PROFITABILITY OF THINNING: SHORT- AND LONG-TERM CONSIDERATIONS

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ABSTRACT

This paper provides a framework within which different thinning systems can be evaluated, taking into consideration both short-term costs (thinning costs) and long-term costs arising from damage and loss of site potential under Swedish conditions.

The paper was previously presented at a seminar on "Mechanisation and Techniques of Thinning Operations" at Nancy in 1979.

INTRODUCTION

Thinning operations give rise to a number of cost and revenue items (Fig. 1). The difference between the costs and the revenue constitutes the net thinning result in the broadest sense.

With purely selective thinning without strip roads as the starting point, in respect of a given stand (same site quality index), thinnings with varying strip-road width, strip-road spacing, and logging techniques can be compared, and the losses itemised in Fig. 1 calculated.

In co-operation with Joran Fries of the Swedish University of Agricultural Sciences, we are working with calculations in which the yield of a stand is weighed against different logging techniques. The calculations have been made in respect of strip-road widths of 3 to 5 m, strip-road spacing of 20, 30, 40, and 70 m, and the following site quality indices*:

Site index	T18	T20	T24	G24	G28	G32
Mean annual production over 100 years (gross volume, m^3)	2.9	3.7	5.5	6.0	7.9	11.0

The purpose of the calculations is to compare different techniques of first thinnings when different strip-road widths and spacings are applied. The calculations are based on a wealth of unreliable input data. This is especially true of the significance of damage caused by logging operations. The problem here is that while new thinning techniques

* T = Pine (**Pinus sylvestris** L.); G = Spruce (**Picea abies** (L.) Karst). The figures 18, 20, 24, etc. denote the mean height of the 100 largest diameter trees per hectare at age 100.

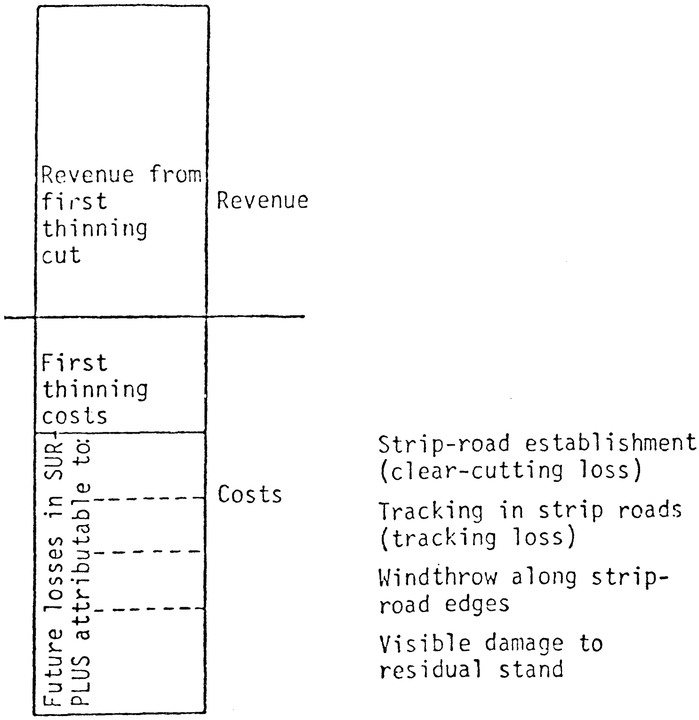


FIG. 1—Cost and revenue items in thinning.

can be developed fairly quickly, a long period of time is required to investigate the biological consequences. Thus, we cannot wait until reliable data become available but must make use of the latest experience gained and update these calculations when new facts are available. Such exercises have already been carried out on a number of aspects and with the application of a variety of calculation methods (Agren 1968; Fries 1973; Dehlen 1977).

MODEL DESCRIPTION

Yield Losses Arising from Strip-road Establishment and Tracking

The effect on the increment of trees bordering strip roads has been analysed by Joran Fries and Stefan Bucht, Swedish University of Agricultural Sciences, in production investigations. The results can be summed up as follows:

- At a high site-quality index the residual trees along the edge of the operating strip take advantage of the clear-cut strip road comparatively quickly;
- At a high site-quality index relatively greater volume increment losses are caused by deep tracks.

Figure 2 illustrates the assumed relative increment losses during a 12-year period after thinning, for different spacings between the strip roads and different strip-road widths.

It also shows the effect of track depth. When the tracks have an average depth of 10–15 cm on a certain tract, they are considered deep. Comparison has been made with selective thinning.

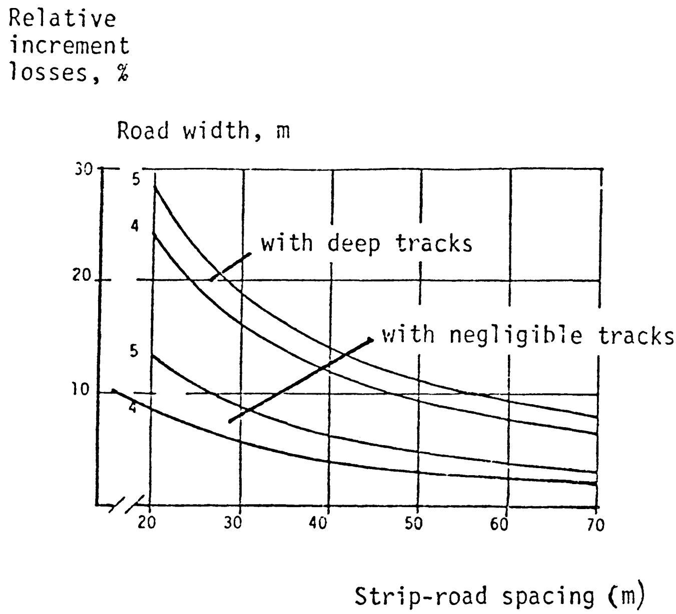


FIG. 2—Relative increment losses (12 years after first thinning) for strip-road spacing and width for stands with or without deep tracks in the road. Site quality index G32.

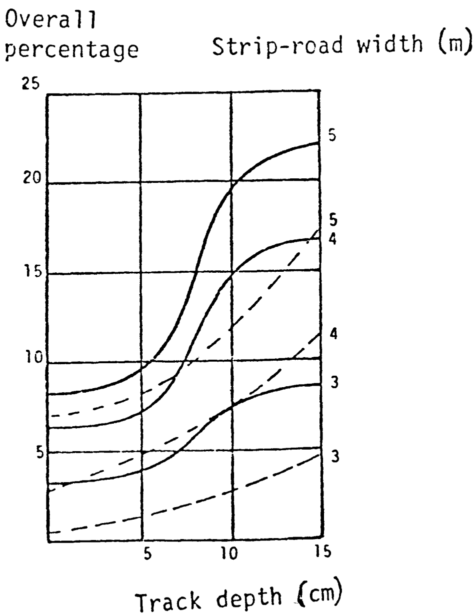
The cutting loss associated with the establishment of strip roads can be worked out by comparing the net result of future thinnings and final felling in a stand that has just been thinned for the first time by means of selective thinning, with the net result in respect of an equivalent stand that has been thinned using strip roads of a given width and given spacing. If we make a similar comparison with a stand in which vehicle tracks have been made in the strip roads, we can also calculate the loss caused by the tracks (*see* Table 1). If we interpolate the values between B and C in Table 1, we can also calculate the loss caused by tracks of varying depths.

TABLE 1—Theory for calculating loss caused by strip-road establishment and by tracks

Type of first thinning	Net result of subsequent thinnings and final felling
Purely selective	A
Road with negligible tracks	B
Roads with deep tracks	C
Clear-cutting loss = A - B	
Loss caused by tracks = B - C	

Windthrow Losses

In the following calculations the risk of windthrow in the strip roads has been taken into account, but the risk of windthrow attributable to thinning has not. Figure 3 illustrates the suppositions made as regards windthrow along a strip-road edge. Windthrow is expressed as a percentage of the residual trees after a first thinning. In theory the zone closest to the road is affected most, but in this Figure all windthrows are confined to a 1-m zone. It is assumed that the incidence of windthrow close to the strip roads increases with increasing road width and track depth, and decreases in direct proportion to an increase in the strip-road spacing. For spruce it is assumed that significant root severance occurs when the track depth is between 5 and 10 cm; pine trees have a deeper root system and are therefore less susceptible to windthrow (Fig. 3). Generally speaking, the curves shown in the figure rely on a single example (Fig. 4) in which the road width was 4 m and the tracks were approximately 5 cm deep (Persson 1975).



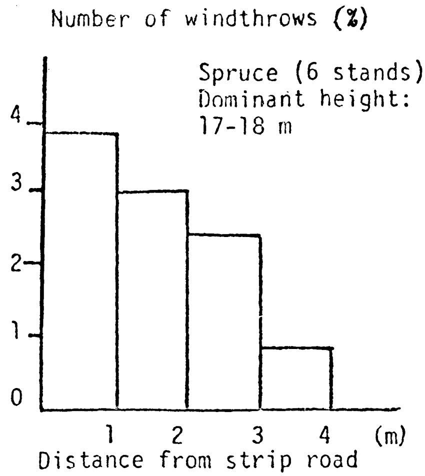


FIG. 3 (left)—Incidence of windthrow along a strip-road edge for tracks of varying depth and for various strip-road widths. The windthrow aggregate is confined to a 1-m zone. Broken lines = pine; solid lines = spruce.

FIG. 4 (right)—Number of windthrows between 1968 and 1972 according to distance from the strip road. The stands from which the study results were obtained were not affected by the violent autumn winds of 1969.

Losses Through Damage to the Residual Stand

The residual stand is subjected to mechanical damage which will cause a reduction in the quality of the wood to be extracted in future thinnings and in final felling. From inventories of visible damage to the residual stand, carried out after thinning operations, we know that most of the damage to the trees occurs about 50 cm above the ground and that in about 30% of the trees it penetrates to the sapwood.

Pine trees can heal over cuts in the bark relatively easily. Only damage that penetrates to the sapwood calls for the trimming of the sawlog and the damage does not have any effect on pulpwood (Fig. 5A). In spruce, mechanical damage has more serious consequences. Studies of blaze or timber-marking rot in spruce trees (Nordfors 1923) have provided us with fairly conclusive knowledge concerning the way in which these trees react to cuts through the bark. Similarly, we have a fairly wide experience of the development of rot after root damage (Nilsson 1967). The rate at which the rot develops differs in the different planes:

Direction	*Rate-of-development ratio*
Radial	1
Peripheral	3
Vertical	70

Sapwood damage gives rise to extensive rot: a severe attack spreads at least 3 m along the butt log and often necessitates trimming of the log to a 3-m pulpwood bolt. Here, we have assumed that half of the damage will necessitate a 3-m bolt being trimmed – in other words, a reduction of the butt log to pulpwood up to 3 m above the felling cut (Fig. 5B).

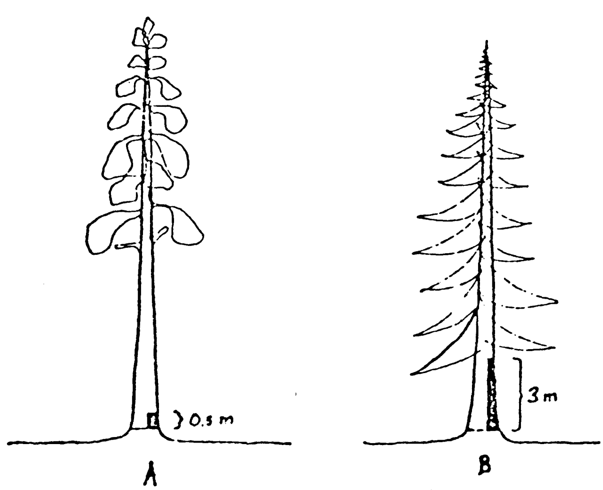


FIG. 5—Assumptions concerning the future effects of mechanical damage on the residual stand.

Evaluating the Yield

When we calculate the future revenue from the yield of a thinned stand, we have to assume a certain quality development. Unfortunately, documentation on this aspect is fairly limited. The current prices of sawlogs and pulpwood are also applied to future cuts.

Future Logging Costs

To calculate the net result of future logging operations, one must assume that a given technique or system will be applied. In this case we have assumed that the best available technique will also be applied in the future.

Damage Inventory after Thinning Operations

During the last 2 years, the Logging Research Foundation (Skogsarbeten) has conducted post-thinning inventories in a large number of stands. The inventories concentrated mainly on the following variables:

- Strip-road spacing
- Strip-road width
- Damaged residual trees (visible damage to stems and roots)
- Depth of tracks

The most important results of the inventory are given in Table 2.

TABLE 2—The mean values of road width and incidence of damaged trees in respect of different thinning systems

Thinning system	Strip-road width (m)	Damaged residual trees (%)
Motor-manual shortwood method without winch	4.6	3.8
Motor-manual shortwood method with winch	4.7	3.9
Winching of trees to thinning processor	4.4	9.1
Winching of trees to processor originally designed for final felling	5.9	12.6

The processor originally designed for final fellings determines the strip-road width in the system in which it is applied, whereas in other systems the forwarding work determines the road width. There is a great difference between the incidence of damage incurred in winching of trees to the strip road and that incurred in winching stems or stem sections.

Figure 6 shows the correlation between the depth of tracks, the ground bearing capacity, the season, and whether or not a winch was used. From a statistical point of view the correlation is weak and should therefore be regarded only as indicative. All the variables are average values for the stand.

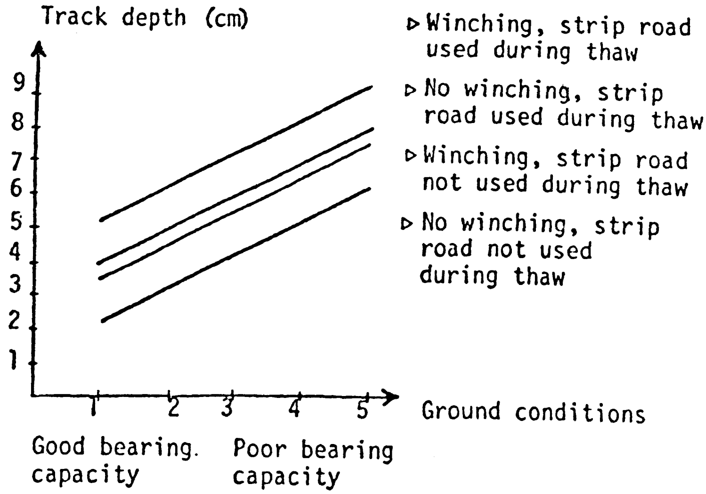


FIG. 6—Correlation between track depth and ground conditions, with and without winching to the strip road and with and without utilisation of the strip road during the spring thaw.

INTRODUCTORY EXAMPLE

Basic Parameters

Let us now look at two examples of the way in which the calculation model operates. The calculations apply to motor-manual cutting, with and without winches, on a site with a quality index of G32. The various activities are carried out as follows: first thinning at stand age 33 years, second thinning at 45 years, third thinning at 61 years, clearfelling at 86 years.

Table 3 shows the strip-road spacing and width, the logging costs, the incidence of damage, and the depth of tracks. Various road widths have been assumed for the two systems. Table 3 also shows the mean diameter of the first thinning cut. It should be noted that the diameter of the cut varies with variations in the uniformity of thinning (for example, changes in the strip-road width and strip-road spacing). The last column gives the depth of tracks in firm ground (ground condition class 1–2 in Swedish terrain classification system).

The assumptions concerning the depth of tracks apply to the snow-free period of the year, with the exception of the spring thaw period. The basic figures are derived from Fig. 7, which shows the depth of tracks for different strip-road spacings, different machine combinations, and good and poor ground bearing capacity. In the calculation of the track depth, a number of "heavy" passes per road have been assumed. There is a tendency for the track depth to increase more rapidly on ground of poor bearing capacity when the number of passes is increased. However, we know that the track depth does not increase appreciably after a given number of passes.

Results

From Table 4 we can see that the shorter distance between strip roads yields a better net result. The difference in the net result between the two systems amounts to SKr 700/ha. If we assume a cut of 60 m^3/ha in the first thinning, the value of the difference will amount to $\frac{700}{60}$ = SKr 11.70/m^3 of the first-thinning cut. The wood revenue and logging costs in the first thinning vary considerably with variations in strip-road spacing, and have a strong influence on the net result. The most significant losses are those attributable to strip-road establishment. When the ground bearing capacity is good, the loss caused by tracks is not so important. The loss due to windthrow is greatest when the strip-road spacing is tight.

A fundamental assumption in the calculations is that the thinning intensity between the strip roads (i.e., the area in which selective thinning is performed) does not vary according to the strip-road spacing. This is the difference between the total thinning cuts. However, when the strip roads are established fairly close to one another, the mean tree diameter in the future stand will be greater because there will be more trees growing alongside strip roads.

Table 5 shows the relationship between the volume of the cuts and their values. A thinning pattern with a strip-road spacing of 70 m produces a 19% lower cut per hectare than that with a strip-road spacing of 20 m. The difference in the value of the cut is greater still, i.e., about 22%. However, on the whole the system that incorporates winching produces a higher volume in the first thinning and through to final felling. Windthrow attributable to strip-road establishment is much more limited in extent with wide strip-road spacing.

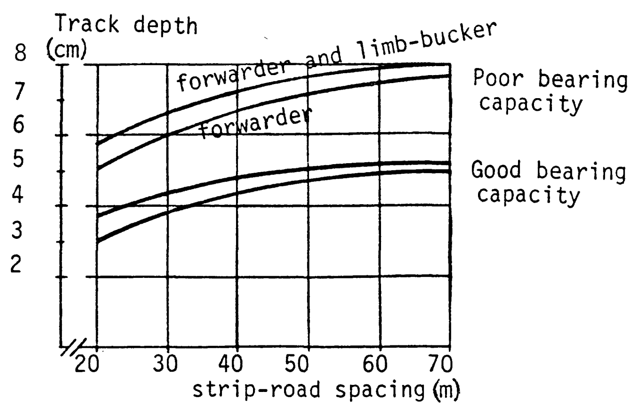


FIG. 7—Assumptions concerning the depth of tracks for varying strip-road spacings, varying ground bearing capacities, and machines of varying weight.

TABLE 3—Basic parameters in the introductory example. Site quality index G32

System	Road spacing (m)	Road width (m)	Mean diameter of cut tree (cm)	Logging cost of first thinning (SKr/m³)*	Damaged residual trees (%)	Track depth in firm ground (cm)
Motor-manual shortwood method with winching	70	4.4	12.0	108.10	3.5	4.9
As above but without winching	20	4.0	12.4	94.90	4.0	3.0

* 1 SKr = US$0.22 = FF 0.22

TABLE 4—Cost and revenue items in the introductory example. Assumed interest rate 3%. Site quality index G32. Good ground bearing capacity

System	Strip-road spacing (m)	Net result (SKr/ha)	First thinning		Losses (SKr/ha) due to:			
			Wood revenue (SKr/ha)	Logging cost (SKr/ha)	Strip-road cutting	Tracks	Wind-throw	Tree damage
Motor-manual shortwood method with winching	70	–660	7070	7290	260	70	50	60
As above but without winching	20	+40	8600	7590	660	80	160	70

TABLE 5—Relationship between the volume and value of the cuts, and of windthrow in the stands after first thinnings. Site quality index G32. Good ground bearing capacity

System	Road spacing (m)	Mean tree diameter (cm)	Relationship first-thinnings cuts		Relationship first-thinning and final-felling cuts	Relationship windthrow after first thinning, up to and including final felling
			Volume	Value		
Motor-manual shortwood method with winching	70	12.0	100	100	100	100
As above without winching	20	12.4	119	122	97.6	336

MOTOR-MANUAL METHODS

Assumed Parameters

The following logging systems are those incurring the lowest costs when the respective strip-road spacing is applied:

- Motor-manual shortwood method, short boom, strip-road spacing 20 m;
- Motor-manual shortwood method with 10-m boom, strip-road spacing 30 m;
- Motor-manual shortwood method with 15-m boom, strip-road spacing 40 m;
- Motor-manual shortwood method with winch, strip-road spacing 70 m.

The logging costs in respect of spruce incurred by the different systems are shown in Fig. 8. The costs in respect of pine are at least SKr 5/m^3 lower than those in respect of spruce with corresponding diameters.

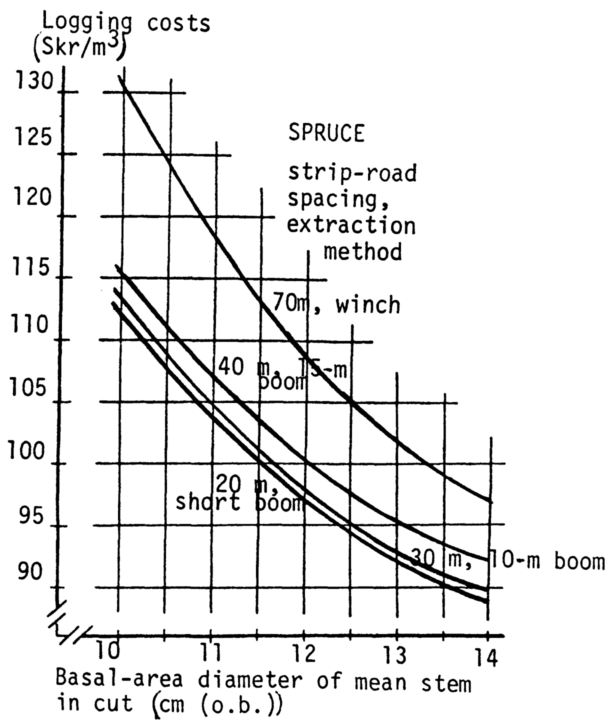


FIG. 8—Logging costs (spruce stands) incurred by different motor-manual thinning systems for thinning cuts of varying diameter.

It is assumed (Table 6) that the strip-road width in the system with a road spacing of 40 m will be greater than that in systems with 20-m and 30-m spacings because the 15-m boom requires a heavier machine base. The higher concentration of wood in the system with 70-m spacing justifies a further increase in the strip-road width. The tracking depths apply to good and poor ground bearing capacity respectively, and are taken from Fig. 7. The forwarders are assumed to be of conventional design, with a single axle at the front.

Results

Table 7 shows the results in respect of an assumed interest rate of 3%, and site quality indices G32, G24, and T18 (Bucht 1981). The net value of the cut will increase as the strip-road spacing decreases because there will be a greater volume of wood to extract in the first thinning and because more efficient methods can be employed. The most significant loss is due to clear cutting, especially for G24 sites where it will take the trees along the strip-road edges a long time to benefit from the exposed strip-road area. Conversely, when the site has a high quality index, the trees along the strip-road edges have the capacity to respond quickly to the establishment of strip roads. In sites with the lowest quality index, the loss attributable to clear cutting will be lower in absolute terms, since the increment in the stand is low in any case. The more passes made by machines along a given road, the deeper will be the tracks. When the strip roads are widely spaced with a good bearing capacity, the tracking loss, on the other hand, will be offset by the fact that the strip roads will have a lower aggregate length per hectare. To some extent the same reasoning applies to losses due to windthrow along the strip-road edges. However, a larger aggregate road length per hectare, with strip roads spaced close together, will have greater significance. Purely mechanical damage ("tree damage" in Table 7) carries little weight in the calculation, especially for pine.

If we look for the optimum "net result" in the table, we will find the most suitable strip-road spacing for the site quality index concerned. Different indices have different values in the "net result" column. However, this type of comparison between the different site quality indices is not really of interest, since the reasoning is marginal, with future reductions in the net value of the cut being determined.

We have made similar calculations for all six indices, using assumed interest rates of 0 and 5%. With interest at 5%, a close strip-road spacing should generally be used. At 0% interest, the road spacing should be between 30 and 70 m.

With ground of poor bearing capacity (ground condition class 4) deeper tracks will occur, as is shown in Table 6. Although it is true that the wider the strip-road spacing, the deeper will be the tracks, the aggregate road length per hectare will be lower. Consequently, losses due to tracks and windthrow will be offset by an increase in the strip-road spacing. The indications concerning the suitability of different strip-road spacings are consistent with those obtained in respect of good ground bearing capacity.

Practical Conclusions

We have now advanced far enough to be able to draw practical conclusions (Figs 9 and 10). Some of the site quality indices, for example T18, depart from the "optimum curve" (the broken line) on the graph. An uncertainty zone is also included, with the level of uncertainty corresponding to around SKr 250/ha in the net result.

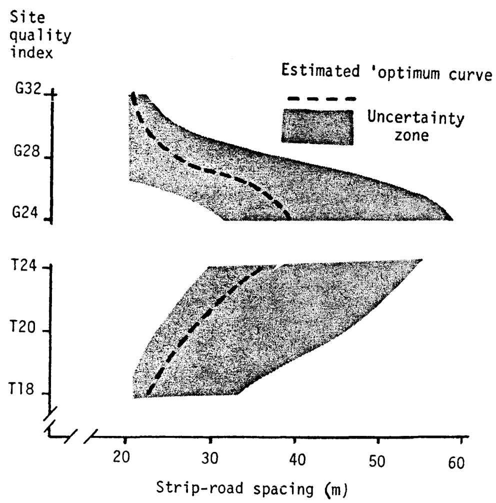
With an interest rate of 5%, the optimum curve is slightly displaced to the left. The method employing forwarders with long booms is apparently the appropriate technique for an interest rate of 3%. At 0% interest, the strip-road spacing should be greater than 25 m. To be assured of a satisfactory silvicultural outcome in the future, winches should be employed at 0% interest.

TABLE 6—Other assumed parameters in the motor-manual methods

System	Strip-road spacing (m)	Road width (m)	Damaged residual trees (%)	Track depth (cm)	
				Good bearing capacity	Poor bearing capacity
Motor-manual shortwood method with short boom	20	4.0	4	3.0	5.0
Motor-manual shortwood method with 10-m boom	30	4.0	5	3.8	5.9
Motor-manual shortwood method with 15-m boom	40	4.2	6	4.3	6.6
Motor-manual shortwood method with winch	70	4.4	3.5	4.9	7.6

TABLE 7—Cost and revenue items in motor-manual systems. Site quality indices G32, G24, and T18. Assumed interest rate 3%. Good ground bearing capacity

Site quality index	Motor-manual shortwood method	Road spacing (m)	Net result (SKr/ha)	Logging surplus loss in first thinning (SKr/ha)	Loss (SKr/ha) due to:			
					Strip-road cutting	Tracks	Windthrow	Tree damage
G32	Short boom	20	40	1010	660	80	160	70
	10-m boom	30	–30	720	460	100	100	90
	15-m boom	40	–250	430	400	100	80	100
G24	Short boom	20	–70	1650	1570	20	90	40
	10-m boom	30	130	1340	1070	20	60	60
	15-m boom	40	120	1090	830	20	50	70
	Winch	70	–60	570	540	20	30	40
T18	Short boom	20	100	460	340	10	10	0
	10-m boom	30	–90	280	330	10	20	10
	15-m boom	40	–150	150	270	10	10	10
	Winch	70	–560	–360	180	10	10	0



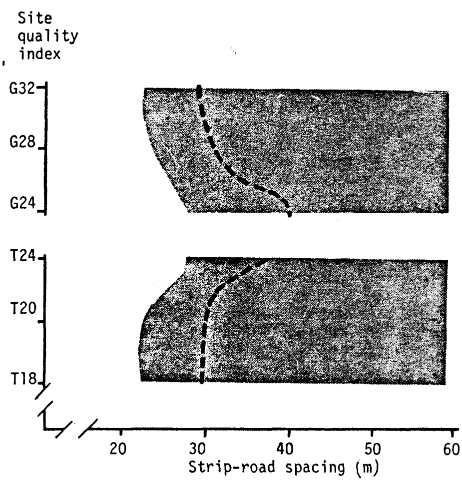


FIG. 9 (left)—Suitable strip-road spacing for different site quality indices. (Motor-manual methods. Assumed interest rate 3%).

FIG. 10 (right)—Suitable strip-road spacing for different site quality indices. (Motor-manual methods. Assumed interest rate 0%).

MECHANISED METHODS

A Standardised Example

The following logging systems incur the lowest costs in conjunction with the respective strip-road spacing. It is assumed that all the systems incorporate motor-manual directional felling away from the strip roads.

Strip-road spacing (m)	*Bunching and processing*
20	10-m boom on limber-bucker
30	Separate bunching machine with 15-m out-reach and a limber-bucker
40	Winch and limber-bucker
70	Winch and limber-bucker

Under Swedish conditions, mechanised systems are less expensive than motor-manual systems when the diameter of the cut trees in spruce stands is greater than 10–12 cm. In pine stands the limit is shifted upwards by about 0.5 cm. A greater variation in diameter enhances the competitiveness of the motor-manual systems. In the motor-manual systems, it is possible to increase the strip-road spacing from 20 m to 30 or 40 m without incurring any appreciable increase in cost. A similar increase in the strip-road spacing in mechanised systems would be more expensive.

The analysis (Fig. 11) advocates a relatively close strip-road spacing at an assumed interest rate of 3%. However, a move towards wide strip-road spacing is clearly indicated.

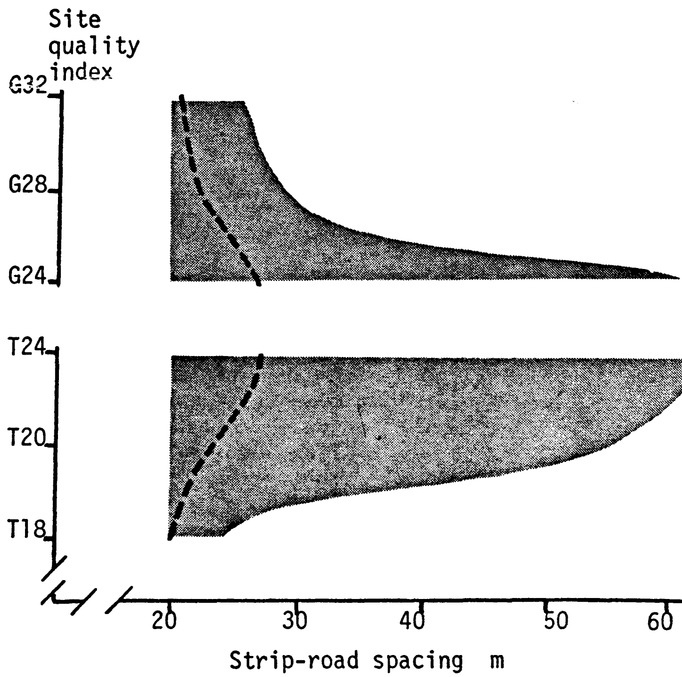


FIG. 11—Suitable strip-road spacing for different site quality indices. (Mechanised processing. Assumed interest rate 3%).

Tentative Practical Conclusions

Our experience of thinning systems in which a strip-road spacing of 20 and 30 m is used is extremely limited.

Another vitally important factor is the question as to whether or not one can achieve the desired strip-road spacing when bunching is carried out exclusively by machines equipped with booms. In practical operation it is highly likely that the desired strip-road spacing will have to be reduced because of irregularities in the stand such as areas of waste ground and stand edges. Thus, the losses due to the establishment of strip roads will increase, and the spacing indicated in Fig. 11 will constitute an unduly favourable view in respect of a dense strip-road network. If we assume that the 20-m spacing will become 17 m, and that 30 m will become 26 m, the "optimum curve" in Fig. 11 will be displaced quite considerably to the right in respect of G24 and T24 site quality indices.

To cope with a strip-road spacing of 30 or 40 m, the logging system depicted in Fig. 12 could be used. "Extended width" felling combined with a limber-bucker with long boom appears to be an interesting method, since the felling work is simplified and the strip-road spacing increased. Unfortunately it is not possible to make a detailed analysis since our knowledge of the costs involved is far too limited. Pending a thorough assessment of this method it would be advisable to employ winches and smaller-duty limber-buckers for mechanised processing on sites with intermediate quality indices. On sites with a higher quality index, and especially those where the ground roughness conditions are favourable, one can endeavour to reduce the strip-road width to about 3.5 m, to employ a narrow strip-road spacing, and to use forwarders and smaller limber-buckers specially designed for thinnings (i.e., machines with low ground surface pressure and able to operate in confined quarters).

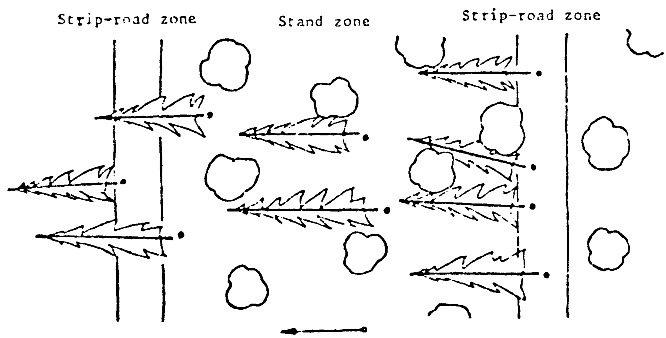


FIG. 12—Example of a simple thinning system in which slightly less than the tree length is used to increase the strip-road spacing. This system has been called "extended width" felling.

The question as to whether forwarders should be large or small has always been keenly debated. The problems involved are illustrated in Table 8. We assume that we have three types of forwarders with different road-width requirements and which create tracks of the specified depths on ground with poor bearing capacity. The assumed strip-road spacing is 20 m.

TABLE 8—Specifications of three types of forwarders

Size	Payload (tonnes)	Wheel assembly front	Tracks	Depth of tracks (cm)	Road width (m)
Small	7	Bogie	Exact*	3	3.5
Medium	9	Single-axle	Conventional†	6	4.0
Large	11	Single-axle	Conventional	6	4.5

* Rear wheels follow the front wheel tracks through a curve.

† Rear wheels do not follow the front wheel tracks through a curve.

If we consider the net values, we can calculate at how much lower cost per cubic metre the medium-sized and the large forwarders must be able to extract the wood, compared with the small forwarder, in order to obtain the same overall net result (due consideration also having been given to the biological losses).

From Table 9 we can see that at an assumed interest rate of 3%, the small forwarder is justifiable on sites with intermediate and high quality indices. At an interest rate of 5%, the small forwarder would be viable only in respect of the highest quality index. However, at an interest rate of 0% the small forwarder would be competitive on all sites.

TABLE 9—Amount (SKr/m^3) by which the medium-sized and large forwarders must be able to operate at less than the small forwarder to obtain the same net result on sites with different quality indices. Assumed rate of interest 3%

Site quality index	Forwarder	
	Medium-sized	Large
G32	5.50	8.80
G24	3.70	6.30
T18	1.50	2.40

In the forestry and energy sectors, where the planning horizons are extremely long range, low interest rates of between 3 and 5% are generally employed. In the forestry sector there are even those who would advocate a zero interest rate since they regard better silviculture as the maintenance of a going concern and not as an investment; after all, sustained yield forestry is a statutory requirement in Sweden. Nonetheless, the rate of interest is useful when the priority of various activities is being assessed.

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