

Optimal Skid Trail Spacing for Small Vehicles in Thinning

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ABSTRACT

In Japan, the extent of man-made forests has reached 10 million ha. These forests were mainly established after World War II and are now at thinning age. Effective methods for thinning are being developed. In this paper the spacing of skid trails suitable for mini-forwarder with a grapple loading boom and a winch and mobile mini-yarder are discussed, mainly from the economic point of view. Results indicate that the skid trail spacing of about 40 m for the timber extraction with the mini-forwarder and about 140 m for the mobile mini-yarder.

Keywords: *thinning, mini-forwarder, mobile mini-yarder, optimal spacing of skid trails.*

INTRODUCTION

In Japan, the extent of man-made forests has reached 10 million ha, 40% of the total forest area of 25 million ha. Most of these man-made forests were established after World War II and now require a silvicultural thinning. Thinning operations, however, have not proceeded fast enough because it is difficult for forest owners to gain profit from such thinnings. The price for the timber is low and thinning operations in mountainous terrain are technically difficult.

About half the total volume of timber harvested annually in Japan (30 million m³) is extracted with cable-yarders and remaining the portion is ground-skidded. Two types of vehicles are used: skidders and forwarders. Small- or medium-sized skidders (total weight 3-6 t) are used for tree-length logging and log-length logging mainly in gentle terrain without construction of skid trails. Small forestry vehicles or mini-forwarders (total weight less than 3 t) with a winch and a loader are used for log-lengths extracting. In both in gentle and steep ter-

rain, the construction of skid trails are required for mini-forwarders.

In thinning operations, mini-forwarders are preferred to skidders because they are relatively efficient and cause less damage to remaining trees. On steep slopes, the logging operations with conventional small forestry vehicles are expensive due to low productivity, and they cause erosion due to the construction of skid trails. In order to practise thinning operations effectively on steep forests, our project team developed a mobile mini-yarder [1]. A schematic diagram of the vehicle is shown in Figure 1. The total weight of the vehicle is 2.8 t and the engine power is 60 hp. The vehicle has a spar of 7.5 m in height and has a maximum reach of 150m.

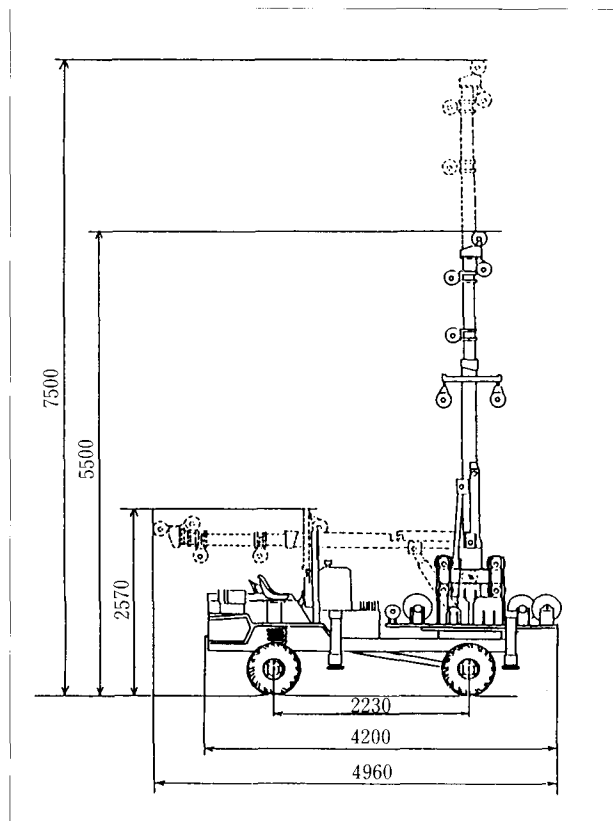


Figure 1. A schematic diagram of the mobile mini-yarder.

In this paper the operational conditions that are economically suitable for mini-forwarders and the new mobile mini-yarders are discussed. The schematic diagram of a mini-forwarder is shown in Figure 2. The total weight of the vehicle is 2.2 t and the engine power is 33 hp. This vehicle has

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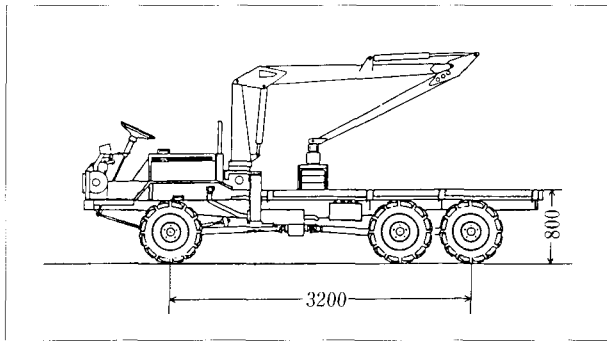


Figure 2. A schematic diagram of the mini-forwarder.

a winch for winching and a grapple loader for handling timber.

In Japan, such machines are used in the thinning of private forests because of a combination of the small tree sizes, low volume yields, difficult terrain and, most importantly, the land ownership patterns.

CHOICE OF METHOD

The productivity of both the mini-forwarder and mobile mini-yarder was investigated in thinning stands (species: *Cryptomeria*; age of stand: 30-33 years) with a slope of 20°-30°. The operational process of a mini-forwarder can be divided into four main functions: winching of log-length to forwarder, loading with a grapple loader, transporting on skid trails and unloading with a grapple loader. At least two workers are needed: an operator and a chokerman. The mobile mini-yarder method can also be divided into four main functions: yarding of tree-length timber by running skyline system, loading with a grapple loader of a separate mini-forwarder after bucking, transporting on skid trail roads and unloading. This requires at least three workers: two operators and a chokerman.

It is assumed that in the mini-forwarder operation, the log-length timber is winched uphill because it is difficult to pull the wire rope upwards. Tree-length logs are yarded both uphill and downhill with mobile mini-yarder, utilizing a running skyline system with an interlock device.

Productivity per machine-hour and man-hour, and the costs of extraction (including the winching cost and forwarding cost on skid trails) in relation to spacing of skid trails are shown in Figures 3-5. In these calculations the transporting distance on skid

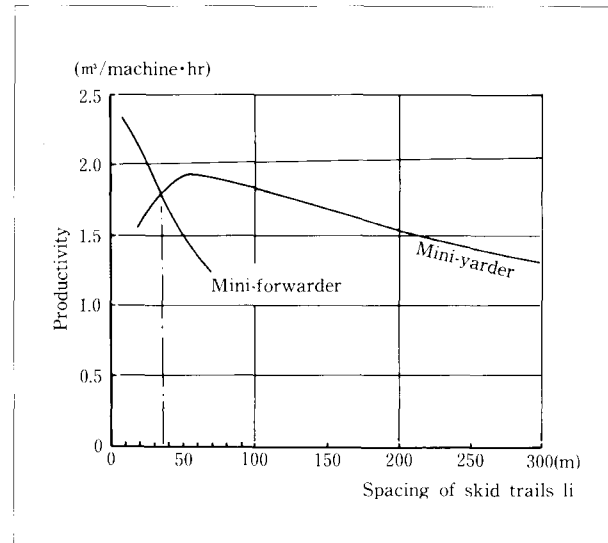


Figure 3. Relation between the productivity per machine-hour of extraction and the spacing of skid trails.

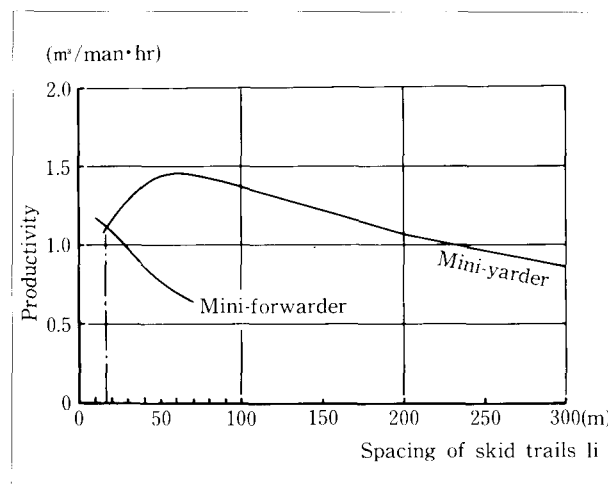


Figure 4. Relation between the productivity per man-hour of extraction and the spacing of skid trails.

trails to the landing was assumed to be $L_s:500$ m by reference to study areas. Machine costs per operating hour of the mini-forwarder method including winching and forwarding, only forwarding and the mini-yarder method are 3,160 Yen/hr, 2,217 Yen/hr and 3,460 Yen/hr respectively (the exchange rate is about 115 Yen/US\$ in April 1993).

Figures 3-5 show that a break-even point for the mini-forwarder method and the mobile mini-yarder method occurs at a skid trail spacing of 35 m for productivity per machine-hour and cost. It occurs at a spacing of 18 m for productivity per man-hour. It

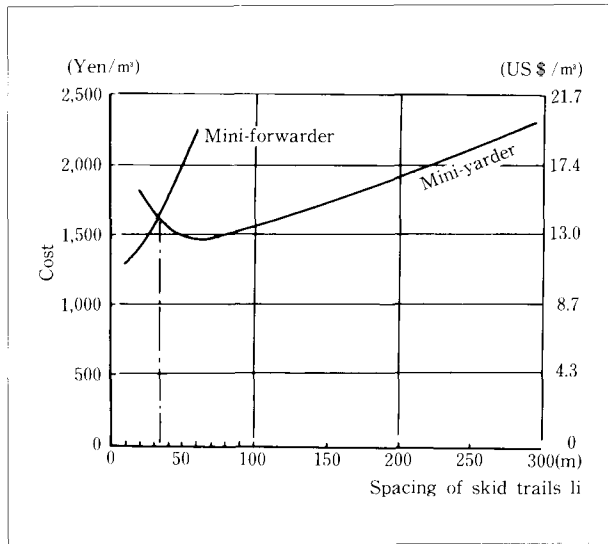


Figure 5. Cost of extraction as a function of skid trail spacing.

is supposed from the above results that the practical break-even point of skid trails between the mini-forwarder method and the mobile mini-yarder method is from 30 m to 40 m. Therefore, if a more dense skid trail network is constructed, the mini-forwarder method can be used more economically than the mobile mini-yarder method, and vice versa.

SKID-TRAIL DENSITY

Theoretical Considerations

For the forwarder method, a simple model (Figure 6) is assumed; The stand is quadrate shape (width: a m, length: b m) along where a forest road has already been constructed. In this model we will construct skid trails in spacing l_i and transport log-length timber on the skid trails after winching logs uphill to the forwarder. The total cost of extraction operations K is equal to the sum of skid trail con-

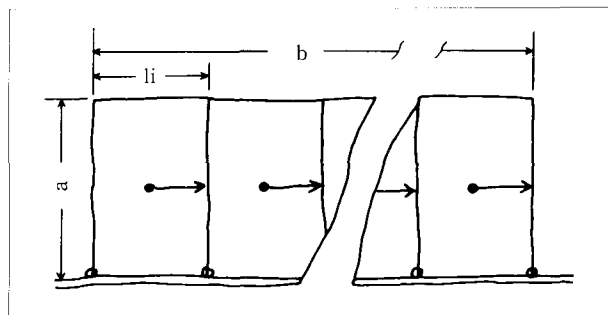


Figure 6. A thinning model for the mini-forwarder method.

struction cost K_s , winching cost K_w and transporting cost on skid trails K_t . Variables and symbols used in the calculations are presented in the following:

- ρ (m^3/ha): Volume produced from a thinning stand
- α (Yen/m): Cost of skid trail construction
- $\delta l + \delta' + \delta''/l$ (Yen/ m^3): Cost of winching operations (l : winching distance, $\delta, \delta', \delta''$: constant as to winching cost)
- $\gamma L + \gamma'$ (Yen/ m^3): Cost of transporting operations on the skid trails (L : transporting distance, γ, γ' : constant as transporting cost)

Namely,

$$K = K_s + K_w + K_t$$

Where,

$$K_s = \alpha_1 \cdot a \cdot \frac{b}{l_i}$$

$$K_w = \left(\delta_1 \cdot \frac{l_i}{2} + \delta_1' + \frac{2\delta_1''}{l_i} \right) \rho \cdot a \cdot \frac{l_i}{10^4} \cdot \frac{b}{l_i}$$

$$K_t = \left(\gamma_1 \cdot \frac{a}{2} + \gamma_1' \right) \rho \cdot a \cdot \frac{l_i}{10^4} \cdot \frac{b}{l_i}$$

Therefore the optimal spacing of skid trails l_o can be obtained by means of calculating the value of the skid trails spacing l_i that make total cost of extraction K minimum. The result obtained from the above process is as follows:

$$l_o = \frac{141.4}{(\rho\delta_1)^{0.5}} \left(\alpha_1 + \frac{2\rho\delta_1''}{10^4} \right)^{0.5}$$

Mobile Yarder Method

The assumed shape of the forest model (Figure 7) is equal to that of forwarder. Tree-length logs are yarded by a running skyline system from both sides of the skid trails both uphill and downhill.

In this case the cost of skid trail construction K_s , cost of yarding K_y and cost of transporting on skid trails K_t are obtained respectively as follows:

$$K_s = \alpha_2 \cdot a \cdot \frac{b}{l_i}$$

$$K_y = \left(\delta_2 \cdot \frac{l_i}{4} + \delta_2'' + \frac{4\delta_2'''}{l_i} \right) \rho \cdot a \cdot \frac{l_i}{10^4} \cdot \frac{b}{l_i}$$

$$K_t = \left(\gamma_2 \cdot \frac{a}{2} + \gamma_2' \right) \rho \cdot a \cdot \frac{l_i}{10^4} \cdot \frac{b}{l_i}$$

Therefore the total cost of extraction operations K is obtained from the sum of K_v , K_y and K_t . Similarly,

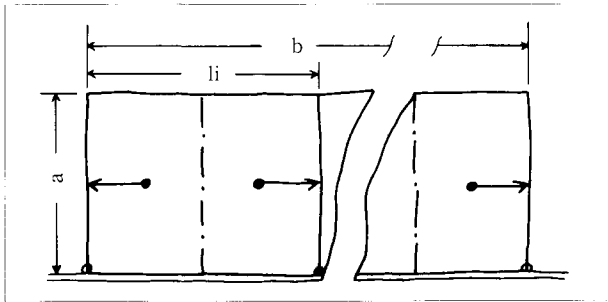


Figure 7. A thinning model for the mobile mini-yarder method.

in the case of the forwarder method, the optimal spacing of skid trails l_0 for the mobile yarder is obtained by the same process as follows:

$$l_0 = \frac{200}{(\rho\delta_2)^{0.5}} \left(\alpha_2 + \frac{4\rho\delta_2'''}{10^4} \right)^{0.5}$$

Optimal Spacing of Skid Trails

The optimal spacing of skid trails for the mini-forwarder and the mobile mini-yarder methods can be calculated by the formulae (5) and (9) as follows:

In the mini-forwarder method

Volume of timber from thinning stand $\rho = 50$ (m^3/ha)

Cost of skid trail construction $\alpha_1 = 200$ (Yen/m)

Cost of winching operations $K_w = 46.78 l_i + 199$ (Yen/ m^3) ($\delta_1 = 46.8$, $\delta_1'' = 0$)

Optimal spacing of skid trails $l_0 = 41$ (m)

In the mobile mini-yarder method

Volume of timber from thinning stand $\rho = 50$ (m^3/ha)

Cost of skid trail construction $\alpha_2 = 300$ (Yen/m)

Cost of yarding operations $K_y = 16.68 l_i + 467 + 3,200/l_i$ (Yen/ m^3) ($\delta_2 = 16.9$, $\delta_2'' = 3,300$)

Optimal spacing of skid trails $l_0 = 131$ (m)

The Effect of Skid Trail Construction on Erosion

Generally, the construction of skid trails increases the possibility of erosion, because of the increased area of exposed soil. On the other hand, it is thought that the possibility of erosion increases as slope angle increases. Therefore, if the area of exposed soil contributing to erosion can be expressed by means of the function of slope angle, the critical density of skid trails can be estimated from that function.

However, it is hard to find scientific data from which to obtain the critical area of exposed soil, occurring erosion of forest. In Japan there is indication that erosion damage occurs at slope angles of 30° to 45° [2]. The results suggest that on slopes of less than 30 degrees, forwarding with closely spaced skid trails is appropriate. On steeper terrain, more widely spaced skid trails should be used.

CONCLUSIONS

In this paper the operational areas suitable for mini-forwarders and mobile mini-yarders were discussed mainly from the economic point of view. It was concluded that the mini-forwarder method with construction of skid trails in spacing about 40 m is suitable for winching in thinning forests of less than about 30° slope, whereas the mobile mini-yarder method with construction of skid trails in spacing of about 140 m is suitable for yarding operations in thinning forests on steeper slopes.

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