Considering Overhead Costs in Road and Landing Spacing Models

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ABSTRACT

Existing road and landing spacing models assume that spacing affects only the costs of road construction and skidding. However, costs that are independent of production and fixed on the basis of time will vary with spacing when specified on a "per-unit-volume produced" basis and therefore should be considered in the model. Costs of this nature are labeled overhead, and considering these costs in the model will lower total costs. The relationship of overhead costs to spacing follows the same pattern as the skidding costs and can be added to the cost of owning and operating the skidder in the model. Overhead costs were considered in models pertaining to three unique sets of conditions: skidding to roadside with a single road standard; skidding to roadside with two road standards; and skidding to a landing. In all cases, considering overhead in the model lowered total cost and reduced road spacing. Actual cost savings will depend on harvest conditions but can be significant.

Key Words: *Road planning, road spacing, economic models, costs, harvesting*

INTRODUCTION

The spacing of forest roads can have a profound effect on the cost of harvesting and transporting wood. If roads are spaced too closely, the cost of building the roads will be prohibitive. If roads are spaced too far apart, the time required to skid wood to roadside or to a landing will be prohibitive. The basic layout of this problem is presented in Figure 1. The objective of most road spacing models is to define, for a given system, the road spacing that will result in minimum total cost per unit of volume produced.

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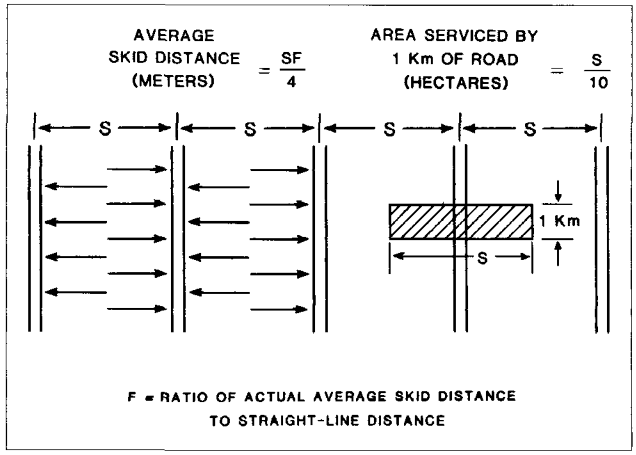

Figure 1. Basic layout of the road spacing problem.

Formulating a road spacing model consists of expressing all relevant costs as a function of road spacing, adding these together, and solving for the minimum of this total relevant cost function. Different harvesting situations require different road spacing models because of the mathematical relationships that characterize the situation. Therefore, it is important to state the assumptions that go along with the model so they will not be misapplied. This paper will analyze some of the basic cost relationships that exist in the optimization of road spacing, then apply these to several harvesting and transport situations.

ANALYSIS OF RELEVANT COSTS

Relevant costs are costs in the system that are either directly or indirectly influenced by changes in road spacing. The objective of this analysis is to minimize the cost of producing wood (on a per-unit-volume basis) by controlling road spacing. Therefore, all relevant costs must be specified on a per-unit-volume basis as a function of road spacing.

Costs Directly Related to Road Spacing

The most obvious cost that varies with road spacing is the cost of building roads. Spacing roads closer together on a given area increases the number of roads constructed, which increases the road cost per unit of wood volume removed from that area. This relationship is shown graphically in Figure 2.

Road maintenance is another cost factor that is directly influenced by road spacing. The cost of maintaining roads increases in direct proportion to

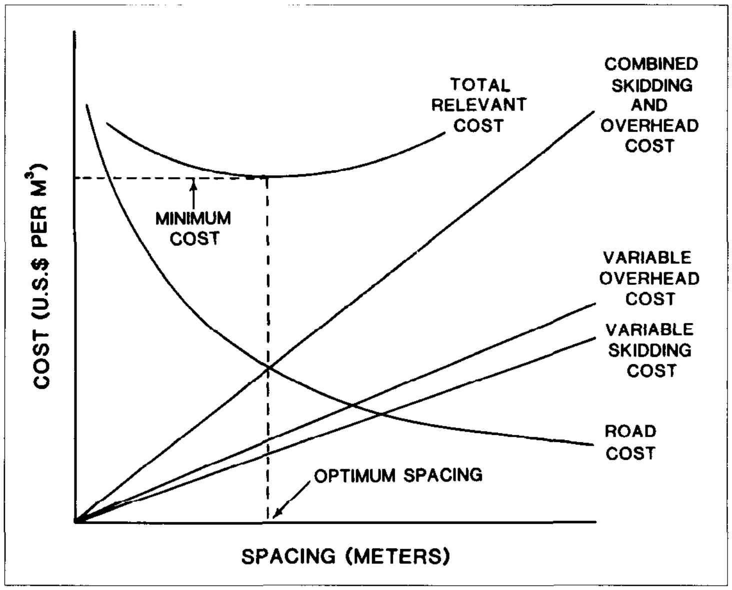

Figure 2. Relevant costs and the optimum road spacing.

an increase in the total road length resulting from closer spacings. However, this effect may be negated by the proportionate reduction in required frequency of maintenance. Road damage (and therefore road maintenance) depends heavily on the number of truck passes over the road. Less frequent maintenance is required for closely spaced roads because there will be proportionately fewer truck passes on each road. These opposing influences should make the road maintenance cost essentially independent of road spacing.

The cost of transporting timber over the road depends on the distance traveled. This distance does not change significantly with road spacing and is not considered a relevant cost. Therefore, the cost of road construction is the only cost in the system directly affected by road spacing. Other system costs are indirectly affected by road spacing because of their sensitivity to production.

Costs Related to Road Spacing Through Production

The most obvious cost related to road spacing through production is the skidding cost per unit of volume produced. The average skidding distance varies in direct proportion to the road spacing. This causes a proportionate change in the distance-dependent skidding time and hence the productivity of the skidder. The skidding cost per unit of time (i.e., the machine rate) does not vary with road spacing. This is essentially a fixed cost. However, when this cost per unit time is divided by the productivity per unit time (which does vary with road spacing), the result is a skidding cost per unit of volume that is sensitive to road spacing. Figure 2 illustrates this skidding cost relationship.

The effect of this change in productivity on other costs in the system is less obvious. Assuming a productive balance is maintained in the system (maintaining balance is a required assumption in road spacing models; otherwise, attempts to optimize costs through road spacing would be futile), the productivity of the system will vary with road spacing in the same way as the skidding productivity. This relationship causes an entire category of costs to be indirectly related to road spacing. Any system cost that is not tied to a particular productive operation (i.e., felling, processing, loading, etc.) and is fixed on the basis of time will vary with road spacing when specified on a per-unit-volume basis.

Using an example to demonstrate this concept, consider a shop building costing about US$250 per month or US$3,000 per year that is dedicated to serving a single harvesting system. This cost will remain the same, regardless of the volume of wood produced by the system in that year. If the average road spacing for that year is 300 meters, the system productivity might be 50,000 m^3 per year, resulting in a shop building cost of US$0.06 per m^3. If, however, the roads were spaced at 600 meters, the system productivity might drop to 30,000 m^3 per year, resulting in a shop building cost of US$0.10 per m^3. Because this type of cost is independent of production, it is sensitive to changes in production when specified on a per-unit-volume basis.

Costs that are fixed on the basis of time and independent of production will be referred to as overhead costs throughout this paper. Examples of overhead costs are administration, bookkeeping, supervision, procurement, shop facilities, maintenance equipment, fuel equipment, machine transport equipment, and inventory. These costs are specific to each individual organization and, therefore, a general calculation method cannot be offered. Each cost must be analyzed and only the portion fixed in time should be considered overhead. Include only those overhead costs that are directly tied to the harvesting system in question. Do not include an overhead contribution in the machine rate of the skidder to avoid counting this portion twice. Because the overhead costs are sensitive to the productivity of the system, they follow the same relationship as the skidding cost (Fig. 2).

System costs that are tied to a productive operation or that vary with productivity (such as stumpage, felling, etc.) do not change significantly with changes in road spacing (on a unit-volume basis) and therefore are not considered relevant costs. Of the three relevant costs identified, the road construction and skidding cost relationships have been recognized in virtually all prior road spacing model development. Overhead costs have not been previously considered. Therefore, the remainder of this paper will address how the inclusion of overhead costs influences several existing road and landing spacing models.

SKIDDING TO ROADSIDE ON FLAT GROUND

The classical road spacing model was formulated by Matthews [5] to determine the road spacing at which the sum of the road construction and skidding costs is a minimum. Lussier et al. [4] further refined this model by specifying the skidding cost in its basic form and adding a factor for sinuosity. Assuming that roads are to be laid out parallel on flat terrain with uniform timber and two-way skidding to roadside, the classical road spacing model is as follows:

Total relevant cost = 10R/SV + TFSC/120U (1)

Optimum road spacing (s) =
(1200RU/TFCV)1/2 (2)

where:
R = road construction cost (US$/km)
S = road spacing (m)
V = timber volume to be removed (m^3/ha)
T = variable skidding time (min/m)
F = sinuosity factor (proportion of actual travel distance to straight-line distance)
C = cost of owning and operating the skidder (US$/SH)
U = average skidder load (m^3)

This model accounts only for the costs of roads and skidding based on the assumption that these are the only costs that vary with spacing. Considering overhead costs as discussed previously results in the following model:

Total relevant cost =
10R/SV + TFSC/120U + TFSQ/120U (3)

Optimum road spacing (s) =
(1200RU/TFV(C+Q))1/2 (4)

where:
Q = overhead costs (US$/SH)

Adding these costs to the analysis will lower the optimum road spacing. The magnitude of this difference will depend on the amount of overhead involved and the harvest conditions (Fig. 3). A comparison of the two approaches using the parameters of a conventional forwarding operation in a northern hardwood poletimber thinning shows that including overhead reduces the optimum road spacing (Table 1). For the conditions given, minimum cost for the classical model occurs at a road spacing of 409 meters. In contrast, minimum cost for the latter approach occurs at a road spacing of 274 meters. This closer spacing results in a savings of US$0.23 per m^3 for this example. Actual differences will depend on harvest conditions.

TWO ROAD STANDARDS RUNNING PERPENDICULAR

In a typical forest access system, timber is skidded to low-standard, temporary roads for further transport by truck. These low-volume, temporary roads normally lead to higher standard, permanent

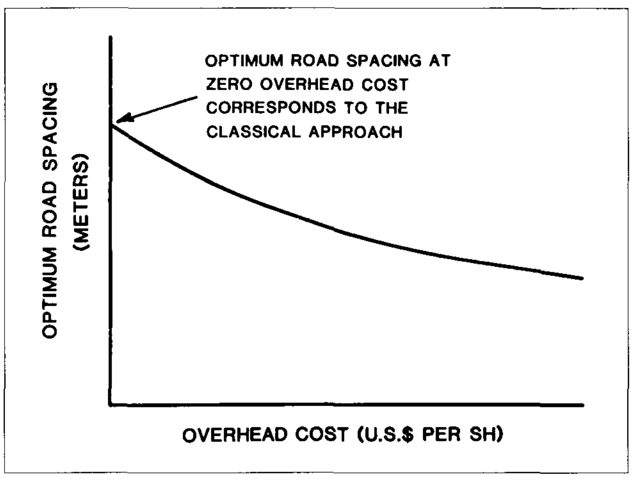

Figure 3. Optimum road spacing as a function of overhead costs.

Table 1. Costs per unit of volume produced for roads, skidding, and overhead as a function of road spacing.[a]

Assumptions:

Skidder cost (C) = US$28.50/SH[b]
Sinuosity factor (F) = 1.25
Skidder load size (U) = 4.8 m3
Variable skidding time (T) = 0.033 min/m

Road cost (R) = US$4100/km
Timber volume (V) = 120 m3/ha
Overhead costs (Q) = US$35/SH

Road spacing (meters)	(1) Road cost (US$/$m^3$)	(2) Variable skid cost (US$/$m^3$)	Total (1)+(2) (US$/$m^3$)	Variable overhead costs (US$/$m^3$)	Total (US$/$m^3$)
150	2.28	0.31	2.59	0.38	2.97
180	1.90	0.37	2.27	0.45	2.72
210	1.63	0.43	2.06	0.53	2.59
240	1.42	0.49	1.91	0.60	2.51
270	1.26	0.55	1.81	0.68	2.49
300	1.14	0.61	1.75	0.75	2.50
330	1.04	0.67	1.71	0.83	2.54
360	0.95	0.74	1.69	0.90	2.59
390	0.88	0.80	1.68	0.98	2.66
420	0.81	0.86	1.67	1.05	2.72
450	0.76	0.92	1.68	1.13	2.81
	Optimum (meters)		Matthews' model 409		Including overhead 274

[a] These figures are based on the results of a conventional forwarding operation thinning a northern hardwood poletimber stand in Tomahawk, Wisconsin, February 1985.
[b] SH = scheduled hours.

roads (Fig. 4). In this situation, relationships must be developed for the optimum spacing of both temporary and permanent roads. Two additional costs must be included in this analysis: the cost of hauling on temporary roads and the cost of building permanent roads. Continuing the work of Bowman and Hessler [2], Baldwin et al. [1] developed a mathematical model that applies to this situation. Assuming that roads are to be laid out parallel on flat terrain with uniform timber and two-way skidding to roadside, Baldwin's road spacing model is as follows:

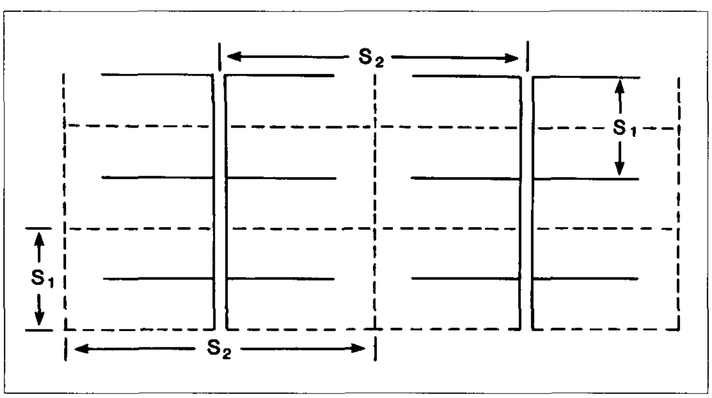

Figure 4. Two road standards running perpendicular, skidding to lower class road from both sides.

Total relevant cost =
10R1(S2-S1)/S1S2V+TFS1C/120U+ (5)

10R2/S2V + H(S2-S1)/2000WP

s1 = ((10R1/V)/(TFC/
120U-H/2000WP))1/2 (6)

s2 = ((10(R2-R1)/V)/(H/2000WP))1/2 (7)

where:
S1 = spacing of temporary roads (m)
s1 = optimum spacing of temporary roads (m)
S2 = spacing of permanent roads (m)

s2 = optimum spacing of permanent roads (m)
R1 = cost of temporary roads (US$/km)
R2 = cost of permanent roads (US$/km)
H = cost of owning and operating the truck (US$/SH)
W = average truck load (m^3)
P = average truck speed over temporary roads (km/hr)

When overhead costs are included in this model, the relationship for permanent road spacing remains the same. However, the relationship for low-volume road spacing becomes:

$$s1 = ((10R1/V)/(TF(C+Q)/120U-I I/2000WP))1/2 \quad (8)$$

For normal ranges of each variable in this model, the influence of haul cost on the spacing of temporary roads will be very small. As the haul cost approaches zero, equation 8 approaches the relationship given in equation 4.

As before, adding overhead costs to the analysis will reduce the optimum spacing of low-volume roads. Assuming the same variable values as the first example along with an hourly truck cost of US$50, an average truckload size of 50 m^3, and an average travel speed of 8 km/hr on temporary roads, the optimum spacing of temporary roads is 416 meters when overhead is neglected and 276 meters when overhead is considered. Again, considering overhead in the model will reduce costs by about the same amount as the first example.

SKIDDING TO A LANDING

Skidding trees to a landing is common in the United States (Fig. 5). Optimizing spacings in this case is difficult because of the complex relationship for average skidding distance and the need to solve for two unknowns. Matthews [5] first formulated this problem and, due to its complexity, suggested an iterative approach to the solution. This method is inaccurate and time-consuming, however. Corcoran [3] used the mathematically correct relationship for average skid distance developed by Suddarth and Herrick [7] to solve for optimum road and landing spacing. These solutions were independently verified by Peters [6] using dimensionless ratios. Peters' method represents an easy-to-use procedure employing tabulated dimensionless ratios to calculate optimum road and landing spacing. Assuming roads are to be laid out parallel on flat terrain with uniform timber, two-way skidding, and adjacent landings, Peters' method of solution is as follows:

Total relevant cost =

$$10R/SV + TFDC/30U + 10{,}000G/LSV \quad (9)$$

where:
D = average skidding distance (m)
G = cost per landing (US$)
L = landing spacing (m)
l = optimum landing spacing (m)

Procedure:

1) Determine the quantities R, V, T, F, C, U, and G.

2) Calculate S = (300RU/TFCV)1/2, L = (300,000GU/TFCV)1/3, and S/L.

3) Use table 2 to determine s/L and l/s given S/L.

4) Calculate the optimum road spacing s = (s/L)L.

5) Calculate the optimum landing spacing l = (l/s)s.

When overhead costs are considered, the only part of the procedure that will change is to substitute C + Q for C when calculating S and L:

S = (300RU/VTF(C+Q))1/2
L = (300,000GU/VTF(C+Q))1/3

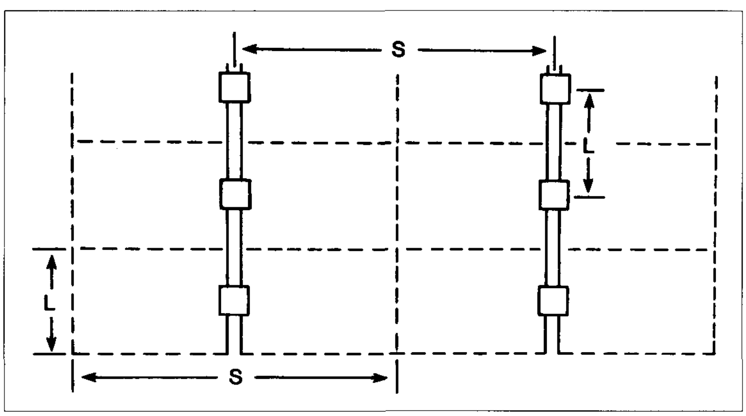

Figure 5. Skidding to a landing from both sides of the road.

Table 2. Nondimensional solutions for optimum spacings of roads and landings [6]

S/L	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
					s/L					
0	1.735	1.748	1.790	1.857	1.945	2.050	2.170	2.300	2.440	2.587
1	2.742	2.901	3.063	3.231	3.402	3.573	3.749	3.927	4.107	4.286
2	4.470	4.653	4.837	5.023	5.209	5.397	5.585	5.774	5.966	6.155
3	6.344	6.534	6.728	6.920	7.113	7.306	7.499	7.693	7.887	8.078
4	8.272	8.466	8.661	8.856	9.051	9.246	9.441	9.637	9.833	10.028
5	10.224	10.420	10.617	10.813	11.010	11.206	11.403	11.600	11.797	11.994
6	12.195	12.392	12.589	12.787	12.984	13.182	13.380	13.577	13.775	13.973
7	14.171	14.369	14.567	14.765	14.963	15.161	15.359	15.557	15.756	15.954
8	16.152	16.351	16.549	16.748	16.946	17.145	17.343	17.542	17.740	17.939
9	18.138	18.336	18.535	18.734	18.933	19.131	19.330	19.529	19.728	19.927
10	20.126	20.325	20.524	20.723	20.922	21.121	21.320	21.519	21.718	21.917
11	22.116	22.315	22.514	22.713	22.912	23.111	23.311	23.510	23.709	23.908
12	24.107	24.307	24.506	24.705	24.904	25.104	25.303	25.502	25.702	25.901
13	26.100	26.300	26.499	26.698	26.898	27.097	27.296	27.496	27.695	27.894
14	28.093	28.293	28.493	28.692	28.891	29.091	29.290	29.490	29.689	29.889
15	30.088	30.288	30.487	30.687	30.886	31.086	31.285	31.485	31.684	31.884
1632.084	....	....	....	.....s/L -> 2 S/L						
					l/s					
0	1.000	0.991	0.960	0.916	0.863	0.807	0.751	0.698	0.648	0.603
1	.561	.524	.490	.459	.432	.407	.384	.364	.345	.328
2	.312	.298	.285	.273	.261	.251	.241	.232	.224	.216
3	.208	.201	.195	.189	.183	.177	.172	.167	.163	.158
4	.154	.150	.146	.143	.139	.136	.133	.130	.127	.124
5	.121	.119	.116	.114	.112	.109	.107	.105	.103	.101
6	.100	.098	.096	.095	.093	.092	.090	.089	.087	.086
7	.085	.083	.082	.081	.080	.079	.077	.076	.075	.074
8	.073	.072	.071	.070	.069	.069	.068	.067	.066	.065
9	.065	.064	.063	.062	.062	.061	.060	.060	.059	.058
10	.058	.057	.056	.056	.055	.055	.054	.054	.053	.053
11	.052	.051	.051	.051	.050	.050	.049	.049	.048	.048
12	.047	.047	.047	.046	.046	.045	.045	.045	.044	.044
13	.043	.043	.043	.042	.042	.042	.041	.041	.041	.040
14	.040	.040	.040	.039	.039	.039	.038	.038	.038	.038
15	.037	.037	.037	.036	.036	.036	.036	.035	.035	.035
16	.035	...				l/s -> 0				

The ratios given by Peters (Table 2) will remain valid. Adding the overhead costs to the skidder cost in these models will result in a more accurate calculation of optimum road and landing spacing. Considering overhead costs in the analysis will lower the optimum road and landing spacings. When the two methods are compared using information for a cable skidding operation (Table 3), the total cost per cubic meter is US$0.08 greater when overhead is neglected than when it is considered. Actual differences will depend on the conditions encountered by the operation.

The effect of overhead costs on the optimum spacing of roads and landings has been demonstrated for three harvesting situations. This approach is considered to be more appropriate than the classical model to minimize wood cost. From a practical point of view, variation in productivity and cost for a given set of conditions will cause optimum spacings to vary. On the average, however, the model that includes overhead should result in the lowest cost.

Table 3. Effect of overhead costs on road and landing spacing for a cable skidding system.

Assumptions:

Timber volume (V) = 120 m^3/ha	Variable skidding time (T) = 0.0082 minutes/m
Road cost (R) = US$4100/km	Sinuosity factor (F) = 1.25
Landing cost (G) = US$75/landing	Skidder cost (C) = US$35.00/SH[a]
Skidder load size (U) = 4.8 m^3/cycle	Overhead costs (Q) = US$35.00/SH

		Classical approach	Considering overhead
Road coefficient:	S	370.3	261.8
Landing coefficient:	L	135.9	107.8
	S/L	2.725	2.428
	s/L	5.822	5.262
Optimum road spacing:	s (meters)	791	567
	l/s	0.230	0.258
Optimum landing spacing:	l (meters)	182	146
Average skidding distance:	D (meters)	208	151
Total cost[b] (US$/$m^3$)		1.51	1.43

[a] SH = scheduled hour.
[b] Distance-dependent costs only.

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