Austro2007/FORMEC´07: Meeting the Needs of Tomorrows´ Forests – New Developments in Forest Engineering, October 7 – 11, 2007, Vienna and Heiligenkreuz – Austria

OPTIMUM ROAD SPACING OF FORWARDING OPERATIONS: A CASE STUDY IN SOUTHERN AUSTRIA

Mohammad Reza Ghaffarian, Karl Stampfer
Institute of Forest Engineering
Department of Forest and Soil Sciences
University of Natural Resources and Applied Life Science Vienna
Peter-Jordan-Strasse 82/3, A-1190 Vienna, Austria
karl.stampfer@boku.ac.at, ghafari901@yahoo.com

John Sessions
Department of Forest Engineering, College of Forestry
Oregon State University
204 Peavy Hall, Corvallis, OR 97331-5706, USA
john.sessions@oregonstate.edu

Keywords: forwarder, production, cost, road density, road spacing

Abstract: *Forwarders are common machines in the cut to length system. The optimum road spacing is important factor in logging planning which was studied in this paper. The regression model for predicting the time of forwarding was developed using 40 working cycles of Ponsse Bufallo Dual forwarder which were collected in Steiermark in Southern Austria. A mathematical model was developed to minimize the sum of roading and forwarding costs. Based on minimizing the sum of the roading and forwarding costs, for one way skidding, the optimum road spacing was estimated as 503 m and road density of 19.9. The optimal average forwarding distance was estimated as 340 m while the actual average forwarding distance was 169 m.*

1. Introduction

Optimum road density is an important factor to help forest engineers optimize the harvesting costs using a suitable forest road network.

In Austria, road density is 49.1 m/ha for small forests, 41.8 m/ha for private forests, 33.7 m/ha for federal forests and average of road density is 45 m/ha (www.bfw.ac.at). Matthews (1942) developed a model to define optimum road spacing based on minimizing the total cost of skidding and roading from the viewpoint of a landowner. Major variables are removals per ha, skidding cost, road costs and landing costs. Many researchers have used and extended Matthews' model. Additional factors influencing optimum road spacing were identified by several researchers.

Price of products, taxation policies, landing costs, overhead costs, equipment opportunity costs, width of road and the size of landing, skidding pattern, profit of logging contractor, slope and topography and soil disturbance have different influence on ORS (Thompson,1998; Sessions ,1986; Peters, 1978; Thompson, 1992; Yeap and Sessions,1988; Wenger, 1984; Sessions and Boston,2006; Bryer,1983; Liu and Corcoran, 1993; Segebaden ,1964; Heinimann,1997 and Akay and Sessions,2001). Stueckelberger et al (2006) considered roading cost, ecological effects and suitability for cable yarding landings in their automatic road-network planning in Switzerland.
Some researchers studied the optimum road density (RD). Picman and Pentek (1998) calculated RD of 14.7 m/ha for ground based skidding system using forest tractors in Croatia. In the Northern forests of

Iran, the case studies on selection cuttings and skidding operations showed optimum road density ranged from 9 to 28 m/ha for different areas (Mostafanejad, 1995; Eghtesadi, 2000; Lotfalian, 2001 and Naghdi, 2004). In two and three-stage cable logging systems, three-stage yarding provided cost savings and a substantial increase in road spacing once critical road costs were exceeded (Howard and Tanz, 1990).

Regarding to forwarding operation, the study of short-wood forwarding in Northern Spain indicated the road density for a purpose-built forwarder is 6 m/ha (Spinelli et al., 2003). Akay and Sessions (2001) developed the model which identified whether the cumulative rut depth caused by a forwarder exceeds the maximum allowable rut depth at the point of prior to the spacing that minimizes the cost, and if so, the rut depth would limit the road spacing. For their assumed conditions, optimum spacing was 600 m for a large forwarder.

Forwarders are common machines in cut-to-length systems. Their productivity has been studied in different areas with the range of 8 to over 20 tones/SMH, depending on the model and working conditions (UK Forestry Commission, 1998; Gullberg, 1997; Martin dos Santos et al. 1995; Saunders, 1996; Geolia et al. 1999; Horvat et al. 1990).

The optimum road spacing for forwarders has not been studied in Southern Austria. Due to increasing of forwarding system in the forest of central Europe, it is necessary to study production and cost of this system. The goals of this study is developing a model to predict the forwarding time and cost and determining optimum road spacing based on minimization of forwarding and roading costs for a single entry, landings at roadside, and negligible landing costs. The effect of harvesting volume on ORS is also studied in this paper.

2. Method of study

2.1. Site of study

The study was carried out in Weiz in Steiermark in southern Austria. In this area, the Ponsse Buffalo Dual forwarder was used in a thinning operation in a mixed stand of spruce, fir, larch and pine. The terrain slope was moderate (11%). The general stand and terrain characteristics are presented in Table 1.

Table 1: Description of study site

Stand area	2.27 ha
Slope	11%
Stand age	70-130 years
Stand density pre-harvest	1089 n/ha
Standing volume (without bark) pre-harvest	510.4 m^3/ha
Number of harvested trees	1073 n
Total harvesting volume	331.8 m^3
Tree volume	0.31 m^3
Harvesting percent	28.7 %
Number of trails	15
Length of trails	40-200 m
Time of harvesting	Spring

In the Dual concept of harvester- forwarder combination, known as the harwarder, (Figure 1), trees were felled; delimbed, topped, and bunched using the harvesting head of the harwarder in the planned trails, then the operator sets up the bunk for forwarding the logs. The grapple head is used to load the logs on to the bunk of the machine. The specifications for the harwarder are in Table 2.

Table 2: Specifications for the Ponsse Buffalo Dual harwarder

Measurements	
Length as a Harvester (mm)	8850 - 9150
Length as a Forwarder (mm)	9400 – 9950
Width (600/700 tires)(mm)	2670 – 2810
Ground clearance (mm)	690
Empty weight of Harvester (Kg)	15700
Forwarding	
Empty weight of forwarder (Kg)	16400
Load capacity (Kg)	14000
Loading area (m^2)	4.5 - 5.1
Length of loading cage (mm)	4040 - 4590
Extension(mm)	0-700
Harvesting capacity	
Harvesting head	Ponsse H53
Power (Kw)	45
Length (cm)	64
Felling diameter (cm)	52
Feed force (kN)	18
Feed speed (m/s)	0-4
Delimbing knives (number)	5
Opening (mm)	Max. 500
Cutting system	Ponsse Opti 4G
Techniques	
Motor	Mercedes-Benz OM906 LA
Power (Kw)	180
Torque (1400 U/min)	900 Nm
Working pump (cm^3)	190
Tractive force (kN)	180
Speed 1. /2. Gear (km/h)	0 – 9/ 0-28
Fuel tank volume (liter)	130 (400)

2.2. Data collection

Affenzeller (2005) used continuous time study method to determine the production rate of Ponsee Buffalo forwarder in downhill forwarding operation in Weiz. The typical work cycle included; loading, travel loaded, unloading and travel empty.

Variables included forwarding distance, piece volume, load volume and slope. Forty working cycles were collected.

Figure 1: Ponsse Buffalo Dual Forwarder preparing for forwarding mode

The system cost for forwarder was assumed to be 120 Euro/h (Affenzeller, 2005). The time data base was used to develop the time predicting model using multiple regression and stepwise method.

In the Steiermark area, the road construction costs ranged from 15 to 18 Euro/m and for road maintenance costs, between 1 to 4 Euro/m. Mean harvesting volume was about 100 m^3/ha with a mean DBH of 25 cm.

2.3. Road spacing

Road density is meters of road per hectare and road spacing is the distance between roads of network. There is road density or spacing which results in lowest roading and forwarding or skidding cost. This is optimal road density or spacing (Sundberg, 1976). To study the optimum road spacing, two methods have been presented in the past. The first was presented by Matthews (1942). The second method introduced by Sundberg (1976). Both of Matthews and Sundberg's formulas are based on minimization of costs and assume that forwarding cost varies linearly with distance (constant speed) and timber and loads are uniformly distributed. It is necessary to verify these assumptions for this case study.

Using the traveling time and traveling distance of time study data base, the velocity was calculated for different distances (Figure 2).

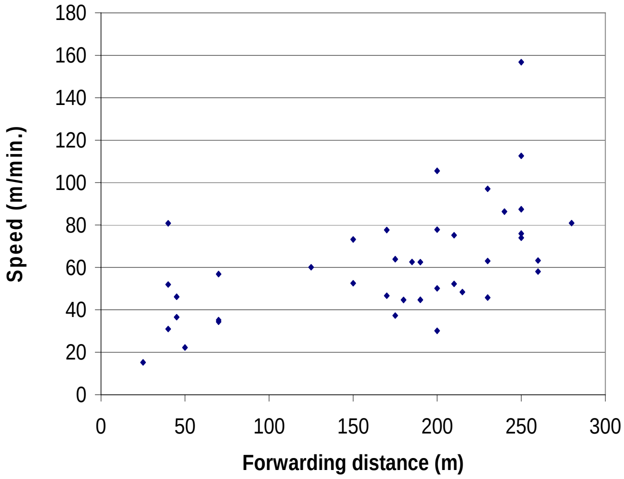

Figure 2: Speed for different distances from forwarding time study

Figure 2 shows that speed is not constant and increases with forwarding distance because larger slope at longer distances during the studied operations (Figure 4).

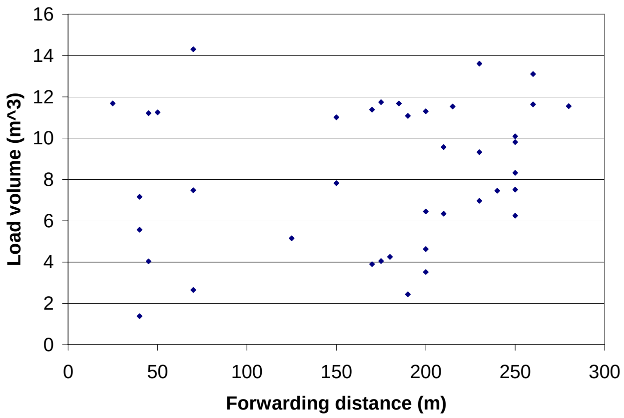

Figure 3: Distribution of logs along the forwarding distance

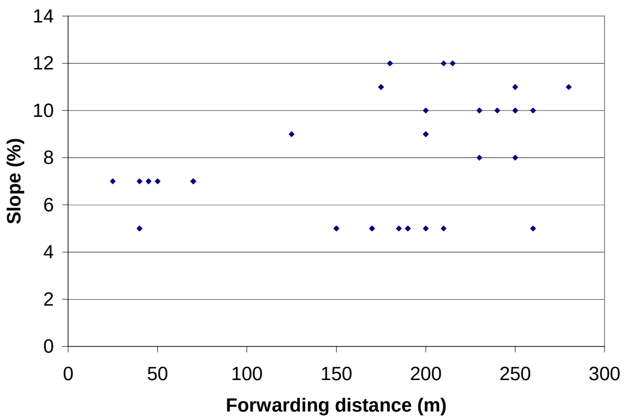

Figure 4: Distribution of slope of trail along the forwarding distance

Figures 2, 3 and 4 showed that the Matthew and Sundberg's formulas are not appropriate for this case study. Therefore we will use the other method to study ORS. In order to determine the optimum road spacing, the forwarding cost per m^3 is calculated through the time predicting model by changing forwarding distance between minimum and maximum forwarding distance observed within the time studies. This method allows the planner to understand the sensitivity of total road and forwarding cost to changes of road spacing. We have assumed that the unloading occurs at the junction of the forwarding trail with the road and that landing construction costs are negligible. We also assume that the roads will only be used for one entry.

Roading costs included a road construction cost of 16.5 Euro/m and road maintenance cost of 3.5 Euro/m (total 20 Euro/m).

In order to transfer forwarding distance to road density, the following formal (Segebaden, 1964) was used for one-way forwarding:

$$AFD = 2\times 2500.T\text{-}corr.V\text{-}corr/D \quad (1)$$

where AFD, D, T-corr and V-corr are the average forwarding distance (m), the road density (m/ha), the correction factor allowing for cases where skidding or forwarding trails are winding and do not always end at the nearest point on the road and the correction factor allowing for cases where the haul roads are winding, meet in junctions, terminate as dead-end roads are not equally spaced in the forest area.

The values of T-corr and V-corr range from 1 to 1.5 and 1 to 2 respectively. The value of 1.10 for T and 1.23 was used in this study (Sundberg, 1978).

Using the above formula, road density was calculated based on forwarding distance.

3. Results

The average production (based on free delay hours) was estimated as 14.94 m^3/h. The average load per trip was 8.25 m^3. The forwarding cost is estimated at about 8.03 Euro per m^3 considering hourly cost of 120 Euro per hour in 2005.

3.1. Forwarding Model

We assumed that forwarding time is a function of the variables including forwarding distance, piece volume and slope. Stepwise multiple regression using SPSS software was used to develop the time predicting model. In this method, if any variable has a significant effect on the Residual Mean Squares (RMS) of the model, it enters the model. The forwarding distance was only significant variable.

T (min/cycle) = 24.959 + 0.048 forwarding distance (m)

R^2=0.14, Adjusted R^2=0.11, Number of observation=40

This multiple correlation coefficient of 0.14 is interpreted as the 14% of total variability, which is explained by the regression equation.

The significant level of this ANOVA table (Table 3) shows that the model is significant at α= 0.05.

Table 3: ANOVA of model

	Sum of Squares	df	Mean Square	F	Sig.
Regression	552.629	1	552.629	6.193	.017
Residual	3390.863	38	89.233		
Total	3943.492	39			

The effect of forwarding distance on forwarding time was studied in Figure 5.

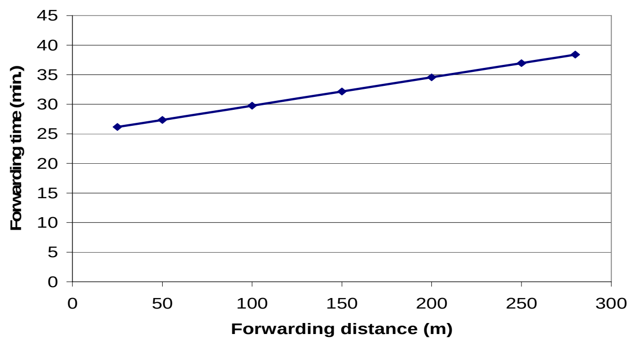

Figure 5: Effect of forwarding distance on forwarding time per trip

Increasing forwarding distance will increase forwarding time. Figure 6 presents the percent of elements of forwarding cycle. In Table 4, the summary statistics of parameters are presented.

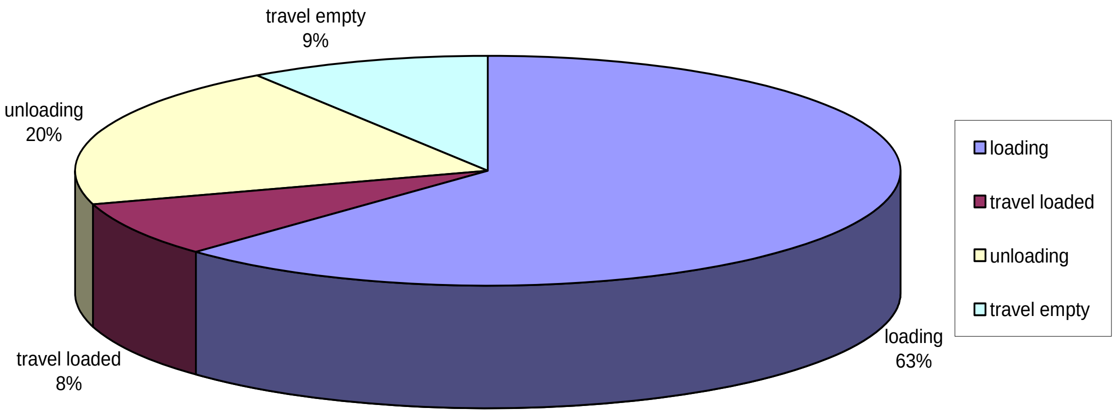

Figure 6: Percent of time in each element of the forwarding cycle

Table 4: Summary statistics of parameters

Parameter	Min.	Max.	Mean
Loading (min)	6.32	42.24	20.75
Loaded Travel (min)	0.35	4.48	2.57
Unloading (min)	0.97	15.32	6.69
Travel Empty (min)	0.4	10.71	3.12
Cycle time (min)	8.9	57.68	33.14
Distance (m)	25	280	169.25
Slope (%)	5	12	8
Load volume (m^3)	1.38	14.31	8.25
Piece volume(m^3)	0.049	0.133	0.098

3.2. Road spacing

Forwarding time was calculated for different forwarding distances using the model. Forwarding cost per m^3 was computed by multiplying forwarding time by hourly cost and dividing to average load as 8.25 m^3(Table 5).
Using a roading cost of 20 Euro/m and harvesting volume of 100 m^3/ha, road cost per m^3 was calculated. Then total cost is the sum of forwarding and roading costs (Figure 7).

Table 5: Forwarding cost per m^3 as a function of forwarding distance

Forwarding distance (m)	Forwarding time (min)	Forwarding cost (Euro/m^3)
30	26.4	6.4
50	27.36	6.63
100	29.76	7.21
150	32.16	7.80
200	34.56	8.38
280	38.4	9.31

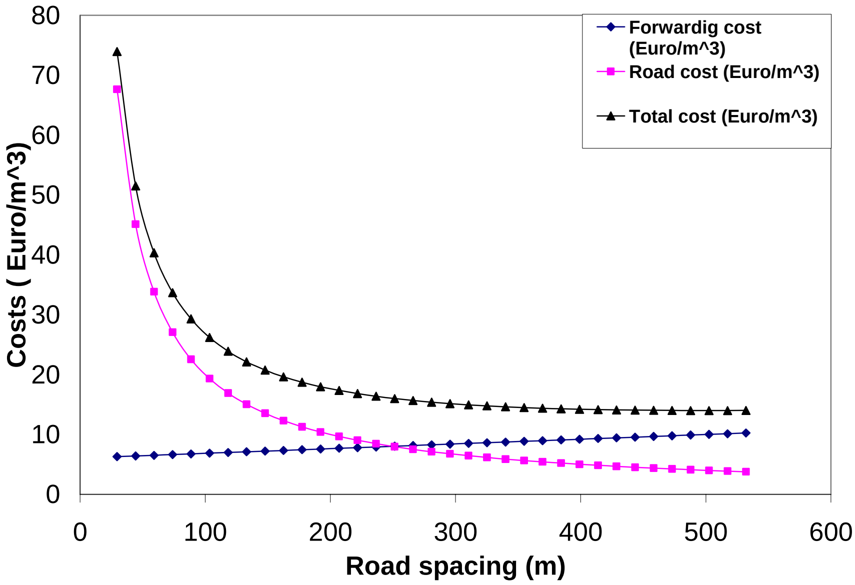

Figure 7: The total cost summary and road spacing for forwarder

Minimum total cost of 13.98 Euro/m^3 occurred when the road spacing is 503 m. So the optimum road spacing, considering harvesting volume of 100 m^3/ha and roading cost of 20 Euro/m, would be 503 m if one way forwarding is applied. The corresponding optimal road density and average forwarding distance are 19.9 m/ha and 340 m respectively. The optimal distance is out of the range of forwarding distance during this study.

3.3. Effect of load volume on ORS

Increasing the load volume will decrease the forwarding cost (Table 6). Maximum load capacity is 14000 kg (Table 2). Considering average wood density of 800 kg/m^3 for Fir, Spruce and Pine, maximum load capacity is estimated as 17.5 m^3.

If machine works always with maximum payload, the minimum total cost is about 8.3 Euro/m^3. The optimal road spacing, road density and forwarding distance would be 739 m, 13.5 m/ha and 500 m respectively.

Table 6: Forwarding cost per m^3 as a function of forwarding distance using a load of 17.5 m^3

Forwarding distance (m)	Forwarding cost (Euro/m^3)
30	3.02
50	3.13
100	3.4
150	3.68
200	3.95
280	4.39

Carrying full load led to increase the productivity and decrease the forwarding cost. It results to higher ORS. It is assumed that if machine works with maximum payload every day, the operating costs are constant if repairing fuel costs are not increased. However the next studies can test if the operating costs change by increasing the payload up to its maximum. It is also useful to study the effect of forwarding direction, slope and soil stability on optimum load size.

4. Conclusion

To achieve optimum road spacing, sum of forwarding and roading cost should be minimized. Minimization of total cost will help forest owner to achieve maximum profit and plan economical road network.

The work sheet created in Excel software, could be useful and easily applied by forest engineers to input data of different machine rates, production models, roading costs of different terrain and ground conditions in each logging area and different timber harvesting volumes.

The next researches can study the effect of soil disturbance on ORS can also be studied in future. The effect of load size on operating cost can be studied in future. The current study was carried out on downhill forwarding. Uphill forwarding can be studied in future to determine optimal road spacing for two-way forwarding.

5. References

Affenzeller, G. (2005). Integrierte Harvester-Forwarder-Konzepte Harwarder), MSc thesis, Institute of Forest Engineering, University of Natural Resources and Applied Life Sciences Vienna.

Akay, A. and J. Sessions. (2001). Minimizing road construction plus forwarding costs under a maximum soil disturbance constraint, The International Mountain Logging and 11th Pacific Northwest Skyline Symposium December 10-12, Seattle, Washington, USA, 268-279.

Bryer, J.B. 1983. The effects of a Geometric Redefinition of the Classical Road and Landing Spacing Model Through Shifting, Journal of Forest Science, 29(3), 670-674.

Eghtesadi, A. (2000), Study of transportation network and machinery in Vaz Forest Area, PhD Thesis, Azad University

Goglia, V., Horvat, D. and S. Sever. (1999). Technical characteristics and test of the forwarder Valmet 860 equipped with a Cranab 1200 crane. University of Zagreb, Faculty of Forest Sceince, Internal Report, Zagreb, 23.

Gulberg, T. (1997). Time consumption model of off-road extraction of shortwood. Institutionen foer Skogsteknik, Sveriges Lantbruksuniversitet, Uppsatser och Resultat 297, 29.

Heinimann, H.R. (1997). A computer model to differentiate skidder and cable-yarder based road network concepts on steep slopes, Journal of Forest Research (Japan) 3(1), 1-9

Horvat, D., Goglia, V. and S. Sever. (1999). Technical characteristics and test of the forwarder Timberjack 1410 and Timberjack 1710. University of Zagreb, Faculty of Forest Sceince, Internal Report, Zagreb.,.32.

Howard, A.F. and J.S.Tanz, 1990. Optimal spacing for multistage cable yarding operation, Canadian Journal of Forest Research, 20, 669-673.

http:// www.bfw.ac.at

Liu, S., and T.J.Corcoran, (1993). Road and landing spacing under the consideration of surface dimension of road and landings, Journal of Forest Engineering, 5(1), 49-53.

Lotfalian, (2001). Study of factors influencing optimum road density in Sangdeh-Mazandaran, PhD Thesis, Faculty of Natural Resources, Tehran University.

Martin dos Santos, S., Machado, C. and Leite, H. (1995). Techno-economical analysis of eucalyptus extraction with forwarder in flat terrain. Revista Arvore, Vicosa 19(2),213-227.

Matthews, D .M. 1942. Cost control in the logging industry. McGraw-Hill, New York. 374.

Mostafanejad, A. (1995). Study of cost production of skidder Timberjack 450 C and optimal length of skid trails, Master Thesis, Faculty of Natural Resources, Tehran University.

Naghdi, R. (2004), Study of optimum road density in tree length and cut to length system, Faculty of Natural Resources, University of Tarbiat Modarres.

Peters, P.A. (1978). Spacing of roads and landings to minimize timber harvest cost, Journal of Forest Science, 24(2): 209-217.

Picman D. and Pentek, T. (1998). The influence of forest roads building and maintenance costs on their optimum density in low lying forests of Croatia Proceedings of the Seminar on Environmentally Sound Forest Roads and Wood Transport in Sinaia, Romania, Food and Agriculture Organization of the United Nations, Rome, 1998, 87-102.

Saunders, C. 1996. West Argyll Valmet 890 forwarder trial 1996. Forestry Commission Research Division- Technical Development Branch, Internet Project Information Note 7/96, 9.

Segebaden, G.V. (1964). Studies of cross-country transportation distances and road net extension, Studia Forestalia Suecica, Nr.18

Sessions, J. (1986). Can income tax rules affect management strategies for forest roads, Western Journal of Applied Forestry 1(1), 26-28.

Sessions, J. and K. Boston, (2006). Optimization of road spacing for log length shovel logging on gentle terrain, Journal of Forest Engineering, 17(1), 67-75.

Spinelli, R., P.Owende, S.Ward and M. Torneo. (2003). Comparison of short-wood forwarding systems used in Iberia. Silvia Fennica 38 (1),85-94.

Stuekelberger, J. A., Heinimann, H.R., Chung, W. and M. Ulber. (2006). Automatic road-network planning for multiple objectives. The 29th COFE meeting, Coeur d'Alene, Idaho, July 30-August 2, W. Chung and H.S. Han, editors,. 233-248.

Sundberg, U. (1976). Harvesting man-made forests in developing countries. FAO

Thompson, M.A. (1988). Optimizing spur road spacing on the basis of profit potential. Forest Product Journal, 38(5), p. 53-57

Thompson, M.A. (1992). Considering overhead costs in road and landing spacing models, Journal of Forest Engineering, 3(2), 13-19

UK Forestry Commision, (1995). Terrain classification. Technical Note 16/95, p. 5

Wenger, K. (1984). Cost control formulas for logging operations. p. 560-563 in Forestry Handbook, 2nd Edition. Society of American Foresters. John Wiley and Sons. New York.

Yeap Y.H., and Sessions, J. 1988. Optimizing spacing and standards of logging roads on uniform terrain.