of rigging and derigging time show values of between 0.68 hours and 3.5 hours. Rigging time for a haulback line adds an additional 0.5 to 1.5 hours to the total time. These results are shown in Table 4. From these results, the time for rigging and derigging appears to be a variable

TABLE 2.

Outrow Spacing Numbers and Lateral Yarding Distances.

OUTROW SPACING NUMBER	MAXIMUM LATERAL DISTANCE METRES.	STEMS REMOVED PER ROW
3	3	1.5
5	6	2.5
7	9	3.5
9	12	4.5
11	15	5.5
13	18	6.5
15	21	7.5
17	23	8.5

TABLE 3.

Published Percent Delay Values.

REF #	OPERATION TYPE	FOREST CONDITION	MACHINE TYPE	TOTAL DELAY TIME, PERCENT
16.	Log length thinning	Natural Douglas Fir	Schield Bantam T350 Yarder	37 %
16.	Whole tree thinning	"	"	40 %
13.	Thinning	Natural Douglas Fir	Igland Jones Trailer Alp	26 %
12.	Delayed Thinning	P.radiata plantation	Timbermaster	40 %
18.	Thinning	P.radiata plantation	Timbermaster	43 %
10.	Thinning	Natural Douglas Fir	Koller K-300	50 %
6.	Thinning	Natural Douglas Fir	Skagit SJ-2	22 %
11.	Thinning	Natural Western Hemlock	Madill 071	33%

TABLE 4.

Published Rigging and DeRigging Times.

REFERENCE NUMBER	RIGGING TYPE	TIME
6.	Single Span System. No Haulback	1.4
11.	Single Span System. With Haulback	1.47
12.	Single Span System. With Haulback	0.68
18.	Single Span System. With Haulback	2.62
11.	Multi-Span System. With Haulback	3.5
13.	Multi-Span System. With Haulback	2.0

factor and sensitive to a variety of unknown influences. For this reason no specific value from a study is used but rather a representative value is used. Rigging and derigging time is set at 2 hours for the multispan system with no haulback and 3 hours for the same system with a haulback.

Output

Following simulation of a complete corridor of given length and lateral yarding distance or outrow number the total time computed by the simulation is divided by the number of simulated cycles required to log the setting to give an average yarding time, delay free. The total time is then adjusted for delays and multiplied by the previously determined hourly operating cost to give a total yarding cost. Added to this cost is the rigging and derigging costs, being equivalent to the hourly fixed costs multiplied by the rigging and derigging time. Road and landing costs are then added to give a total yarding cost.

The total yarding cost is divided by the simulated yarded volume to give an average cost per cubic metre for the operation. The total time, including delays, is divided into the total volume to give an average hourly production rate for the system. A full program listing and sample output is shown in Appendix E.

Values used for Simulation

For each of the three machines listed above, values for average cost (dollars per cubic metre), average production rates (cubic meres per hour) and delay free cycle time (minutes) were determined. These values were computed using the model for a series of slope distances from 70 metres to the maximum machine capability in steps of 30 metres. For each slope distance the outrow number, and hence the lateral outhaul distance was varied from 5th row outrow to 17th row outrow, with an average piece size set at 0.2 cubic metres. This sequence was repeated for average piece sizes of 0.25 cubic metres, 0.3 cubic metres and 0.35 cubic metres. These piece sizes represent average yields of 110, 138, 167 and 194 cubic metres per hectare respectively or the expected yield of plantation grown radiata pine in the Tumut Management Area at ages 13, 16, 18 and 20 years respectively. (Forestry Commission of New South Wales 1984).

Model Verification

Many research studies into harvesting are undertaken with an objective to compare different harvesting methods. To complete this, all other conditions are kept as constant as possible to reduce the variation of results. Even under these conditions it is not uncommon for regression coefficients of determination for cycle time and production rate models to be lower than 0.3. This is to be expected however due to the wide range of operating conditions, equipment variation, manpower experience and weather conditions that occur in reality.

Despite this, such models are often prepared from data obtained by detailed cycle time analysis of logging operations. Many authors (Gabrielli 1980, Kellogg 1980, Kellogg and Olsen 1984) state that such models are useful for comparing costs and evaluating alternatives, preparing management strategies based on the predicted results. Caution is often expressed however against using such models for sale appraisal purposes.

In order to verify this model, simulated values for delay free cycle times and production rates are compared to published results from previous studies (Table 5).

The average delay free cycle time predicted by this model for a set of lateral outhaul distances (6 to 24 metres) is shown to vary between 5.10 and 5.50 minutes for the Koller K-300, 4.95 to 5.47 minutes for the Timbermaster and between 4.87 and 5.30 minutes for the Madill 071, as shown in Figure 9. This compares to delay free cycle times from published studies in similar size material shown in Table 5.

As expected, production rates predicted by this model and those published elsewhere are more variable than cycle times. Production rate is sensitive to several factors, especially piece size. Values for hourly production predicted by the model are shown in Figures 10, 11, 12 and 13. These values ranged from 18 cubic metres per hour to less than 4 cubic metres per hour. This compares to published production rates of between 4.3 and 15.8 cubic metres per hour, shown in Table 5.

TABLE 5.

Production Rates and Cycle Times From Previous Studies.

REF. #	SYSTEM	DELAY FREE CYCLE TIME (Minutes)	HOURLY PROD. (m^3)	AVERAGE DBH. (cm.)	AVERAGE SLOPE DIST. (m.)
1.	Single span skyline with haulback, non clamping carriage	7.0	47/Day	26	95
6.	Single span skyline. No haulback. Clamping carriage.	4.37 - 5.7	7.2 - 8.2	13 - 20	77 - 106
12.	Single span with haulback MSP carriage	4.03 - 4.21	12.7 - 15.8	30	78
15.	Multispan with haulback	4.48	4.3 - 6.9	36	68
17.	Single span skyline with haulback	2.14	11.5	23	92
18.	Single span skyline with clamping carriage	3.8 - 4.5	5.5 - 5.8	32	87

3. RESULTS

Data from the simulation runs were analysed and charts were produced which represented the yarding cost per cubic metre and the production rate per hour for the optimal lateral spacing distance over the range of slope distances for each machine. The optimal lateral spacing distance was determined as the outrow spacing which resulted in the lowest yarding cost per cubic metre, including road, landing and rigging costs.

Production Rate

The production rate for each machine operating in similar sized material at various slope distances are shown in Figures 10, 11, 12 and 13. Production rates were sensitive to piece size and slope distance. They varied from 10 cubic metres per hour to 18 cubic metres per hour over the range of piece sizes on a slope distance of 70 metres. The Koller K-300 consistently worked at the slowest rate of production behind the Timbermaster and the Madill 071. This difference in production was smallest at the shorter spans and increased progressively as the slope distance increased. The increased difference in production rates between machines at the longer spans reflects the greater payload capacity of the taller towers. At the shorter slope distances all machines were able to yard a full turn of 6 trees, the only difference in production rate being yarder power for identical slope distances. As slope distance increased, deflection decreased, causing a drop in allowable payload for each machine. At these longer spans the difference in production rates was the result of several factors including yarder power, safe working tension of the skyline and tower height.

Production rates at the longer spans were very low, below 3 cubic metres per hour. At these slope distances the allowable payload is just 1 tree for most of the span.

Total yarding cost

Total yarding, road and landing costs per cubic metre are graphed against slope distance for piece sizes of 0.2, 0.25, 0.3 and 0.35 cubic metres. These graphs are shown in Figures 14, 15, 16 and 17. The cost represented in each case is for the optimal lateral yarding distance.

Costs ranged from more than $80 per cubic metre for a Madill 071 on a long setting in small size material to $9 per cubic metre for a Koller K-300 operating at an optimal slope distance of 190 metres and yarding material with an average piece size of 0.35 cubic metres.

For each piece size the shape of the total average cost curve declines steadily to a minimum at an optimal slope distance, then rises sharply beyond this point. The optimal slope distance is the distance which results in the lowest average cost for the yarding operation, including road, landing and rigging costs. The Koller K-300 and the Timbermaster showed similar costs per cubic metre when used to yard material at slope distances less than or equal to 310 metres which is the maximum yarding distance for the Koller K-300. From slope distances greater than 310 to 400 metre costs for the Timbermaster rose sharply. Using the Madill 071 to yard slope distances up to 310 metres resulted in higher total yarding costs than the two smaller towers. This difference in total cost was greatest for operations in smaller piece size material and shorter slope distances.

Both the Koller K-300 and the Timbermaster were most economical when operated on slope distances of between 190 metres and 250 metres. The Madill 071 was most economical at longer spans, between 310 metres and 370 metres. For all machines, yarding beyond the optimal slope distance was more sensitive in terms of cost than yarding shorter distances.

The optimal lateral yarding distance was almost invariably the lateral yarding distance associated with an outrow spacing of 17 outrows or 48 metres between landings. At very long settings the simulated costs showed that outrow spacings of 13 or 15 rows were more favourable, but the total cost difference was less than $0.20 per cubic metre in all cases.

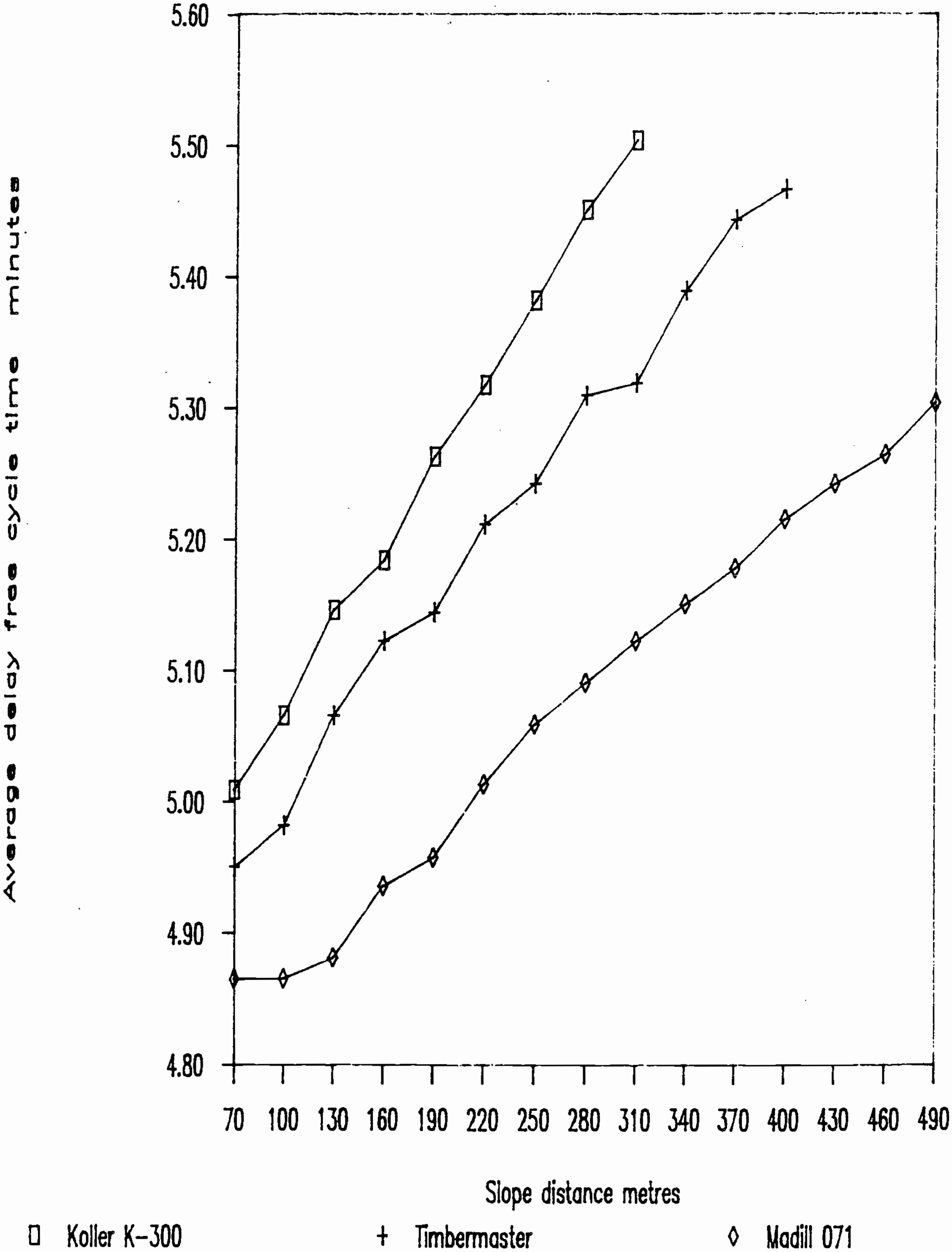

Figure 9. Average Delay Free Cycle Time.

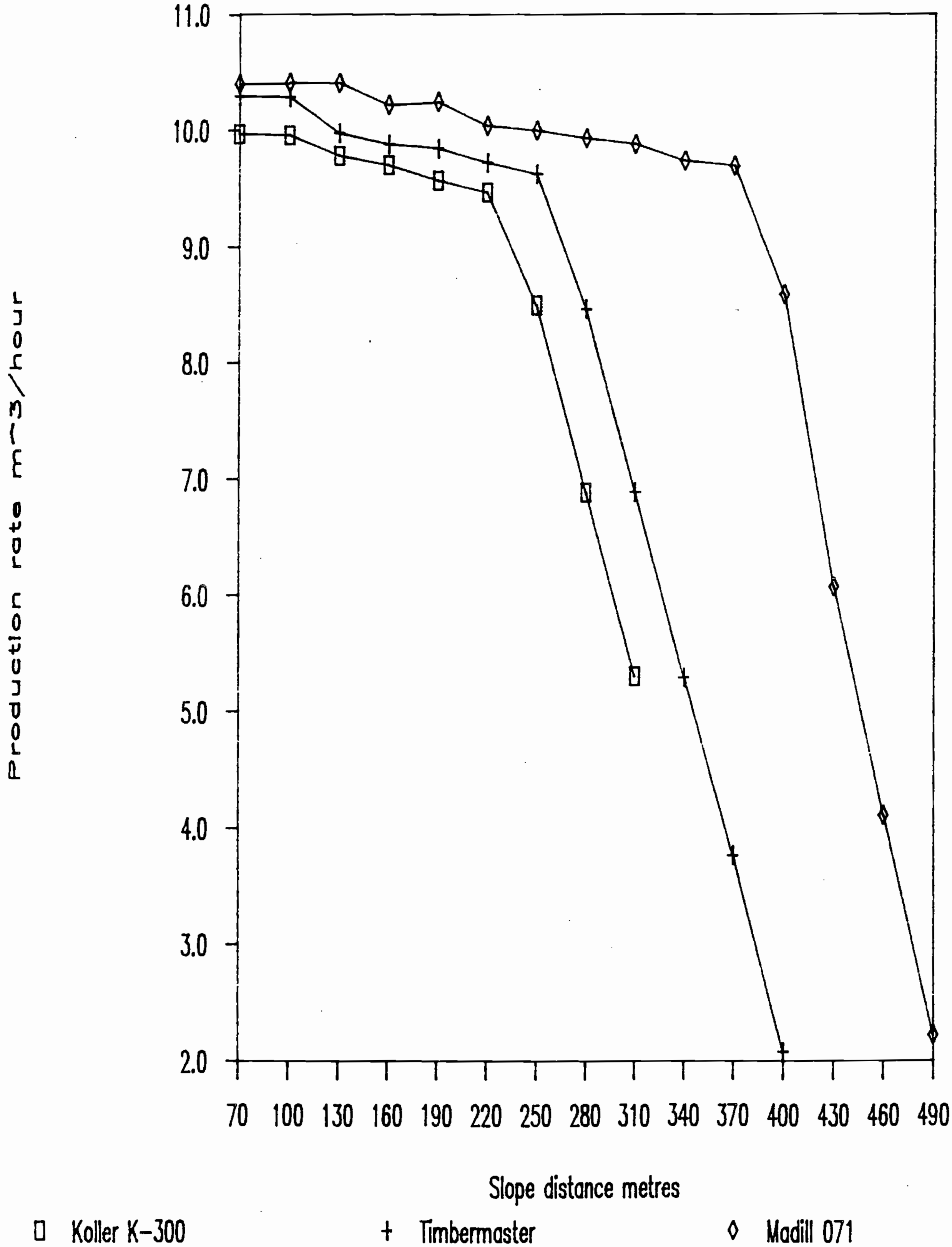

Figure 10. Production Rate, 0.20 cubic metre tree size.

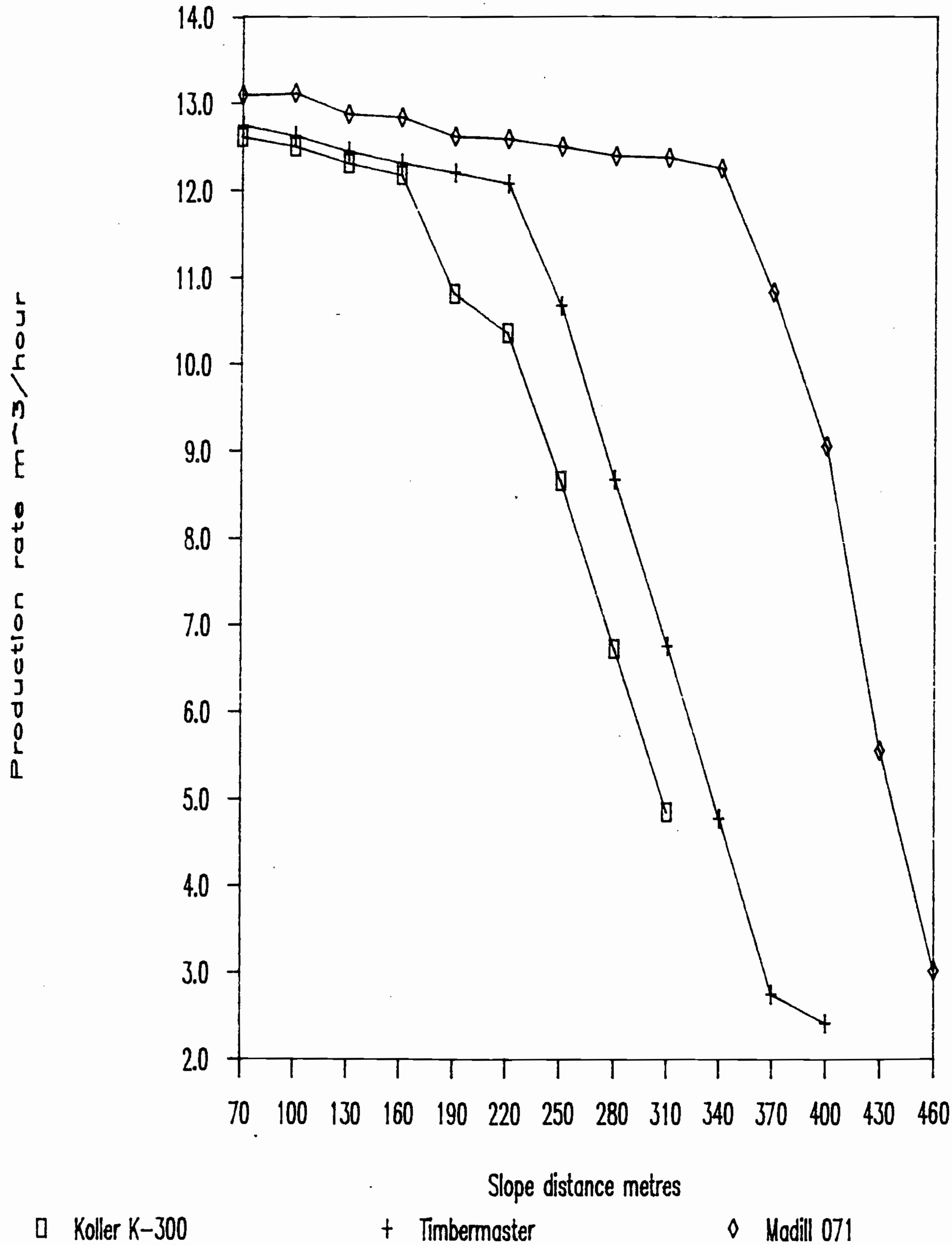

Figure 11. Production Rate, 0.25 cubic metre tree size

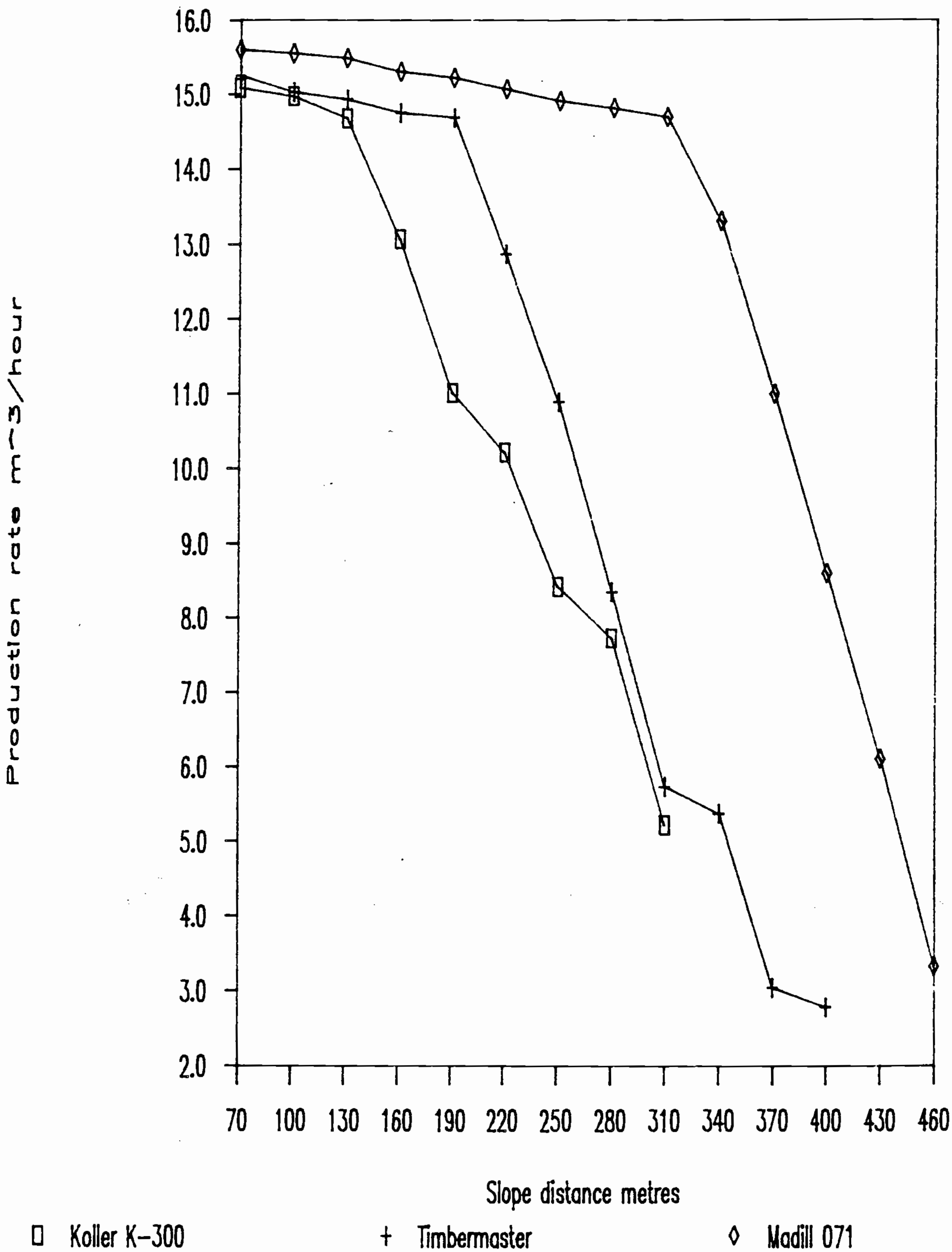

Figure 12. Production Rate, 0.30 cubic metre tree size.

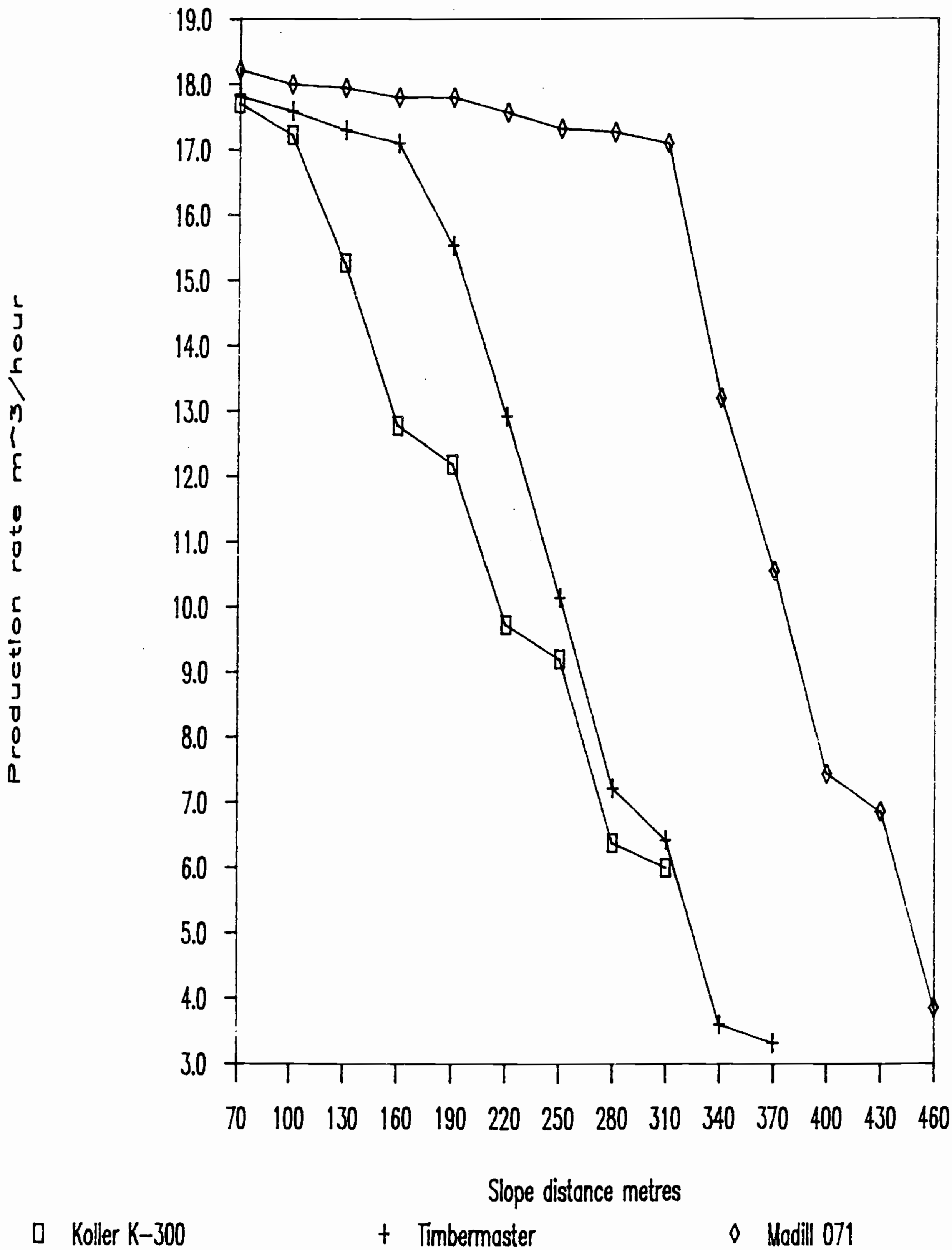

Figure 13. Production Rate, 0.35 cubic metre tree size.

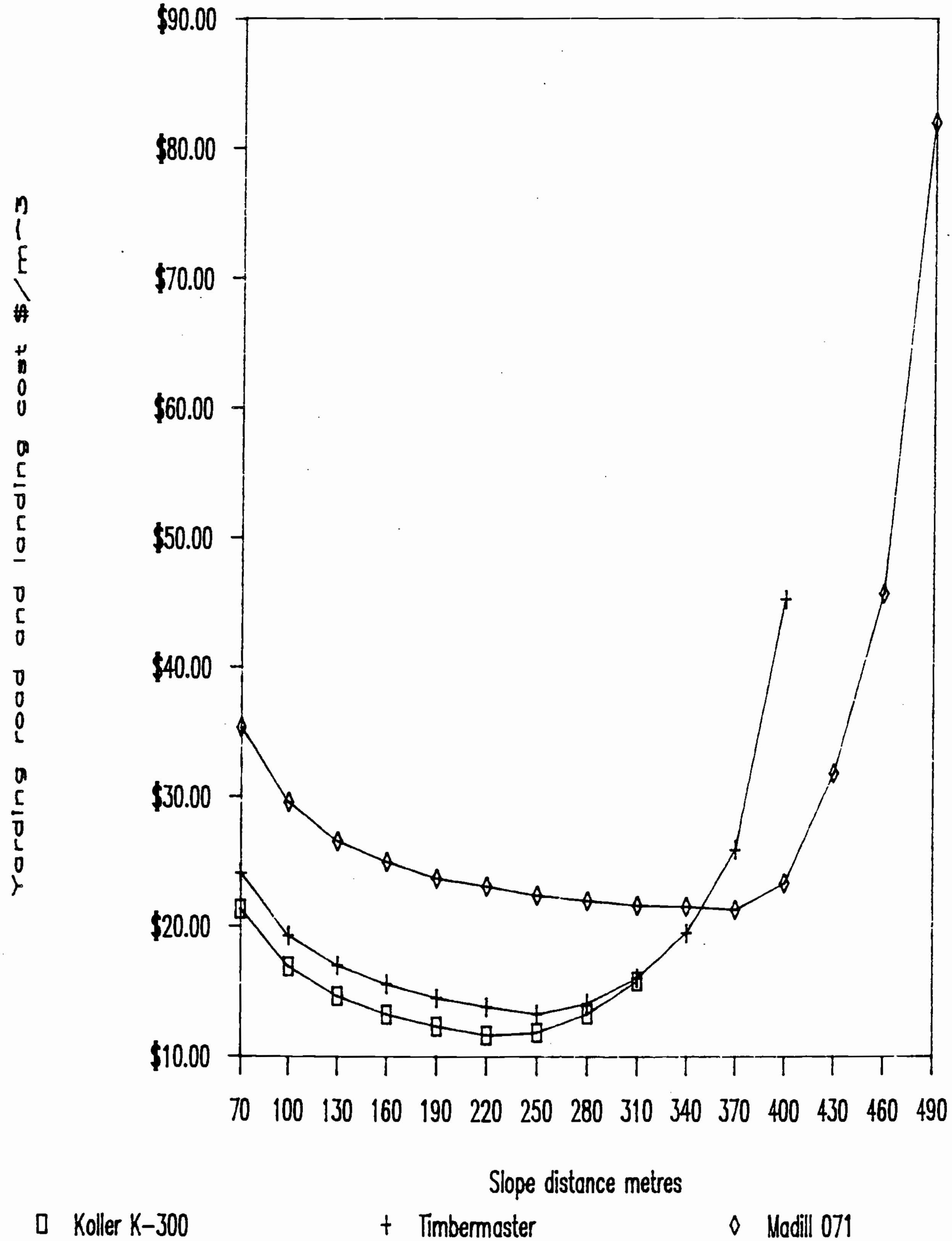

Figure 14. Yarding, Road, and Landing Cost, 0.20 cubic metre tree size.

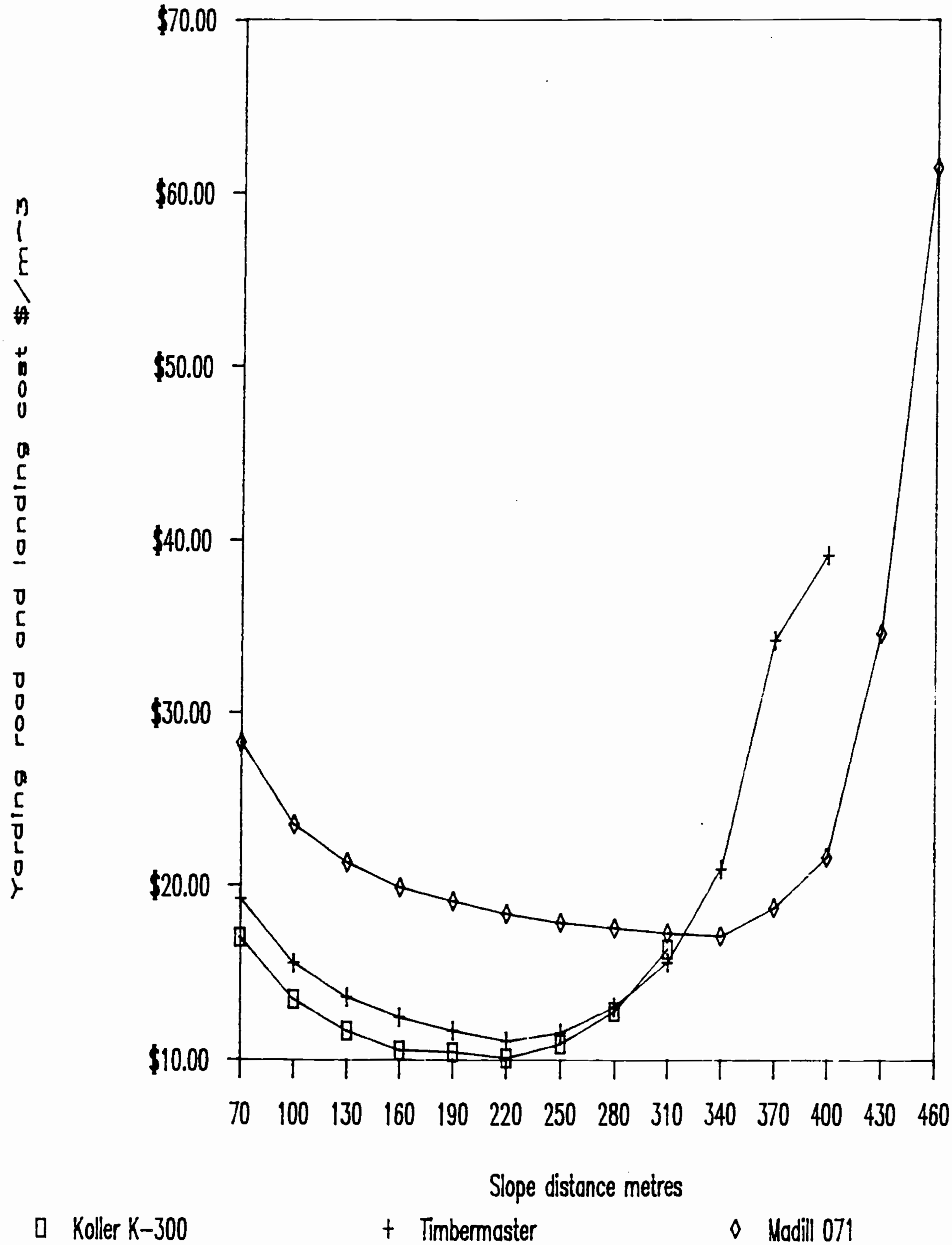

Figure 15. Yarding, Road, and Landing Cost, 0.25 cubic metre tree size.

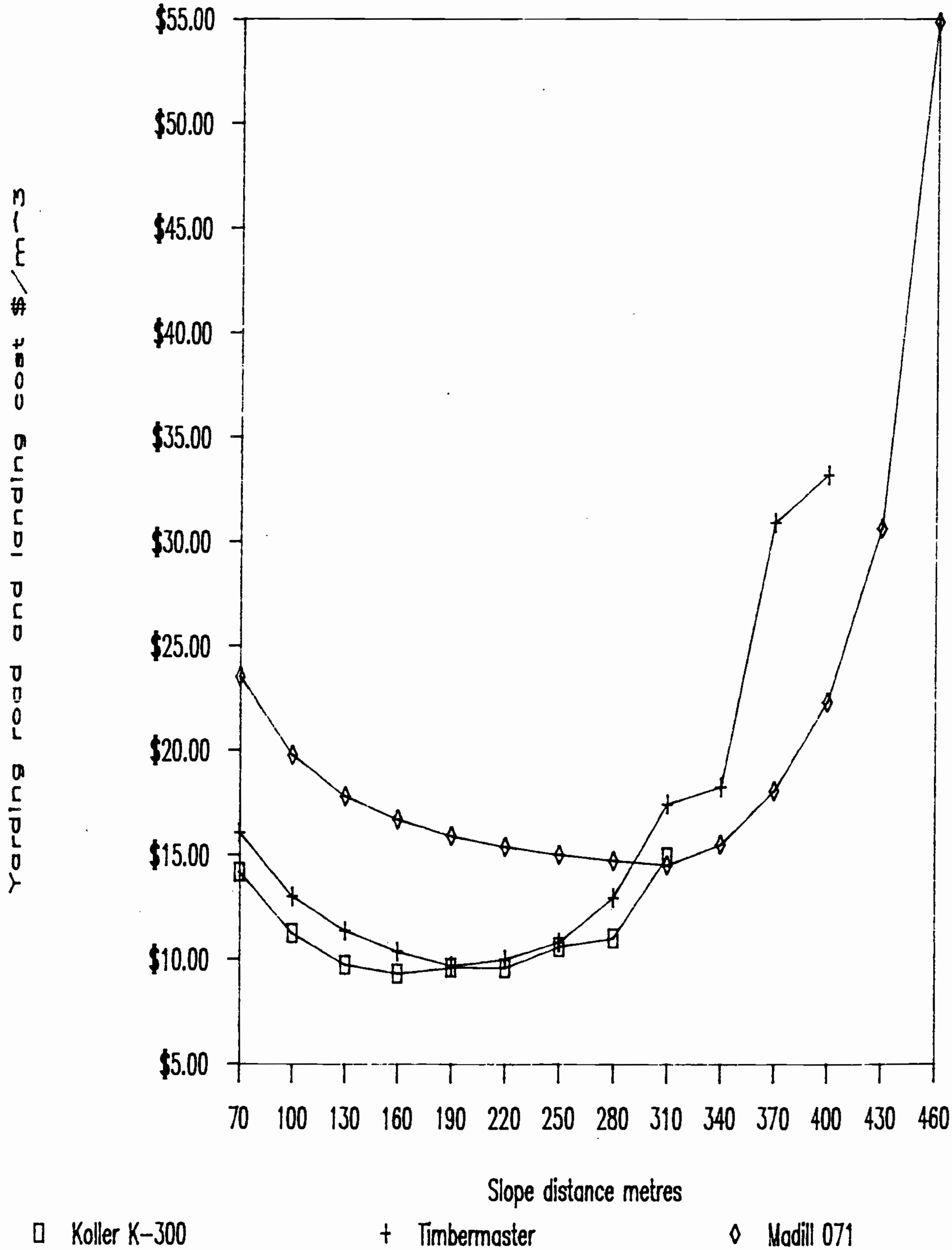

Figure 16. Yarding, Road, and Landing Cost, 0.30 cubic metre tree size.

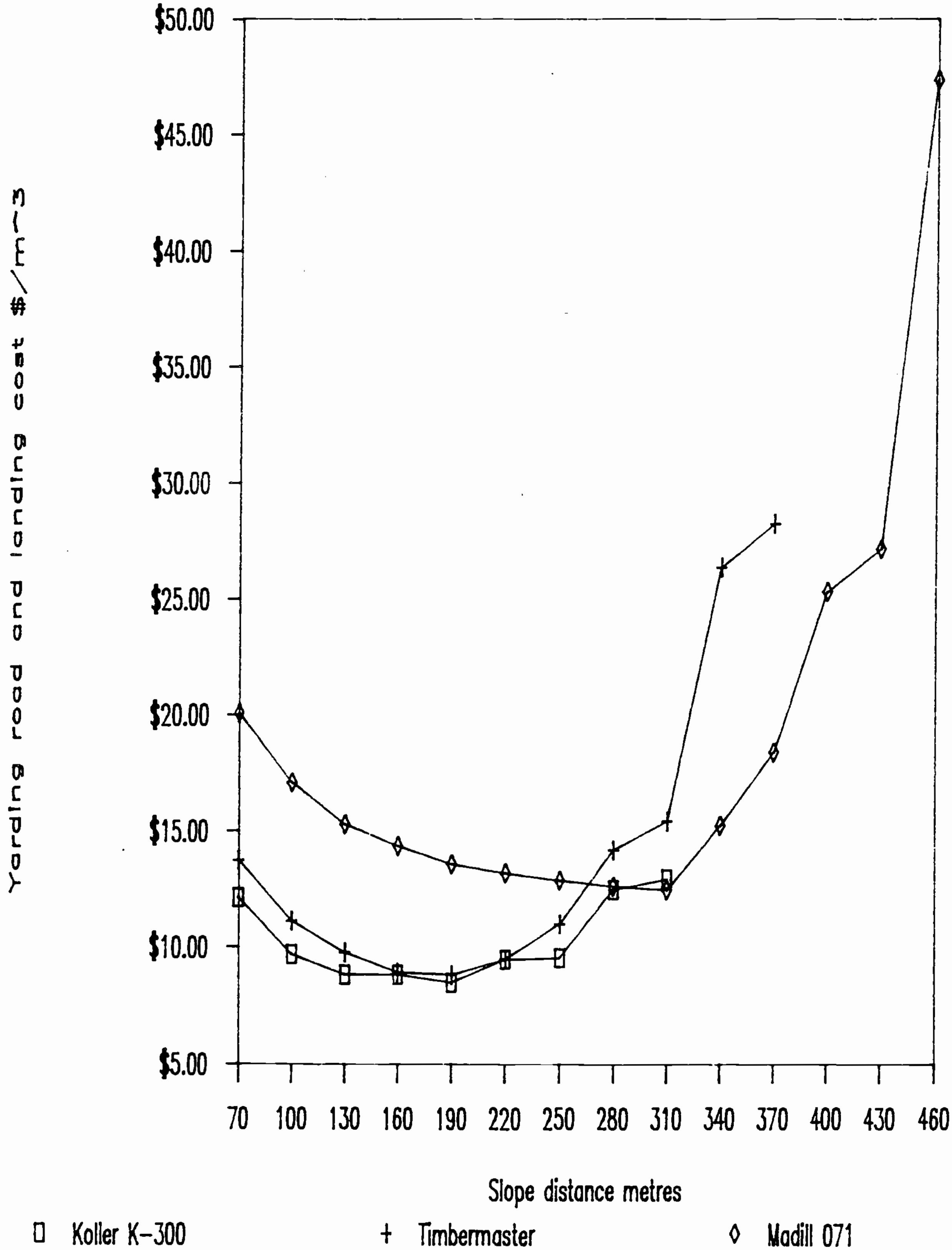

Figure 17. Yarding, Road, and Landing Cost, 0.35 cubic metre tree size.

4. DISCUSSION

The results of this study demonstrate the sensitivity of cable yarding costs and production rates to changes in slope distance, average piece size and lateral yarding distances. This sensitivity can be taken advantage of by adequate pre-harvest planning to ensure the slope distance, outrow spacing, landing width and piece size all contribute to a satisfactory job.

For each machine operating in a forest of given piece size an optimal slope distance and lateral yarding distance could be identified. For the Koller K-300 the optimal slope distance ranged from 190 to 220 metres, depending on the average size of the material yarded. For the Timbermaster the optimal yarding distance ranged between 190 and 220 metres. For the Madill 071 the optimal slope distance ranged betweem 310 and 370 metres.

In all cases, operations in forests with the smallest average piece size coincided with the longest optimal slope distance. This effect of the larger piece material is analogous to the effect of operating in a forest of greater yield. That is, more volume is yarded in almost the same time which dilutes the influence of fixed costs. The shape of the curve showing total average yarding cost versus slope distance was generally flat for slope distances approaching the optimal but increased rapidly for distances beyond the optimal.

Optimal outrow spacing for a setting at the optimal slope distance was always 17 outrows, or a maximum lateral outhaul distance of 24 metres. This result would indicate that a landing spacing greater than 17 rows would be more economical. Lateral outhaul distance was set at a maximum of 24 metres for this model as it was felt that manual outhauling of the line would be strenuous beyond this distance. This problem may be overcome with the mechanical slackpulling carriage however other considerations need to be made. These include the possibility of increased damage and greater risk of snagging the load at greater outhaul distances. The increase in delay free cycle time for increased lateral outhaul distances was assumed to be linear on the basis of several previous studies. It is suspected however that the function may not be linear, increasing by some unknown power either from zero or from some threshold distance. With these factors in mind the actual optimal lateral distance may vary from that indicated by this model.

The relatively low cost of production for the Koller K-300 and the Timbermaster yarders at certain slope distances is a direct result of the available payload capacity being fully utilized and small capital and labour costs. During the simulation the maximum number of logs that could be yarded without exceeding the safe working limit of the lines was always yarded onto a turn. This may not always be the case in reality for any number of reasons. One reason may be that the operator will deliberately not load a turn to capacity to avoid an expected log jam. Other reasons the operator may not load a full turn include concern over residual stand damage, choker setter safety or the probability of mainline failure. These factors were not considered in this simulation model. It is important however that they be recognized when interpreting the results from the simulation. These results would indicate that consistently not loading the rigging to its full capacity will cause a rapid increase in total yarding cost.

As mentioned previously, 6 trees was the maximum load considered by this model for practical reasons. The simulation runs indicated however that more than 6 trees per turn can easily be supported by all machines for shorter spans. If practical experience shows that more than 6 trees can be yarded in one turn the resultant higher payload would alter the total costs and production rate values obtained. The larger payload capacity of these machines on shorter spans could be utilized by prebunching the thinned material under the skyline prior to yarding. The higher tower, greater power and heavier skyline of the Madill 071 would be particularly suited to a prebunching operation, provided the additional payload could provide a sufficient reduction in total yarding cost to pay for the prebunching operation.

The importance of an intermediate support to increase the payload is also demonstrated by these results. Without an intermediate support, payloads adequate to maintain production rates close to that achieved at the optimal slope distance would only be possible at short spans. This would rapidly increase the total yarding cost as payload decreased beyond slope distances less than or equal to the optimal slope distances found using intermediate supports. This would affect the shorter Koller K-300 tower to the greatest extent. The use of a multispan also tends to equalize the productivity of machines with similar skyline diameters, assuming equal yarder power, since the "tower height" for the downhill span is constant at the intermediate support block height, regardless of the yarder tower height. The height of the yarder towers and their location relative to the road edge affects the location of the intermediate support. For intermediate supports of given height, higher towers enable intermediate supports to be located further down the hill, which in turn increases the payload capacity.

Intermediate supports also allow the position of the yarder well back from the road edge without sacrificing deflection. This allows adequate landing space on level ground in front of the yarder.

The increase in cost per cubic metre for yarding with the Timbermaster over the Koller K-300 is due almost entirely to the higher hourly cost of this machine. This higher hourly cost results from an additional crew member and higher capital costs. The additional crew member for the Timbermaster is required to act as a chaser, since the engineer is seated at the controls and can not easily perform both jobs. Caution should be used when interpreting these results since the capital cost and salvage value of both the Koller K-300 and the Timbermaster were estimated. The Timbermaster is a local product and therefore its price is not subject to fluctuating exchange rates and variable shipping costs which affect the imported yarder. These two factors coupled with a high interest rate may bring the relative ownership costs of the Koller K-300 and the Timbermaster closer together.

The average piece size of the forest also influenced the total yarding cost. For operations in forests of smaller piece size, more stems had to be yarded per hour to obtain the same production rates as operations in larger sized material. This resulted in the total average yarding cost being more sensitive to slope distance for small piece size operations. An increase in piece size also resulted in a reduction in total yarding costs for all systems.

Although this study is focused primarily on the cost per cubic metre and rate of production for yarding thinning material these results must be viewed in the light of a total harvest system. The whole tree yarding system outlined here assumes the economic operation of a tree processor and a forwarder at the landing. The low production rate of these yarders may increase the idle time of these machines to a point where operation is uneconomical. One improvement may be to yard corridors sufficiently small such that the entire production from the setting can be accommodated in front of the yarder. Material from several days yarding then being processed and forwarded in one operation, at a rate more applicable to the ground based machines. Another improvement may consider the use of one processor with two yarders.

Manual falling of the thinnings is assumed throughout this model. An alternate harvest sequence may involve the processing of trees manually in the forest, eliminating the need for a processor at the landing. The effect of yarder production on such an alternative is unknown. An important consideration of such a suggestion however is faller safety, which may be unsatisfactory on steeper slopes.

Fire hazards in the exotic softwood plantations of South Eastern Australia are a great concern. Any logging system must be evaluated in terms of its potential fire risk. The increased fire risk brought about by running a haulback line through the forest is therefore another consideration when analysing cost and production rates of various systems.

5. CONCLUSIONS

Results of this study show that the cost of yarding thinning material from steep areas of radiata pine plantations is within the range of $9 to $12 per cubic metre for certain conditions. These conditions include yarder selection, optimal slope distance and lateral yarding distance. The payload capacity of the rigging must also be fully utilized.

The use of intermediate supports is an important factor. It is shown that the cost of production is sensitive to decreased payload capacity. Payload capacity can be maintained at longer spans with intermediate supports.

Although this paper focused on the hourly production and cost per cubic metre of cable yarding thinnings, these results must be viewed in the light of a total logging operation. This may involve modifications to the assumed logging system including additional supports, prebunching or manual processing.

The higher total hourly cost of the Madill 071 over the Koller K-300 or Timbermaster yarders resulted in this machine showing a higher total yarding cost, even with road and landing costs included in this cost. With the high interest rates prevalent in the Australian economy, low capital machines are economically attractive. The smaller size yarders are also easier to operate, an important consideration when introducing new machinery to an area.

6. SUGGESTIONS FOR FURTHER STUDY

Further investigation into the accuracy and implementation of the assumptions used in this model is desireable. Such assumptions include the lateral outhaul function, the hook time function and the unhooking time function. The maximum number of chokers that can be effectively managed in this forest and the distance that lateral mainline can be pulled also requires further investigation. The assumed production rate compatibility of a mechanical processor and a cable yarder also warrants investigation.

Other investigation is required into the level of stand damage which would result from the operation of a cable yarder in these forests and the influence certain operating conditions may have on this damage. Operating conditions which may influence stand damage include lateral yarding distance, logs per turn and thinning intensity.

The suitability of plantation grown radiata pine for use as support trees and anchor stumps also requires further investigation.

The possible cost advantage of a prebunching operation within these forest types could also be investigated as a suggestion to improving productivity and reducing cost.

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APPENDIX A.

Landing Design.

Landing Construction Cost.

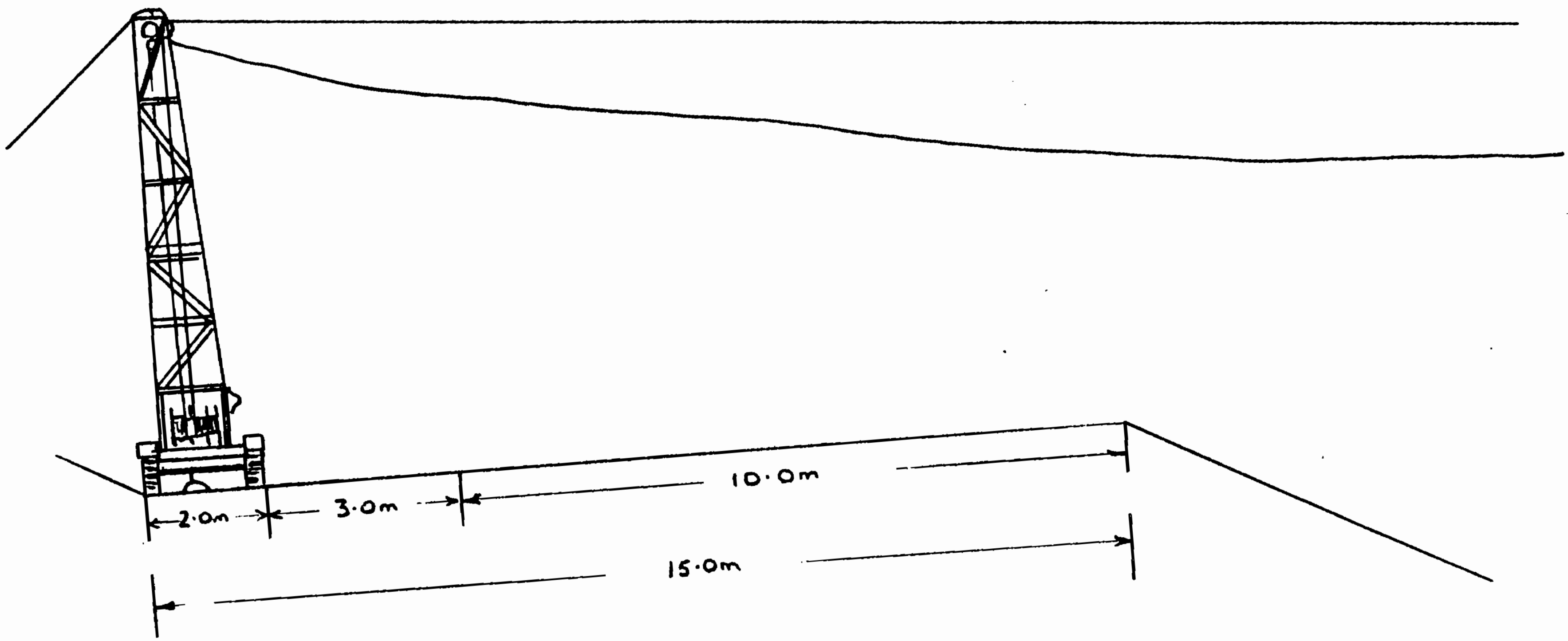

Figure 18. Landing Width Dimension, Koller K-300

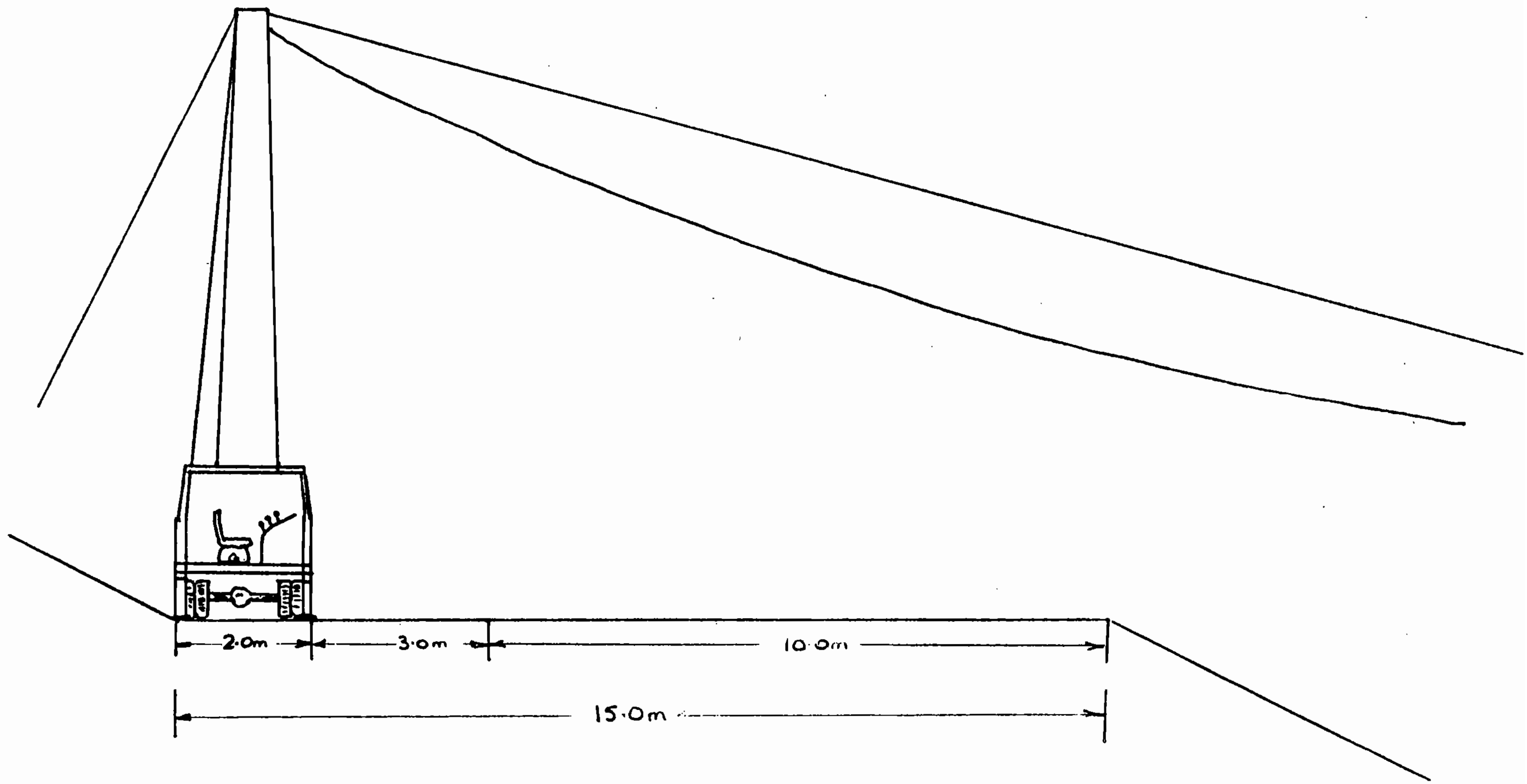

Figure 19. Landing Width Dimension, Timbermaster

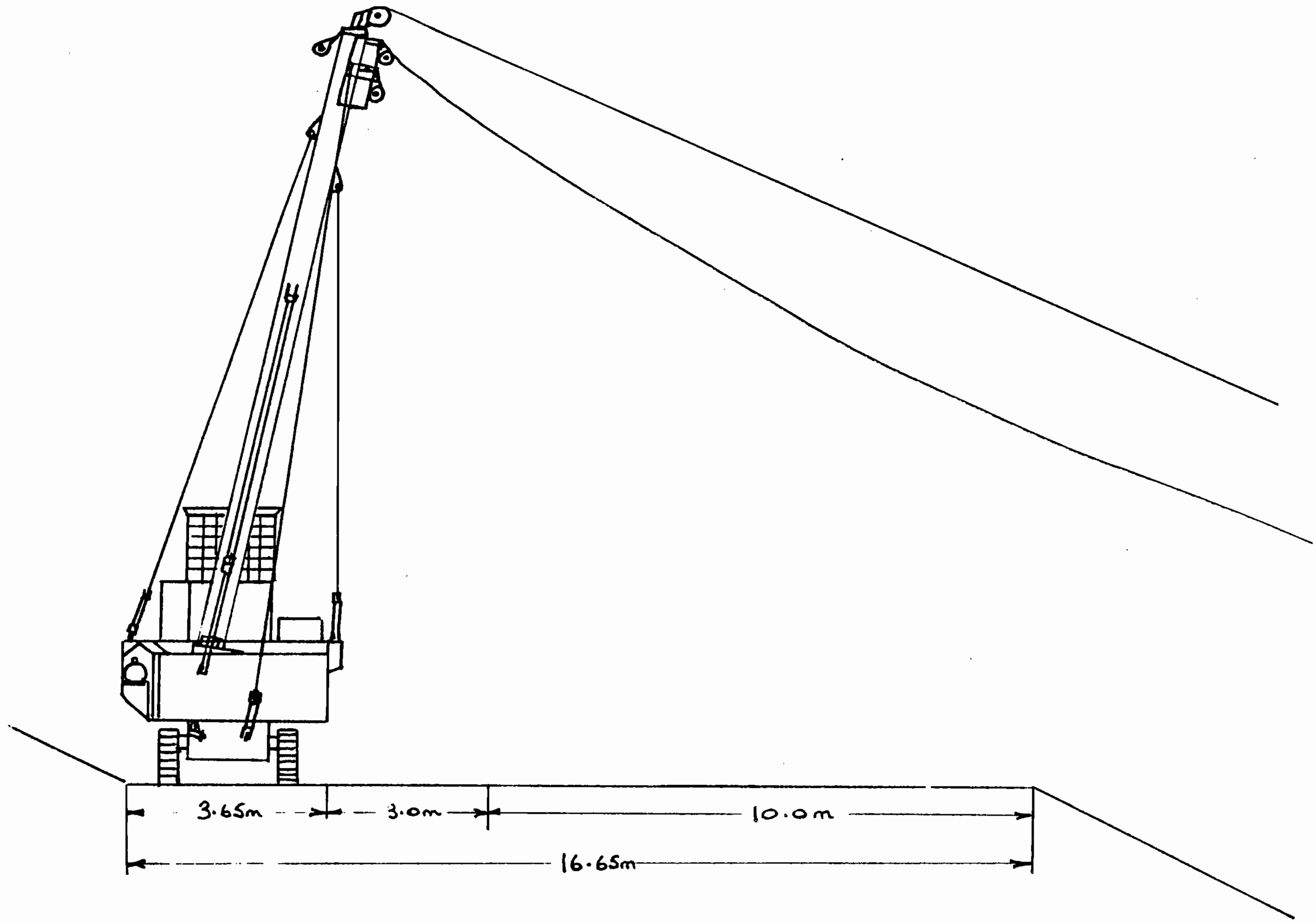

Figure 20. Landing Width Dimension, Madill 071

Calculation of Landing Construction Costs.

Daily Cost of Tractor	
8 hours @ $71.00 per hour	$568
Daily Cost of Grader	
8 hours @ $42.00 per hour	$336
Daily Cost of Labour	
2 Group 1 Labourers	$160
2 Machine Operators	$216
TOTAL	$1280
Landings constructed per day	4
COST PER LANDING	$340

APPENDIX B.

Machine Description and Specification.

Koller K-300, Timbermaster, Madill 071.

MACHINE DESCRIPTION KOLLER K-300

The Koller K-300 mobile yarder consists of a collapsible tower mounted on a trailer for towing by a vehicle or attached to a farm tractor by a three point linkage. The yarder has two drums, one mainline and one skyline. Four guyline drums are attached to the tower. Power is supplied either via a trailer mounted engine of power take off from a farm tractor. Yarder power is 37 kilowatts.

Tower height	6.85 metres
Skyline drum capacity	350 metres of 16mm diameter wire rope.
Mainline drum capacity	350 metres of 9.5mm diameter wire rope.
Guylines	4 hand wound winch drums each of 30m capacity.

Both drums are mechanically driven. They are fitted with band brakes and clutches which are hydraulically controlled.

MACHINE DESCRIPTION TIMBERMASTER

The Timbermaster is a mobile yarder and tower mounted on a chassis similar in size to a 5-8 tonne truck. The machine has three drums; skyline, mainline and haulback. Power is supplied by a diesel engine mounted adjacent to the tower on the chassis. Yarder power is 52 kilowatts.

Tower height	9.80 metres.
Skyline drum capacity	450 metres of 16mm diameter wire rope.
Mainline drum capacity	400 metres of 9mm diametre wire rope.
Haulback drum capacity	700 metres of 9mm diameter wire rope.

All drums are mechanically driven with band brakes. Clutches are hydraulically controlled.

MACHINE DESCRIPTION MADILL 071

The Madill 071 is a crawler mounted mobile yarder. Five drums are mounted on the yarder frame. A Skyline, mainline, haulback, strawline and tagline. The yarder is powered by a frame mounted diesel engine. Maximum power 213 kilowatts.

Tower height	14.32 metres.
Skyline drum capacity	590 metres of 25mm diameter wire rope.
Mainline drum capacity	960 metres of 16mm diametre wire rope.
Haulback drum capacity	1340 metres of 16mm diameter wire rope.
Straw and Tagline drum capacity ...	1460 metres 8mm diameter wire rope.

Three hydraulic winch, power in and power out mechanical latched guylines are operated from the cab by low air pressure.

All drums are mechanically driven through air applied multi disk clutches. The mainline and haulback drums have low inertia fluid cooled brakes. The skyline, straw and tag line drums are fitted with bank brakes. All are operated by a low pressure air system.

APPENDIX C.

Hourly Costing Calculation.

Koller K-300, Timbermaster, Madill 071.

Example of Hourly Costing for Koller K-300

EQUIPMENT	PRICE $	SALVAGE $	LIFE YEARS	DEPRECIATION [P-S]/N $	AAI (P-S)(N+1)/(2N) +S
Yarder	70000	14000	8	7000	45500
Radio	9000	1800	8	900	5850
Carriage	13000	2600	8	1300	8450
Rigging	2000	-	8	-	1125
Totals	94000	18400		9200	60925

FIXED COSTS PER HOUR

Opportunity Cost	60925*.185 =	11271
Depreciation		9200
Insurance	60925*.02 =	1218
Total		21689
Total operating hours	220 days* 7.5 hours/day	1650
Hourly Costs, Fixed		13.14
Labour Cost, Fixed	1*18.7 + 2*12.7 =	44.10

Total Fixed Costs Per Hour.......................... 57.24

OPERATING COSTS. PER HOUR

Maintenance	0.5*7000 + 0.2*(900 + 1300)/1650 =	2.39
Fuel	0.256kg/kw-hr*37kw*0.55/0.84kg/l*$0.48/l =	2.98
Lubrication	0.1*2.98	.30
Rigging	1550/1650	.94

Total Operating Costs Per hour...................... 6.61

TOTAL FIXED COSTS PLUS OPERATING COSTS
PER HOUR...$63.85

Example of Hourly Costing for Timbermaster

EQUIPMENT	PRICE $	SALVAGE $	LIFE YEARS	DEPRECIATION [P-S]/N $	AAI (P-S)(N+1)/(2N) +S
Yarder	100000	20000	8	10000	65000
Radio	9000	1800	8	900	5850
Carriage	13000	2600	8	1300	8450
Rigging	2000	-	8	-	1125
Totals	124000	24400		12200	80425

FIXED COSTS PER HOUR

Opportunity Cost	80425*.185 =	14879
Depreciation		12200
Insurance	80425*.02 =	1609
Total		28688
Total operating hours	220 days* 7.5 hours/day	1650
Hourly Costs, Fixed		17.39
Labour Cost, Fixed	1*18.7 + 3*12.7 =	56.80

Total Fixed Costs Per Hour.......................... 74.19

OPERATING COSTS. PER HOUR

Maintenance	0.5*10000 + 0.2*(900 + 1300)/1650 =	2.39
Fuel	0.256kg/kw-hr*52kw*0.55/0.84kg/l*$0.48/l =	4.18
Lubrication	0.1*4.18	.42
Rigging	1900/1650	1.15

Total Operating Costs Per hour...................... 8.14

TOTAL FIXED COSTS PLUS OPERATING COSTS PER HOUR..$82.33

Example of Hourly Costing for Madill 071

EQUIPMENT	PRICE $	SALVAGE $	LIFE YEARS	DEPRECIATION [P-S]/N $	AAI (P-S)(N+1)/(2N) +S
Yarder	500000	100000	8	50000	325000
Radio	9000	1800	8	900	5850
Carriage	9000	1800	8	900	5850
Rigging	2000	-	8	-	1125
Totals	520000	103600		51800	337825

FIXED COSTS PER HOUR

Opportunity Cost	337825*.185 =	62498
Depreciation		51800
Insurance	337825*.02 =	6757
Total		121055
Total operating hours	220 days* 7.5 hours/day	1650
Hourly Costs, Fixed		73.37
Labour Cost, Fixed	1*18.7 + 3*12.7 =	56.80

Total Fixed Costs Per Hour..........................130.17

OPERATING COSTS. PER HOUR

Maintenance	0.5*50000 + 0.2*(900 + 900)/1650 =	17.33
Fuel	0.256kg/kw-hr*213kw*0.55/0.84kg/l*$0.48/l =	17.13
Lubrication	0.1*17.13	1.71
Rigging	12000/1650	7.27

Total Operating Costs Per hour.........................43.44

TOTAL FIXED COSTS PLUS OPERATING COSTS PER HOUR...$173.61

APPENDIX D.

Description of Payload Calculation.

Example of payload calculation for a multi span standing skyline.

Given conditions;

Ground slope, θ

Tower height, TH

Intermediate support block height, ISH

Tail block height, TBH

Slope distance, SD

Landing width, RL

Carriage width, CD

Carriage weight CW

Choker length ι

Log length, ll

Ratio of log centre of gravity to log length, CoG

Coefficient of log to ground friction μ

Log to ground clearance H

Step #1. Calculate the segment geometry for uphill and downhill spans. Refer to Figure 21. The slope distance from the road edge to the intermediate support block, ISD is calculated for a given skyline clearance at the road edge, δ.

$$ISD = \frac{(y + ISH)}{\sin\theta} \tag{1}$$

$$y = x \cdot \tan\gamma \tag{2}$$

$$\gamma = \tan^{-1} \cdot \frac{(TH - \delta)}{RL} \tag{3}$$

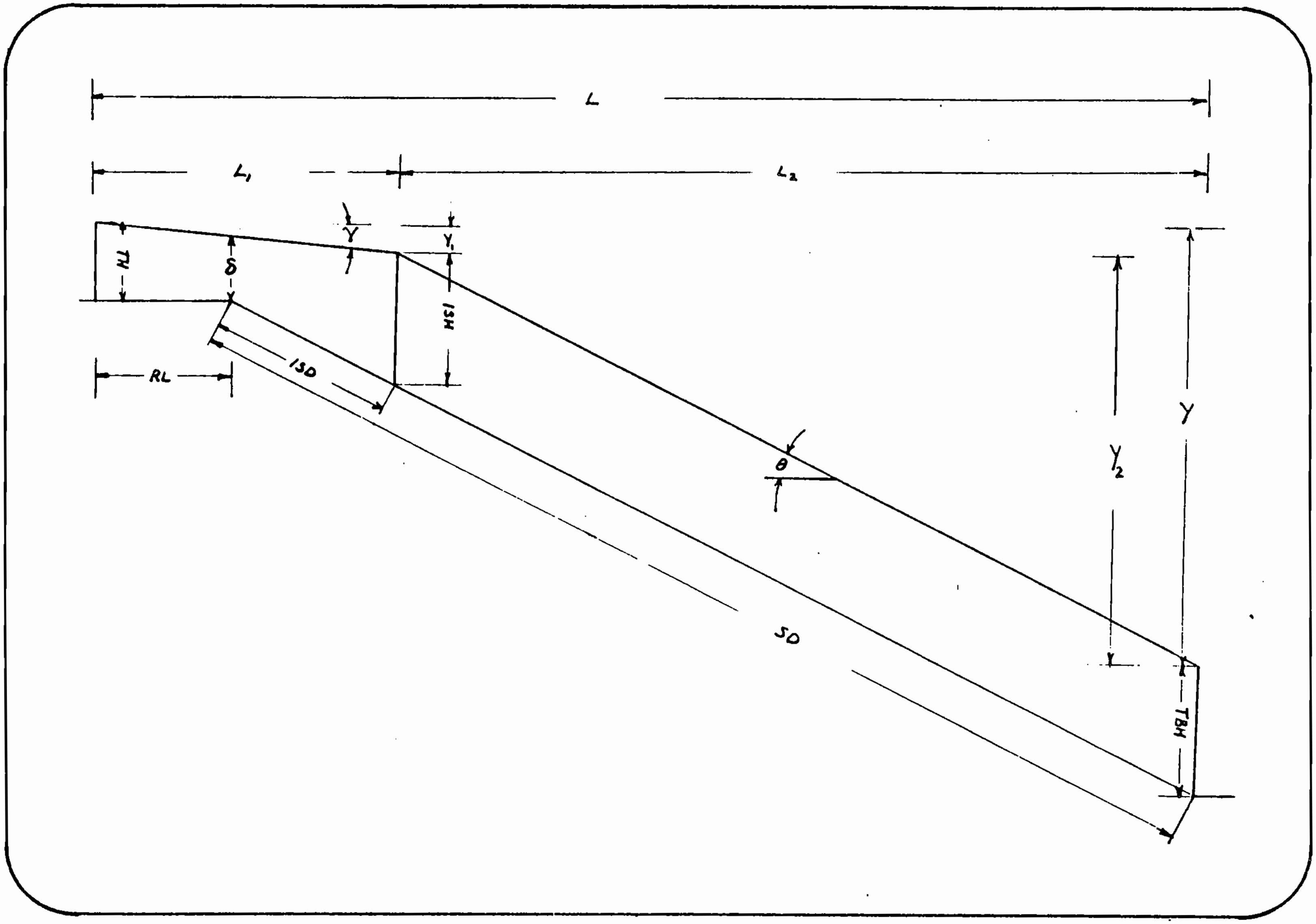

Figure 21. Skyline Clearance at Road Edge

$$x = ISD \cdot \cos\theta - \left(\frac{\delta}{\tan\gamma}\right) \tag{4}$$

Combining equations (1), (2), (3) and (4) and simplifying;

$$ISD = \frac{(ISH - \delta)}{\sin\theta - \cos\theta \cdot \tan\gamma} \tag{5}$$

The toatal span of the system, L is calculated as;

$$L = SD \cdot \cos\theta + RL \tag{6}$$

The uphill span, L_1 is calculated as;

$$L_1 = RL + ISD \cdot \cos\theta \tag{7}$$

The downhill span, L_2 is calculated as;

$$L_2 = L - L_1 \tag{8}$$

The total vertical displacement, Y is calculated as ;

$$Y = TH + SD \cdot \sin\theta - TBH \tag{9}$$

The vertical displacement of the uphill span Y_1 is calculated as;

$$Y_1 = TH + ISD \cdot \sin\theta - ISH \tag{10}$$

The vertical displacement of the downhill span, Y_2 is calculated as;

$$Y_2 = Y - Y_1 \tag{11}$$

Step #2. Calculate the minimum line length, s, required to maintain a minimum clearance, H at the front of the choked log. Trial points on the ground are selected at the midpoint of the uphill span and by dividing the downhill span into ten equal sections. The skyline clearance at each of these points, k is calculated as;

$$k = \iota \cdot \sin\theta + H - \iota . \cos\theta \cdot \tan\alpha \tag{12}$$

where α is the choker angle with respect to the horizon required to maintain the clearance, h. Refer to Figure 22. Sessions (1986) gives an expression for α as;

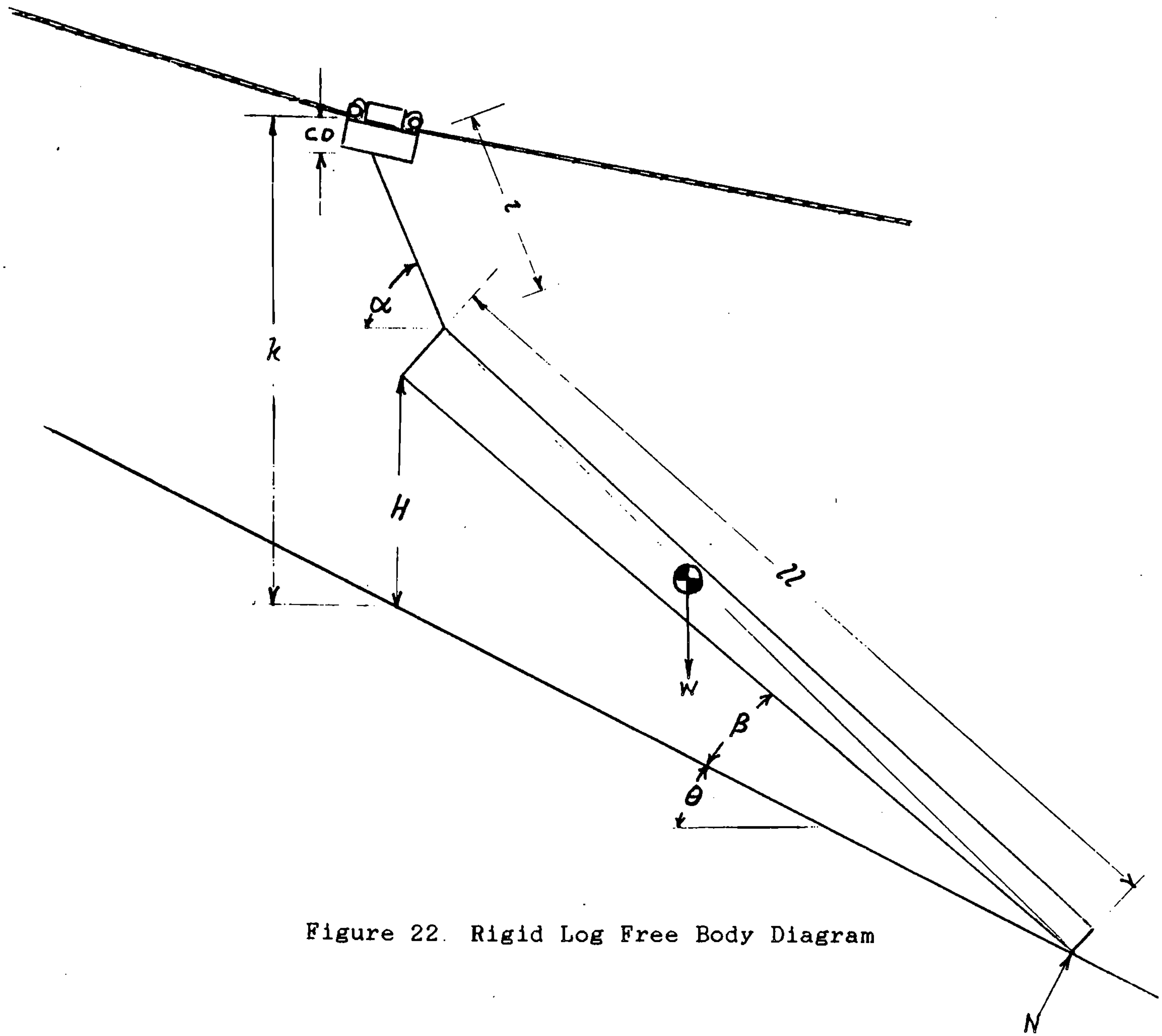

Figure 22. Rigid Log Free Body Diagram

$$\alpha = \tan^{-1} \cdot \left(2 \cdot \tan(\alpha + \beta) + \frac{\cos\theta - \mu \cdot \sin\theta}{\sin\theta + \mu \cdot \cos\theta} \right) \tag{13}$$

assuming the log is a homogenous, cylindrical column of negligible diameter to length ratio.

The log to ground angle, β, refer to Figure 22 is calculated as;

By rule of Sine;

$$\frac{H}{\sin\beta} = \frac{ll}{\sin 90 + \theta} \tag{14}$$

simplifying,

$$\beta = \sin^{-1}\left(\frac{\cos\theta \cdot H}{ll} \right) \tag{15}$$

The line length, s required at each point is calculated as;

$$s = s_1 + s_2 \tag{16}$$

where s_1 is the uphill span line length and s_2 is the downhill span line length.

The line length is calculated for each trial point as;

$$\sqrt{L_1^2 + Y_1^2} + \sqrt{d_{1l}^2 + h_{1l}^2} + \sqrt{d_{2l}^2 + h_{2l}^2} \tag{17}$$

where d_{1l} is given and $d_{2l} = L_2 - d_{1l}$

$$h_{1l} = ISH + d_1 \cdot \tan\theta - k - CD \tag{18}$$

$$h_{2l} = Y_2 - h_{1l} \tag{19}$$

The above procedure is repeated for each trial point and the minimum line length is saved. The above example is a line length calculation for a point contained in the downhill span. For the trail point in the uphill span the first term in equation (17) is written as;

$$\sqrt{L_2^2 + Y_2^2} \tag{17a}$$

and the respective d_i and h_i values are for the uphill span.

Step #3. Calculate the required tension for a given log load. Using the same points and the minimum line length calculated above the segment geometry is calculated assuming an elliptical load path. From Sessions (1986);

$$h_1 = a + b \tag{20}$$

where

$$a = \frac{Y_1 \cdot c}{2 \cdot (s_i^2 - Y_i^2)} \tag{21}$$

$$b = \frac{\sqrt{4 \cdot d_1^2 \cdot s_i^2 \cdot (Y_i^2 - s_i^2) + s_i^2 \cdot c^2}}{2 \cdot (s_i^2 - Y_i^2)} \tag{22}$$

$$c = s_i^2 + d_i^2 - d_2^2 - Y_i^2 \tag{23}$$

d_1 and d_2 are given and h_2 is calculated as in equation (19).

For a given tension at the tower, T_{1u} the payload of the system, the geometry of which is calculated above, is calculated using rigid link assumptions. From Sessions (1986);

$$HC_1 = \frac{T_{1u} \cdot d_1}{l_1} \cdot \sqrt{1 - \left(\frac{\omega \cdot d_1}{2 \cdot T_{1u}}\right)^2} - \frac{\omega \cdot d_1 \cdot h_1}{2 \cdot l_1} \tag{24}$$

where

HC_1 is the horizontal component of segment 1, ω is the skyline weight in kilograms per metre of length and l_1 is the line length of the segment, calculated as;

$$l_1 = \sqrt{d_1^2 + h_1^2}$$

The vertical component at the lower end of the span is calculated as;

$$V_{1l} = \frac{HC_1 \cdot h_1}{d_1} - \frac{\omega \cdot l}{2} \tag{25}$$

For an unclamped carriage the tension in the skyline is equal at the carriage, therefore $T_{1l} = T_2$ where;

$$T_{1l} = \sqrt{HC_1^2 + V_{1l}^2} \tag{26}$$

and T_2 represents the tension in the lower segment of the skyline at the carriage.

If the carriage is below the tailspar the horizontal component of the downhill segment is calculated as;

$$HC_2 = \frac{T_2 \cdot d_2}{l_2} \cdot \sqrt{1 - \left(\frac{\omega \cdot d_2}{2 \cdot T_2}\right)^2} + \frac{\omega \cdot d_2 \cdot h_2}{2 \cdot l_2} \tag{27}$$

and the vertical component at the carriage is;

$$V_2 = \sqrt{T_2^2 - HC_2^2} \tag{28}$$

If the carriage is above the tailspar the horizontal component is calculated as in equation (24) and the vertical component of the downhill segment at the carriage is calculated as in equation (28), except that the sign of the force is reversed since the vertical component is acting down on the carraige.

Since the skyline is set at a minimum length, the clearance of the skyline, k is calculated as;

$$k = (Y + TBH) - (d_2 \cdot \tan\theta + h_1 + CD) \tag{29}$$

The choker angle, α with respect to the horizon and the log to ground angle, β are solved for simultaneously using equation (13) and the equation for β from Sessions (1986);

$$\beta = \sin^{-1} \cdot \left(\frac{k \cdot \cos\theta - \iota \cdot \sin\alpha - \theta}{ll}\right) \tag{30}$$

From Sessions (1986) the horizontal component of the mainline can be expressed as;

$$HC_3 = \frac{\tan\alpha \cdot (HC_1 - HC_2) - (V_{1l} + V_{2uorl} - CW) + \frac{\omega \cdot l_1}{2}}{\frac{h_1}{d_1} - \tan\alpha} \tag{31}$$

and the vertical component of the mainline;

$$V_{3l} = \tan\alpha \cdot (HC_1 - HC_2 + HC_3) - (V_{1l} + V_{2uorl} - CW) \tag{32}$$

The payload capacity of the system is therefore;

$$V_{1l} + V_2 + V_{3l} - CW \tag{33}$$

For a log load partially supported by the ground this payload is the vertical component of the choker cable tension. For a given log load, W at a log to ground angle, β calculated in equation (30) and a choker cable angle, α calculated as in equation (13), the vertical component of the choker cable tension, W_v is calculated as;

$$W_v = W \cdot \left(1 - \frac{\cos\theta - \sin\theta \cdot \tan\beta}{\frac{1}{CoG} \cdot (1 + \mu \cdot \tan\beta)} \cdot (\cos\theta - \mu \cdot \sin\beta)\right) \tag{34}$$

The vertical component of the choker cable tension that results from a given tension in the skyline at the tower is matched to that required for a given log load as calculated in equation (34). Using the secant search technique the tension required for a given log load is calculated by the following procedure;

Step (i) Set the tension of the sykline at the tower to the maximum safe working tension and calculate the corresponding payload capacity for a log partially supported by the ground. Store this Tension as T_a and the difference Z_a where;

$$Z_a = Payload for T_a - W_v for \log load \tag{35}$$

Step (ii) Calculate the payload capacity for a new skyline tension at the tower, T_b about 2 percent more than the first tension and the difference Z_b.

Step (iii) For all following iterations adjust the previous tension by the factor;

$$-\left(\frac{Z_b}{\left(\frac{Z_b - Z_a}{T_b - T_a}\right)}\right) \tag{36}$$

Using this variable step size the tension is matched to the load in four to eight iterations. The tension required for such a load is then matched to the maximum safe working tension. If the safe working tension is exceeded then the load is reduced and the calculation repeated.

The above procedure is repeated for all trial points defined in Step #2. From these calculations the maximum log load that can be yarded from each point on the total skyline span is determined.

APPENDIX E.

Program Listing and Sample Output.

```
10 '
20 '
30 '
40 'Program for the simulation of cable yarding first thinnings from P.radiata
50 'plantations in South Eastern Australia.
60 '
70 'Master of Forestry Paper, Phil Deamer  July 1987.
80 '
90 '*****************  Define Functions   Dimension Arrays  ****************
100 '
110 '
120 '
130 RANDOMIZE TIMER
140 DEF FNASIN(X) = ATN(X/SQR(1-X*X))
150 DIM T3(100),TIME(100),VY(100),V(100),TME(100),TB(100),N(100)
160 '
170 '******************  Sequence to input variables  ************************
180 '
190 '
200 '
210 OPEN "RADM20.DTA" FOR OUTPUT AS #1
220 '
230 '
240 TBH = 12                    :'Height of tail block, m.
250 SLP = 50                    :'Slope of corridor, percent
260 AVGT = .2                  :'Average tree volume cubic metres
270 LL = 20                     :'Average log length, metres
280 '
290 CLS
300 FOR I = 1 TO 6
310 PRINT
320 NEXT I
330 '
340 '
350 '
360 PRINT
370 PRINT
380 '
390 '
400 '
410 '
420 '
430 '
440 '
450 '
```

```
460 PRINT"1. Koller K-300 Tower and Yarder rigged as a standing skyline,
             3 man crew, SKA-1 Carriage":PRINT
470 '
480 PRINT"2. Timbermaster Tower and Yarder rigged as a standing skyline,
             4 man crew, SKA-1 Carriage":PRINT
490 '
500 PRINT"3. Madill 071 Tower and Yarder rigged as a standing skyline,
              4 man crew, Danebo MSP Carriage"
510 '
520 '
530 FOR I = 1 TO 4
540 PRINT
550 NEXT I
560 '
570 INPUT"Input the number corresponding to your selection and hit return";ME
580 '
590 'ME Is the machine indicator variable.
600 '1 is a Koller K-300
610 '2 is a Timbermaster
620 '3 is a Madill 071
630 '
640 IF ME = 1 THEN GOSUB 6100       :'Loads Koller K-300 variables
650 '
660 IF ME = 2 THEN GOSUB 6540       :'Loads Timbermaster variables
670 '
680 IF ME = 3 THEN GOSUB 6980       :'Loads Madill 071 variables
690 '
700 IF ME<=3 OR ME=>1 THEN 830
710 '
720 FOR I = 1 TO 3
730 PRINT
740 NEXT I
750 '
760 '
770 INPUT"Type 1 to reselect or 0 to end";DILL
780 '
790 IF DILL = 1 THEN 290        :'Reloads machine selection routine or quits
800 GOTO 1760
810 '
820 '
830 GOSUB 3810                        :'Costing subroutine
840 '
850 '
860 '
870 '
880 '
```

```
890 '*******     Simulation control sequence for multi span system   *******
900 '
910 '                          Commence yarding corridor
920 '
930 '
940 FOR SD = 70 TO TD STEP 30     :'For slope distances from 70 metres to the
950 '                               limit of the machine
960 '
970 XROW = (SD-3)/3               :'Calculates the number of plantation rows
980 '                             : within the given slope distance
990 '
1000 '
1010 GOSUB 1770                   :'Multispan payload calculation. Loads the
1020 '                              number of whole tree lengths that can be
1030 '                              yarded from a given point on the slope.
1040 '
1050 '
1060 M = 1                        :'Variable used to calculate maximum lateral
1070 '                              yarding distance for a given outrow space
1080 '
1090 '
1100 FOR ORB = 5 TO 17 STEP 2     :'Sets the outrow space from 5 to 17 outrows
1110 '
1120 M = M + 1
1130 '
1140 '
1150 '
1160 '
1170 YROW = 0                     :'Sets the current number of rows yarded to 0
1180 '
1190 '
1200 '
1210 LOGS = 0                     :'Sets the logs remaining in a row to 0
1220 '
1230 '
1240 '
1250 TIME = 0                     :'Sets the total yarding time to 0
1260 '
1270 '
1280 '
1290 VY = 0                       :'Sets the total yarded volume to 0
1300 '
1310 '
1320 '
```

```
1330 LOGPOS = (RL-4)/COS(ATN(Y1/L1))+3*COS(THETA)/COS(ATN(Y1/L1))
1340 'Initial position of logs, expressed as metres down the skyline chord
1350 'slope from the returned carriage position. This value is updated as
1360 'yarding progresses to represent the distance down the skyline chord
1370 'of logs closest to the yarder.
1380 '
1390 XCOUNT = 0                    :'Sets the current number of cycles to 0
1400 '
1410 '
1420 '
1430 GOSUB 2890                    :'Multispan cycle time sequence
1440 '
1450 '
1460 '
1470 XCOUNT = XCOUNT + 1           :'Adds 1 to the count of completed cycles
1480 '
1490 '
1500 '
1510 IF XROW <= YROW THEN GOSUB 4250   :   GOTO 1620
1520 '     If the number of rows on the slope is less than or equal to the
1530 '     number of rows yarded then the cycle is complete and the data is
1540 '     output. A new outrow (and) corridor is loaded and simulated.
1550 '
1560 '
1570 '
1580 GOTO 1410                     :'Another cycle is simulated
1590 '
1600 '
1610 '
1620 NEXT ORB                      :'Loads the next outrow number
1630 '
1640 '
1650 '
1660 NEXT SD                       :'Loads the next slope distance
1670 '
1680 '
1690 '
1700 CLOSE #1
1710 '
1720 '
1730 '
1740 '
1750 '
1760 END
```

```
1770 '*****   Subroutine to compute payload for multispan system     *******
1780 '
1790 THETA = ATN(SLP/100)      :'Change theta to radians
1800 H = 2                     :'Set minimum log clearance to 2 metres
1810 '
1820 BETA = FNASIN((COS(THETA)*H)/LL)  :'Log to ground angle
1830 ALPHA = ATN(2*TAN(THETA + BETA) + ((COS(THETA) - MU*SIN(THETA))/(SIN(THETA)
+ MU*COS(THETA))))
1840 KA = LENGTHCHOKE*SIN(ALPHA)
1850 KB = H - LENGTHCHOKE*COS(ALPHA)*TAN(THETA)
1860 K = KA + KB       :'Skyline clearance for minimum clearance log clearance
1870 A = SD*COS(THETA)
1880 A1 = ISBSD*COS(THETA)
1890 A2 = A - A1
1900 L = RL + A             :'Total span
1910 L1 = RL + A1           :'Uphill span
1920 L2 = L - L1            :'Downhill span
1930 Y = TOWERH + SD*SIN(THETA) - TBH       :'Total vertical displacement
1940 MIN = SD*10
1950 Y1 = TOWERH + ISBSD*SIN(THETA) - ISBH  :'Uphill vertical displacement
1960 Y2 = Y - Y1                            :'Downhill vertical displacement
1970 '
1980 D1 = L1/2                              :'Left hand span
1990 D2 = L1 - D1                           :'Right hand span
2000 IF (D1-RL)>0 THEN H1 = Y1 + ISBH - D2*TAN(THETA) - K - CARWID:GOTO 2020
2010 H1 = TOWERH - K - CARWID
2020 H2 = ABS(Y1 - H1)
2030 S1 = SQR(D1^2 + H1^2)
2040 S2 = SQR(D2^2 + H2^2)
2050 S = S1 + S2 + SQR(L2^2 + Y2^2)
2060 IF S < MIN THEN SMIN = S  : MIN = SMIN
2070 FOR SECT = L2/10 TO L2-.1 STEP L2/10
2080 D1 = SECT
2090 D2 = L2 - D1
2100 H1 = ISBH + D1*TAN(THETA) - K - CARWID
2110 H2 = Y2 - H1
2120 S1 = SQR(D1^2 + H1^2)
2130 S2 = SQR(D2^2 + H2^2)
2140 S = S1 + S2 + SQR(L1^2 + Y1^2)
2150 IF S < MIN THEN SMIN = S  : MIN = SMIN
2160 NEXT SECT
2170 '
```

```
2180 'After calculating minimum line length required, calculate eliptical
2190 'load path co-ordinates, then tension for a given log load.
2200 NUMBER = 6
2210 IF NUMBER = 0 THEN PRINT"Yarding not possible" :STOP
2220 I = 1
2230 S = SMIN - SQR(L2^2 + Y2^2)       :'Line length for uphill segment
2240 D1 = L1/2
2250 D2 = D1
2260 C = S^2 - Y1^2
2270 PART1 = Y1*C/(2*(S^2 - Y1^2))
2280 PART2 = (SQR(4*D1^2*S^2*(Y1^2 - S^2) + S^2*C^2))/(2*(S^2 - Y1^2))
2290 H1 = PART1 + PART2
2300 H2 = Y1 - H1
2310 TU = T1A : GOSUB 4780            :'Beginning of secant search for maximum
2320 TA = TU : DIFFA = DIFF           :'load given tension
2330 TU = T1A + 100 : GOSUB 4780
2340 TB = TU : DIFFB = DIFF
2350 F = (DIFFB - DIFFA)/(TB - TA)
2360 TA = TB : DIFFA = DIFFB
2370 TB = TB - DIFFB/F
2380 TU = TB : GOSUB 4780
2390 DIFFB = DIFF
2400 IF ABS(DIFF) > .1 THEN 2350
2410 IF TB < T1A THEN N(I) = NUMBER  : GOTO 2430
2420     NUMBER = NUMBER - 1 : GOTO 2220
2430 T3(I) = T3
2440 I = 2
2450 FOR SECT = L2/10 TO L2-.01 STEP L2/10
2460   NUMBER = 6
2470    IF NUMBER = 0 THEN PRINT"Yarding not possible" : STOP
2480     S = SMIN - SQR(L1^2 + Y1^2)
2490      D1 = SECT
2500       D2 = L2 - SECT
2510        C = S^2 + D1^2 - D2^2 - Y2^2
2520        PART1 = Y2*C/(2*(S^2 - Y2^2))
2530        PART2 = (SQR(4*D1^2*S^2*(Y2^2 - S^2) + S^2*C^2))/(2*(S^2 - Y2^2))
2540        H1 = PART1 + PART2
2550        H2 = Y2 - H1
2560        TU = T1A : GOSUB 4780
2570        TA = TU : DIFFA = DIFF
2580        TU = T1A + 200 : GOSUB 4780
2590        TB = TU : DIFFB = DIFF
2600        F = (DIFFB - DIFFA)/(TB - TA)
2610        TA = TB : DIFFA = DIFFB
2620        TB = TB - DIFFB/F
2630        TU = TB : GOSUB 4780
2640        DIFFB = DIFF
2650       IF ABS(DIFF) > .1 THEN 2600
2660      IF TB > T1A THEN 2690
2670     IF N(I-1) < NUMBER THEN N(I) = N(I-1) : GOTO 2700
2680    N(I) = NUMBER : GOTO 2700
2690   NUMBER = NUMBER - 1 : GOTO 2470
2700  T3(I) = T3
2710  I = I + 1
2720 NEXT SECT
2730 T3(I) = T3(I-1) :  N(I) = N(I - 1)
2740 RETURN
```

```
2890 '******   Subroutine for multi span cycle time sequence      *********
2900 '
2910 'Calculate skyline angle
2920 SKYANG1 = ATN(Y1/L1)               :'Skyline chord slope angle for uphill
2930 SKYANG2 = ATN(Y2/L2)               :'and downhill spans
2940 '
2950 'Set initial conditions
2960 '
2970 OUTDIST = 0                    :'Instantaneous distance the carriage is
2980 CARPOS = 4/COS(SKYANG1)        :'out from the yarder down the chord slope
2990 OUTVEL = 0                     :'Instantaneous velocity of out carriage
3000 TIM = 0                        :'Current yarding time for corridor
3010 '
3020 GOSUB 3380                     :'Outhaul subroutine
3030 '
3040 SKY = SKYANG                   :'Adjust the current skyline angle
3050 IF LOGPOS*COS(SKYANG1) < L1 THEN J = INT(LOGPOS*COS(SKYANG1)/L1 + .5) + 1 :
 GOTO 3070
3060     J = INT((((LOGPOS - L1/COS(SKYANG1))*COS(SKYANG2))/L2)*10)+2
3070 'Add on lateral outhaul, hook and lateral inhaul time
3080 '
3090 LD = ((ORB-1)+M)               :'Lateral distance over 3.0 metres
3100 LD = (LD-3)*RND +3
3110 TIME = TIME + 57.32 + 1.14*LD          :'Lateral out time
3120 TIME = TIME + 116.4            :'Hook time
3130 TIME = TIME + 28.8 + 1.08*LD + 2.16*N(J)    :'lateral inhaul time
3140 TIM = 0
3150 '
3160 GOSUB 3520                     :'Inhaul subroutine
3170 '
3180 'Add on unhook time
3190 '
3200 TIME = TIME + 34               :'34 seconds for unhook time
3210 '
3220 'Update position of closest logs to yarder
3230 '
3240 '
3250 ROWPTURN = N(J)/(ORB/2)        :'Rows required to fill a turn.
3260 ROWPTURN = ROWPTURN - LOGS
3270 ROWA = INT(ROWPTURN)+1
3280 LOGS = ROWA - ROWPTURN         :'Logs remaining in row closest to yarder
3290 '
3300 YROW = YROW + ROWA             :'Update total rows yarded
3310 '
3320 LOGPOS = LOGPOS + ROWA*3*COS(THETA)/COS(SKYANG)
3330 '
3340 VY = VY + N(J)*AVGT
3350 '
3360 RETURN
3370 '
```

```
3380 '**********Outhaul          Subroutine******************************
3390 SKYANG = SKYANG1
3400 OUTF = CW*SIN(SKYANG)*9.8
3410 OUTACC = OUTF/CW
3420 OUTDIST = .5*OUTACC + OUTVEL
3430 OUTVEL = OUTVEL + OUTACC
3440 CARPOS = CARPOS + OUTDIST
3450 TIM = TIM + 1
3460 IF OUTVEL >= 4 THEN OUTACC = 0  :'Max. speed of carriage set at 4 m/sec
3470 IF CARPOS > LOGPOS THEN TIME = TIME + TIM : RETURN
3480 IF CARPOS > SQR(Y1^2 + L1^2) THEN SKYANG = SKYANG2
3490 IF OUTACC = 0 THEN 3420
3500 GOTO 3400
3510 '
3520 '********          Inhaul   Subroutine          ***********
3530 CARPOS = LOGPOS
3540 IF CARPOS*COS(SKYANG) < L1 THEN INFORCE = T3(1)*.0098 : GOTO 3600
3550 CARPOS = CARPOS - L1/COS(SKYANG1)
3560 INFORCE = CARPOS*COS(SKYANG2)/L2
3570 INFORCE = INFORCE*10
3580 INFORCE = INT(INFORCE)+2
3590 INFORCE = T3(INFORCE)*.0098
3600 INVEL = EFP*.9*.7/INFORCE
3610 CARPOS = CARPOS - INVEL
3620 TIM  = TIM + 1
3630 IF CARPOS < 1/COS(SKYANG1) THEN TIME =  TIME + TIM : RETURN
3640 GOTO 3540
3650 '
3660 '
3670 '
3680 '
3690 '
3700 '
3710 '
3720 '
3730 '
3740 '
3750 '
3760 '
3770 '
3780 '
3790 '
3800 '
```

```
3810 '**********Fixed and Operational Costs Subroutine *****************
3820 '
3830 DEPRY = (P - SV)/N                     :'Yarder depreciation
3840 '
3850 DEPRC = (CARCOST - CARCOST*.2)/N  :'Carriage depreciation
3860 '
3870 DEPRR = (RADIO - RADIO*.2)/N       :'Radio depreciation
3880 '
3890 DEPR = DEPRY + DEPRC + DEPRR       :'Total depreciation
3900 '
3910 AAI = (((P + RIGGING + CARCOST + RADIO) - (SV + RADIO*.2 + CARCOST*.2))*(N
+ 1))/(2*N) + SV + RADIO*.2 + CARCOST*.2
3920 OPPC = AAI*IR
3930 '
3940 INSUR = AAI*.02
3950 '
3960 FCM = (OPPC + INSUR + DEPR)/(220*7.5)
3970 '
3980 FC = FCM + LABOUR                  :'Total fixed costs
3990 '
4000 MAINTC = (.5*DEPRY + .2*DEPRC + .2*DEPRR)/(220*7.5)
4010 '
4020 FUELC = (.256*EFP*LF/SGD)*FUEL       :'Hourly fuel cost
4030 '
4040 LUBEC = .1*FUELC                     :'Hourly lube cost
4050 '
4060 ROPEC = WIRER/1650                   :'Hourly wire rope cost.
4070 '
4080 OC = ROPEC + FUELC + LUBEC + MAINTC  :'Hourly operating cost
4090 '
4100 TOTALC = FC + OC                     :'Total hourly cost
4110 '
4120 '
4130 '
4140 '
4150 RETURN
4160 '
4170 '
4180 '
4190 '
4200 '
4210 '
4220 '
4230 '
4240 '
```

```
4250 '*****  Subroutine to output average costs and production rates.  *****
4260 'Calculate rigging, derigging costs
4270 ROAD = (ORB*3)*2          :'Road reconstruction cost for outrow spacing
4280 RIGC = 2*FC               :'Rigging and derigging costs per outrow
4290 LAND = 340                :'Landing construction costs per outrow
4300 '
4310 'Calculate total yarded volume and cost
4320 '
4330 TYC = (TIME/.7)*TOTALC/3600 + RIGC + ROAD + LAND :'30 percent delay time
4340 AVERAGEC = TYC/VY                   :'Average cost $/m^3
4350 AVERAGEP = VY/((TIME/.7)/3600)      :'Average production m^3/hour
4360 '
4370 '
4380 CLS
4390 PRINT
4400 PRINT
4410 PRINT
4420 '
4430 IF ME = 1 THEN PRINT"For a Koller K-300 rigged as a standing skyline a SKA-
1 Carriage,"
4440 IF ME = 1 THEN PRINT" 1 engineer/chaser";: GOTO 4490
4450 IF ME = 2 THEN PRINT"For a Timbermaster rigged as a standing skyline a SKA-
1 Carriage,"
4460 IF ME = 2 THEN PRINT"1 engineer 1 chaser";: GOTO 4490
4470 PRINT"For a Madill 071 rigged as a standing skyline a Danebo MSP Carriage,"

4480 PRINT"1 engineer 1 chaser";
4490 PRINT"2 Choker setters. Operating in a P.radiata plantation with an average
 tree"
4500 PRINT"size of";AVGT;" cubic metres and a log length of";LL;"metres, on a sl
ope of";
4510 PRINT USING" ## ";SLP;
4520 PRINT"percent and a corridor length of";SD;"m. The following costs are calc
ulated;"
4530 PRINT"Outrow number = ";ORB:PRINT
4540 PRINT"Total volume yarded was ";
4550 PRINT USING"####.#";VY;
4560 PRINT" Cubic metres ":PRINT
4570 PRINT"Road and landing costs equal ";
4580 PRINT USING" $####";ROAD+LAND:PRINT
4590 PRINT"Rigging cost equals ";
4600 PRINT USING" $####";RIGC:PRINT
4610 PRINT"Total cost including road, landing and rigging costs was ";
4620 PRINT USING" $####.##";TYC:PRINT
4630 PRINT"Total time to yard was (excluding rigging time) ";
4640 PRINT USING"##.##";(TIME/.7)/3600;
4650 PRINT" Hours":PRINT
4660 PRINT"Average delay free cycle time was ";
4670 PRINT USING"#.##";(TIME/60)/XCOUNT;
4680 PRINT" Minutes ":PRINT
4690 PRINT"Average cost was ":
4700 PRINT USING" $##.##";AVERAGEC;
4710 PRINT" per cubic metre":PRINT
4720 PRINT"Average production was ":
4730 PRINT USING" ##.##";AVERAGEP;
4740 PRINT" Cubic metres per hour"
4750 PRINT"------------------------------------------------------------------------
----"
4760 WRITE #1.ME,AVGT,SD,ORB,VY,TYC,(TIME/.7)/3600.(TIME/60)/XCOUNT.AVERAGEC,AVE
RAGEP'
4770 RETURN
```

```
4780 '**********      Subroutine for payload calculation       ***********
4790 '
4800 ' CALCULATE FORCES FOR SEGMENT No. 1  SKYLINE LEFT (TOPSIDE)
4810 '
4820 '
4830 D = D1 : E = H1 : LW = SLW
4840 GOSUB 5660
4850 V1L = VL
4860 HC1 = HORCOMP
4870 T1L = SQR(V1L^2 + HC1^2)
4880 '
4890 '
4900 'CALCULATE FORCES FOR SEGMENT No. 2 SKYLINE RIGHT (BOTTOMSIDE)
4910 '
4920 '
4930 D = D2 : LW = SLW
4940 IF H2 > 0 THEN E = H2 : TU = T1L : GOSUB 5660 :'CARRIAGE ABOVE TAILSPAR
4950 IF H2 < 0 THEN E = -H2 : TL = T1L : GOSUB 5790 : 'CARRAIGE BELOW TAILSPAR
4960 HC2 = HORCOMP
4970 IF H2 > 0 THEN V2 = -(SQR(TU^2 - HC2^2))      :'PULLS DOWN ON CARRIAGE
4980 IF H2 < 0 THEN V2 = VB        :'PULLS UP ON CARRIAGE
4990 '
5000 '
5010 ' For a given skyline position, calculate the required alpha
5020 '
5030 '
5040 W = NUMBER*AVGT*1000
5050 '
5060 '
5070 '
5080 IF I = 1 THEN 5100
5090 K = Y2+TBH - (D2*TAN(THETA)+H1+CARWID) : GOTO 5170
5100 IF D1<RL THEN K = TOWERH - (H1 + CARWID) : GOTO 5170
5110 K = (Y1+ ISBH)-(D2*TAN(THETA) + H1 + CARWID) : GOTO 5170
5120 '
5130 '
5140 '
5150 '
5160 '
5170 '
5180 '
5190 '
5200 '
```

```
5210 IF K > LL THEN 5570                                  :'LOG LOAD FLYING
5220 '
5230 '
5240 ALPHA = 1 : GOSUB 5920
5250 ALPHAA = ALPHA : UA = U
5260 ALPHA = 1.1 : GOSUB 5920
5270 ALPHAB = ALPHA : UB = U
5280 Q = (UB - UA)/(ALPHAB - ALPHAA)
5290 ALPHAA = ALPHAB : UA = UB
5300 ALPHAB = ALPHAB - UB/Q
5310 ALPHA = ALPHAB : GOSUB 5920
5320 UB = U
5330 IF ABS(U) > .00001 AND ABS(UA - UB) > .00001 THEN 5280
5340 '
5350 '
5360 '
5370 '
5380 A = V1L + V2 - CW
5390 '
5400 B = HC1 - HC2
5410 '
5420 HC3 = (TAN(ALPHA)*B-A+(MLW*(H1^2+D1^2)^.5)/2)/(H1/D1-TAN(ALPHA))
5430 '
5440 V3 = TAN(ALPHA)*(B + HC3) - A
5450 '
5460 T3 = SQR(HC3^2 + V3^2) + MLW*H1
5470 T3(I) = T3
5480 SUMV = A + V3
5490 WV = W*(1 - ((COS(THETA) - SIN(THETA)*TAN(BETA))/((1/CG)*(1 + MU*TAN(BETA)
))*(COS(THETA) - MU*SIN(THETA)))
5500 DIFF = WV - SUMV
5510 H = SIN(BETA)*LL/COS(THETA)
5520 RETURN
5530 '
5540 '
5550 '
5560 '
5570 HC3 = HC2 - HC1
5580 V3 = HC3*H1/D1 - MLW*SQR(H1^2+D1^2)*.5
5590 T3 = SQR(V3^2+HC3^2)+MLW*H1
5600 T3(I) = T3
5610 DIFF = W - (V1L + V2 - CW) + V3
5620 RETURN
5630 '
5640 '
5650 '
```

```
5660 '*****SUBROUTINE FOR H, V GIVEN  T UPPER (RIGID LINK ASSUMPTIONS)*****
5670 S = SQR(D^2 + E^2)
5680 HORCOMP = TU*D/S*SQR(1 - (.5*LW*D/TU)^2) - .5*LW*D*E/S
5690 VL = HORCOMP*E/D - .5*LW*S
5700 RETURN
5710 '
5720 '
5730 '
5740 '
5750 '
5760 '
5770 '
5780 '
5790 '****SUBROUTINE FOR H, V GIVEN T LOWER (RIGID LINK ASSUMPTIONS)******
5800 S = SQR(D^2 + E^2)
5810 HORCOMP = TL*D/S*SQR(1 - (.5*LW*D/TL)^2) + .5*LW*D*E/S
5820 VB = HORCOMP*E/D - .5*LW*S
5830 RETURN
5840 '
5850 '
5860 '
5870 '
5880 '
5890 '
5900 '
5910 '
5920 '*********     Subroutine to evaluate the angle Alpha     *************
5930 BETA = ((K*COS(THETA) - LENGTHCHOKE*SIN(ALPHA - THETA))/LL)
5940 BETA = FNASIN(BETA)
5950 U = ALPHA - ATN(2*TAN(THETA + BETA) + ((COS(THETA) - MU*SIN(THETA))/(SIN(TH
ETA) + MU*COS(THETA))))
5960 RETURN
5970 '
5980 '
5990 '
6000 '
6010 '
6020 '
6030 '
6040 '
6050 '
6060 '
6070 '
6080 '
6090 '
```

```
6100 '*****      Subroutine to input variables for Koller K-300         *******
6110 T1A = 6230  :'16mm. Dia       Max. skyline tension kgs (Safe Factor = 3)
6120 T3A = 2270  :'9.5mm. Dia      Max. mainline tension kgs (Safe Factor =3)
6130 CG = .4                       :'Centre of gravity/log length ratio
6140 LENGTHCHOKE = 1               :'length of choker  metres
6150 MU = .6                       :'coefficient of log  / ground friction
6160 P = 70000!                    :'Initial machine capital cost AUS $
6170 CARCOST = 13000               :'Initial cost of carriage AUS $
6180 RADIO = 9000                  :'Cost of Talkie tooter radio system
6190 RIGGING = 2000                :'Value of lines and rigging AUS $
6200 WIRER = 1550                  :'Value of wire rope used AUS $
6210 FUEL = .48                    :'Fuel costs per litre AUS $
6220 LABOUR = (1*18.7+2*12.7)*(40/37.5)   :'Labour Costs 3 Men $AUS
6230 SV = P*.2                     :'Machine salvage value  AUS $
6240 N = 8                         :'Machine life years
6250 IR = .185                     :'Current applicable interest rate
6260 CARWID = .7                   :'Carriage width metres
6270 CW = 150                      :'Carriage weight kgs
6280 TOWERH = 6.85                 :'Tower height metres
6290 SLW = 1.07                    :'Skyline weight kilograms/metre
6300 MLW = .39                     :'Mainline weight kilograms/metre
6310 LF = .55                      :'Medium load factor
6320 SGD = .848                    :'Specific gravity of desiel fuel  kg/litre
6330 EFP = 37                      :'Engine flywheel power Kilowatts
6340 ISBH = 12                     :'Intermediate support block height, metres
6350 RL = 14                       :'Hor. distance from tower top to road edge
6360 SCS = ATN((TOWERH - 6)/RL)    :'Skyline chord slope
6370 THETA = ATN(SLP/100)          :'Ground slope
6380 ISBSD = (ISBH-6)/(SIN(THETA)-COS(THETA)*TAN(SCS)) :'Intermediate support
6390 '                             block location down the ground slope
6400 PRINT"ISBSD = ";ISBSD
6410 TD = 310                      :'Yarding capacity of machine
6420 RETURN
6430 '
6440 '
6450 '
6460 '
6470 '
6480 '
6490 '
6500 '
6510 '
6520 '
6530 '
```

```
6540 '** Subroutine to input variables for Timbermaster and SKA-1 Carriage **
6550 T1A = 6230  :'16mm Dia.      :'Max. Skyline Tension Kilograms
6560 T3A = 2270  :'9.5mm. Dia     :'Max. Mainline Tension Kilograms
6570 CG = .4                      :'Centre of gravity/ log length ratio
6580 LENGTHCHOKE = 1              :'Length of Choker, metres
6590 MU = .6                      :'Coefficient of log to ground friction
6600 P = 100000!                   :'Initial Capital Cost of Machine $AUS
6610 CARCOST = 13000              :'Initial  Capital Cost of Carriage $AUS
6620 RADIO = 9000                 :'Initial Capital Cost of Radio system
6630 RIGGING = 2000               :'Value of lines and rigging $AUS
6640 WIRER = 1900                 :'Initial value of wire rope $AUS
6650 FUEL = .48                   :'Fuel cost per litre $AUS
6660 LABOUR = (1*18.7+3*12.7)*(40/37.5)    :'Labour costs, 4 men $AUS
6670 SV = P*.2                    :'Machine salvage value
6680 N = 8                        :'Estimated machine life
6690 IR = .185                    :'Current applicable interest rate
6700 CARWID = .7                  :'Carriage Width         metres
6710 CW = 150                     :'Carriage weight        Kgs.
6720 TOWERH = 9.8                 :'Height of tower, metres
6730 SLW = 1.07                   :'Skyline weight per metre, kg
6740 MLW = .39                    :'Mainline weight per metre, kg
6750 LF = .55                     :'Load factor for fuel consumption calc.
6760 SGD = .848                   :'Specific gravity of desiel fuel, kg/litre
6770 EFP = 52                     :'Gross engine flywheel power, KW
6780 ISBH = 12
6790 RL = 14
6800 SCS = ATN((TOWERH - 6)/RL)
6810 THETA = ATN(SLP/100)
6820 ISBSD = (ISBH-6)/(SIN(THETA) - COS(THETA)*TAN(SCS))
6830 PRINT"ISBSD = ";ISBSD
6840 TD = 400
6850 RETURN
6860 '
6870 '
6880 '
6890 '
6900 '
6910 '
6920 '
6930 '
6940 '
6950 '
6960 '
6970 '
```

```
6980 '** Subroutine for input of Madill 071 Variables, Danebo MSP Carriage ***
6990 T1A = 15650                    :'Max. Skyline Tension Kilograms
7000 T3A = 6230                     :'Max. Mainline Tension Kilograms
7010 CG = .4                        :'Centre of gravity/log length ratio
7020 LENGTHCHOKE = 1.2              :'Length of choker, metres
7030 MU = .6                        :'Coefficient of log to ground friction
7040 P = 500000!                     :'Initial capital cost of machine $AUS
7050 CARCOST = 9000                 :'Initial capital cost of carriage $AUS
7060 RADIO = 9000                   :'Initial capital cost of radio system
7070 RIGGING = 2000                 :'Value of lines and rigging
7080 WIRER = 12000                  :'Replacement value of wire rope
7090 FUEL = .48                     :'Fuel cost per litre, $AUS
7100 LABOUR = (1*18.7+3*12.7)*(40/37.5)      :'Labour costs, 4 men $AUS
7110 SV = P*.2                      :'Estimated machine salvage value
7120 N = 8                          :'Estimated machine life, years
7130 IR = .185                      :'Current commercial interest rate
7140 CARWID = 1                     :'Carriage width, metres
7150 CW = 265                       :'Carriage weight, kilograms
7160 TOWERH = 14.32                 :'Tower height, metres
7170 SLW = 2.73                     :'Weight of skyline, kilograms/metre
7180 MLW = 1.07                     :'Weight of mainline, kilograms/metre
7190 LF = .5                        :'Machine load factor
7200 SGD = .848                     :'Specific gravity of desiel fuel kg/litre
7210 EFP = 213                      :'Gross engine flywheel power
7220 ISBD = 12
7230 RL = 12.8
7240 SCS = ATN((TOWERH - 9)/RL)
7250 THETA = ATN(SLP/100)
7260 ISBSD = (ISBH-9)/(SIN(THETA) - COS(THETA)*TAN(SCS))
7270 PRINT"ISBSD = ";ISBSD
7280 TD = 580
7290 RETURN
```

SAMPLE OUTPUT FROM SIMULATION RUN.

For a Timbermaster rigged as a standing skyline a SKA-1 Carriage,
1 engineer 1 chaser
2 Choker setters. Operating in a P.radiata plantation with an average tree size of .2 cubic metres and a log length of 2Ø metres, on a slope of 5Ø percent and a corridor length of 19Ø m. The following costs are calculated;
Outrow number = 17

Total volume yarded was 1Ø5.6 Cubic metres

Road and landing costs equal $ 442

Rigging cost equals $ 156

Total cost including road, landing and rigging costs was $1529.9Ø

Total time to yard was (excluding rigging time) 1Ø.71 Hours

Average delay free cycle time was 5.11 Minutes

Average cost was $14.49 per cubic metre

Average production was 9.86 Cubic metres per hour
