

## On the Maximum Skidding Output of the "Timberjack 380" Forest Tractor

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### ABSTRACT

An analysis has been carried out of the skidding operations performed by the "Timberjack 380" forest tractor for an initial thinning of a *Pinus radiata* D. Don plantation. Knowing the maximum tractive force exerted by the tractor and allowing for the different resistances to forward movement (rolling friction, slope and load resistance), it has been calculated that the tractor can skid 10.1 m<sup>3</sup> of material on a dry, compacted earth track, and 5.2 m<sup>3</sup> on a wet track.

An examination of the various phases of the operations shows that total time per trip to be expressed by the following relation:

$$T = \frac{d}{s_u} + \frac{d}{s_u - aV} + 3.30$$

where  $s_u$  (speed of tractor without load) = 151.45 m/min

$$a = 13.4352$$

$V$  = volume transported

$d$  = skidding distance.

On the basis of this relation and of the more general one expressing the output ( $P = 60 V/T$ ), the maximum output was calculated for the "trip without load" phase and for the whole log removal phase. For the "trip with load" phase the maximum output, whatever the skidding distance, is obtained by transporting 5.636 m<sup>3</sup>, while, for the whole cycle, to achieve the maximum output the load should be 6.970 m<sup>3</sup> over a distance of 800 m, and 8.180 m<sup>3</sup> over a distance of 100 m.

From the analysis carried out and the results obtained, it is clear that the tractor, to ensure maximum

performance, should transport material having a high unit volume, such as that obtained from clearcutting operations.

**Key Words:** *Skidder, Timberjack 380, Skidder Output.*

### INTRODUCTION

A basic requisite for the correct management of a felling site in a wooded area is knowledge of the suitability of the machine to be used in the various operations.

Skidding includes collection of the material, partly or wholly trimmed, from its felled position, and subsequent transport to the next place of processing.

It is therefore necessary, in assessing the economic limits of this operation, to know the technical limits of the vehicle in order to exploit its potential to the utmost. The only limitations to using tractor in skidding operations are the slope of the land and, naturally, lack of skidding traction.

Skidding trials, carried out using a "Timberjack 380" forest tractor fitted with a grapple, have made it possible to evaluate not only working times [2], but also the working conditions that permit the maximum output to be achieved.

### Characteristics of the tractor

The "Timberjack 380" is an articulated tractor of 102 kW (136 HP), weighing 9670 kg evenly distributed on two axles. The maximum tractive force developed by the tractor is given by:

$$F_1 = K_1 P$$

with  $P$  the weight of the tractor and  $K_1$  the coefficient of adherence which, in the case of a compacted earth track, has the value of 0.55 if the ground is dry and 0.35 if it is wet.

$F_1$  is therefore:

$$F_1 = 0.55 \times 9670 = 5318 \text{ kg (dry track)}$$

$$F_1 = 0.35 \times 9670 = 3384 \text{ kg (wet track)}$$

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The forces resisting forward movement of the tractor are: rolling friction, track slope and load resistance. If the tractor has low pressure tyres with a broad tread, the resistance due to rolling friction is calculated as follows:

$$R_1 = K_2 P$$

where  $K_2$ , the coefficient of rolling friction, is equal to 0.06 in the case of a dry track, and to 0.10 with a wet track.

For these two cases we have:

$$R_1 = 0.06 \times 9670 = 580 \text{ kg}$$

$$R_1 = 0.10 \times 9670 = 967 \text{ kg}$$

Supposing that skidding takes place uphill (track with a slope of 10%), then the force opposing the forward movement of the tractor without a load (or favouring it, downhill) is given by the component parallel to the ground of the tractor's weight  $P$ , i.e. by  $P \sin \alpha$  where  $\alpha$  = ground slope.

For small values of the angle  $\alpha$ , it may be taken that  $\sin \alpha = \tan \alpha$ , and therefore the above mentioned force is equal to the weight of the tractor by the slope of the ground expressed as a percentage.

The resistance to uphill motion is therefore:

$$R_2 = 0.10 \times 9670 = 967 \text{ kg}$$

The total resistance absorbed by the rolling friction and the slope of the ground is respectively:

$$R_1 + R_2 = 580 + 967 = 1547 \text{ kg (dry track)}$$

$$R_1 + R_2 = 967 + 967 = 1934 \text{ kg (wet track)}$$

The force  $F$  available for the load will therefore be:

$$F = 5318 - 1547 = 3771 \text{ kg (dry track)}$$

$$F = 3384 - 1934 = 1450 \text{ kg (wet track)}$$

Among the resisting forces, it now remains to consider the load resistance. In general, this is given by the weight  $P$  of the material being skidded multiplied by a coefficient of sliding friction. But in the case of a load lifted off the ground (semi-sliding) it is

advisable to substitute the above coefficient with a skidding coefficient  $K_s$ , defined as the ratio between the force necessary to pull the weight  $P_1$  over level ground and said weight  $P_1$ .

The values of  $K_s$  are 0.3 if the track is dry and 0.2 if it is wet. The total reduction factor, allowing also for the slope, will then be 0.4 for a dry track and 0.3 for a wet one.

The weight of the load that may be skidded is therefore:

$$3771/0.4 = 9427 \text{ kg (dry track)}$$

$$1450/0.3 = 4833 \text{ kg (wet track)}$$

In the case under examination, as the volume mass in the fresh state of *Pinus radiata* D. Don material is 0.933 t/m<sup>3</sup>, the tractor can skid:

$$10.1 \text{ m}^3 \text{ of material (dry track)}$$

$$5.2 \text{ m}^3 \text{ of material (wet track)}$$

## EXPERIMENTAL METHOD

During the course of an initial thinning of a plantation of *Pinus radiata* D. Don the working times were measured in relation to the removal of the material (arranged in bundles with the branches lopped), and the output of the "Timberjack 380" was calculated [2]. The skidding operation on a cleared, compacted earth track entailed 114 trips with variable distances and loads.

An analysis of the working phases shows them to be:

- the in-trip (without load)
- manoeuvring
- attachment of material
- out-trip with load
- unloading and stacking of material
- non-productive and rest times

All these items make up the skidding cycle, and contribute, in various percentages towards determining the total trip time and the hourly skidding output, provided by the relation:

$$P = 60 V/T$$

where  $V$  is the volume transported and  $T$  is the total time per trip in minutes.

However, of the working phases, only one item is "active," i.e. the out-trip with load. All the other items are necessary but are complementary to the above item.

In managing a timber utilization site, the problem arises of knowing (allowing for the nature of track, the slope, etc.) whether the tractor has been used in the best way and, if not, it is clear that action can only be taken on the "active" item of the operation as all the other items (except the trip with no load phase, which depends on the material removal distance) have little influence and are therefore more or less constant.

It might seem at first sight that, to increase output, it is enough to increase the load (within the limits of the load that the tractor can pull), but this clearly involves a decrease in the speed of the tractor, with a consequent increase in the time taken.

The following relation should now be considered:

$$t' = \frac{d}{s_1}$$

This represents the time necessary to cover, at speed  $s_1$ , the skidding distance  $d$  with a load  $V$ . Dividing the previous relation by  $V$ , then:

$$\frac{t'}{V} = \frac{d}{s_1 V} = t_1 \tag{1}$$

and therefore the time necessary to move a unit of load.

It appears evident that, taking into consideration only the "trip with load" phase, the maximum output is obtained by minimizing the time to shift a unit of load, and from relation (1) this occurs when the product  $s_1 V$  is maximum. Expressing  $s_1$  as a function of  $V$  by means of a relation of the type:

$$s_1 = s_u - aV$$

with:

- $s_u$  = speed of tractor without load
- $V$  = load transported
- $a$  = a constant to be determined,

experimental data show that:

$$s_1 = 151.45 - 13.4352 V$$

with  $s_1$  in m/min and  $V$  in  $m^3$ .

Making substitutions in relation (1), the following is obtained:

$$t_1 = \frac{d}{V(151.45 - 13.4352 V)} \tag{2}$$

Deriving:

$$\frac{dt_1}{dV} = \frac{d(151.45 - 2 \times 13.4352 V)}{V^2 (151.45 - 13.4352 V)^2}$$

The derivative is annulled by:

$$151.45 - 26.8704 V = 0$$

and therefore:

$$V = 5.636 \text{ m}^3$$

This is the value which, when substituted in (2), gives the minimum value, and it is the only value which, whatever the skidding distance, makes it possible to obtain the maximum output, taking only this working phase into consideration.

As seen in Fig. 1, which shows the variation of  $t_1$  as a function of the load for various skidding distances, all the curves have a minimum at  $V = 5.636 \text{ m}^3$ .

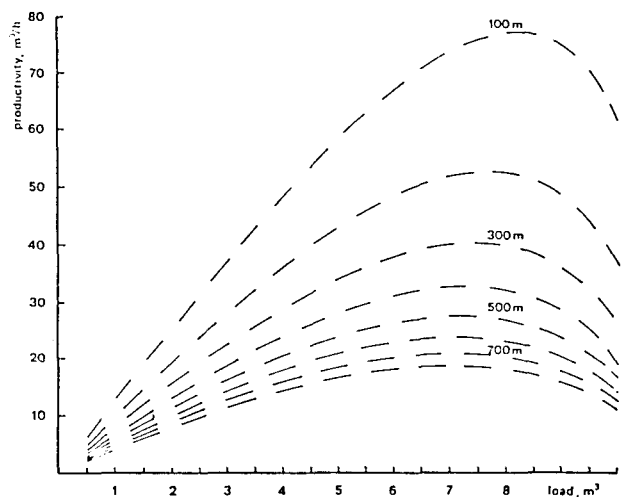


Fig. 1 - Time per  $m^3$  as a function of the load transported for various skidding distances.

They also show two vertical asymptotes for  $V=0$  and  $V=11.273 \text{ m}^3$ , and they are symmetrical with respect to the axis passing through  $V=5.636 \text{ m}^3$ .

The analysis of the "trip with load" phase establishes the maximum output for this, but the problem must be considered within the overall framework of the skidding cycle, since the percentage incidence of this phase with respect to all the others is certainly not constant, but varies with the load and with the skidding distance.

All the working phases should now be considered:

a) *in-trip without load.*

Given that the tractor moves at a constant speed  $s_u = 151.45 \text{ m/min}$ , the trip time is proportional to the skidding distance, viz.:

$$t_u = \frac{d}{s_u}$$

b) *out-trip with load.*

As already seen the time per unit of load is given by:

$$t_1 = \frac{d}{V(s_u - aV)}$$

and therefore the time required to transport the load  $V$  is:

$$t_1 V = \frac{d}{s_u - aV}$$

with  $a = 13.4352$

c) *other items in the cycle.*

From an examination of the 114 tractor trips it is found that the average amount per trip of the times of manoeuvring, attachment of material, unloading, stacking, unproductive time and rest time is 3.30.

The total time  $T$  for the whole skidding cycle is therefore expressed by:

$$T = t_u + t_1 V + 3.30$$

or:

$$T = \frac{d}{s_u} + \frac{d}{s_u - aV} + 3.30$$

from which the total trip time is obtained as a function of the distance  $d$  and of the load  $V$ . This makes it possible to establish the percentage incidence of the "trip with load" phase with respect to all other phases.

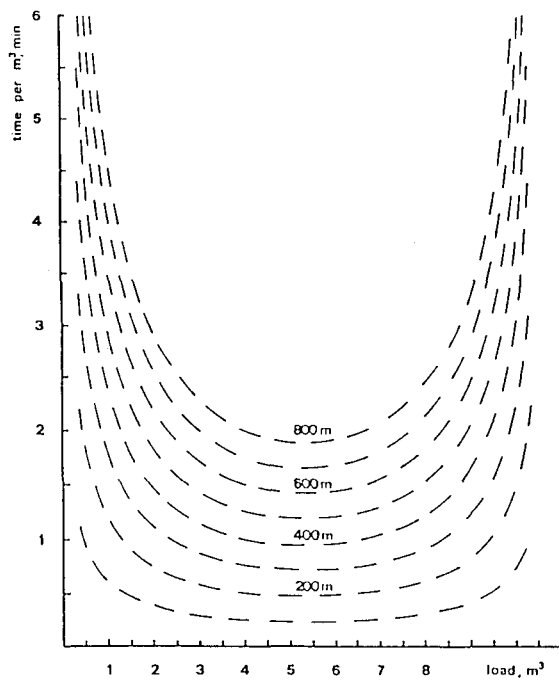


Fig. 2 - Skidding output according to load transported for different skidding distances.

Considering for example a skidding distance of 500 m, and varying the load from 1 to 9 m<sup>3</sup>, the following is obtained:

	load of 1 m <sup>3</sup>		
$t_1 V$	$T$		$t_1 V/T$
3.62	10.22		35.4%
	load of 9 m <sup>3</sup>		
$t_1 V$	$T$		$t_1 V/T$
16.37	22.98		71.3%

whereas, with a load of 5 m<sup>3</sup>, varying the distance from 100 to 800 m results in:

	distance 100 m		
$t_1 V$	$T$		$t_1 V/T$
1.19	5.15		23.1%
	distance 800 m		
$t_1 V$	$T$		$t_1 V/T$
9.49	18.07		52.5%

This different percentage will therefore entail a change in the value  $V = 5.636 \text{ m}^3$  - already deter-

mined for the "trip with load" phase - to which the maximum output corresponded.

The expression for skidding output should now be considered, which is given by:

$$P = \frac{60V}{T}$$

$$= \frac{60 s_u V (s_u - aV)}{d(s_u - aV) + ds_u + 3.30s_u (s_u - aV)}$$

The variation of this output as a function of the load transported for different skidding distances (from 100 m to 800 m) is shown in Fig. 2. All the curves have a maximum peak, deducible analytically from a study of the function  $f(P)$ , namely:

- Max. output of 77.085 m<sup>3</sup>/h with load of 8.180 m<sup>3</sup> for distance d = 100 m.
- Max. output of 52.483 m<sup>3</sup>/h with load of 7.881 m<sup>3</sup> for distance d = 200 m.
- Max. output of 40.193 m<sup>3</sup>/h with load of 7.405 m<sup>3</sup> for distance d = 300 m.
- Max. output of 32.603 m<sup>3</sup>/h with load of 7.250 m<sup>3</sup> for distance d = 400 m.
- Max. output of 27.450 m<sup>3</sup>/h with load of 7.146 m<sup>3</sup> for distance d = 500 m.
- Max. output of 23.714 m<sup>3</sup>/h with load of 7.071 m<sup>3</sup> for distance d = 600 m.
- Max. output of 20.879 m<sup>3</sup>/h with load of 7.015 m<sup>3</sup> for distance d = 700 m.
- Max. output of 18.652 m<sup>3</sup>/h with load of 6.970 m<sup>3</sup> for distance d = 800 m.

## CONCLUSIONS

From the examination made it follows that knowledge of the tractor's maximum output, both for the "trip with load" phase and, above all, for the whole skidding cycle, is the basis for the correct management of a forest felling / thinning site.

In fact, knowing the optimum mass that a tractor can clear, it is easier to organize the work in the phases preceding and following the actual skidding.

In the case in question, it should be observed that the tractor, having to transport material of small unit volume, such as that produced by an initial thinning, obtained good outputs, although below those established as optimal.

These outputs, while liable to improvement, are still far from the maxima that could be attained using the tractor to skid large size material.

## REFERENCES

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