Avdelningen för Skog och Träteknik
HÖGSKOLAN DALARNA

Smaller forestry machines (to contribute to more eco-friendly and flexible forestry management systems)

- a feasibility study

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Feasibility study

The overall idea behind the project is to develop a machine that is environmental friendly and has good technical and biological characteristics in selective cuttings at a reasonable cutting cost. Damages from machines are a major problem in forestry. Damages cause rot infections in roots or on stems, wood damages, reduced tree growth, increased risk for wind falls, erosion, etc. Estimations from Sweden show that the root rot causes losses of about 500 million SEK per year only in Sweden (Bendz-Hellgren, 1997). The today industry's requirement for an even flow of fresh timber all over the year, even in times when the site is sensitive to machine traffic, has contributed to make the problem bigger.

To reach the ***environmental friendliness*** the machine must have:

- Low ground pressure
- Smooth designed ground contact
- Good distribution of traction forces to combine high traction and low environmental impact
- Narrow machine width when necessary
- Good flexibility in curves and terrain with obstacles to minimise increase in "practical" machine width

The machine requirement, from an environmental point of view, varies widely between different site conditions and different stages in the stand treatment. In general, early thinning, has the highest requirements for narrow strip-road (and machine) width, due to high number of stems per ha. Later in the stand development increased spacing between trees reduces the requirement for narrow machine width. The desired maximum strip-road width is about the same as the average distance between trees after thinning (Wästerlund, 1994). For Swedish conditions about 2,5 m in first thinning, giving a maximum machine width of about 2 m including clearance.

The requirements regarding which forces are acceptable to the ground varies a lot. In northern countries frozen ground sometimes makes it possible to use conventional forest machines on most areas without causing any damages. However, short and uncertain time of frozen conditions often limits that possibility. Low ground bearing capacity is a common problem. In some areas the low bearing capacity lasts all year around but in many areas it is a serious problem only in periods with much moist. Wästerlund (1989) concludes that a desired ground pressure should not exceed 50-70 kPa on a 5-6 tonne machine on podzolic soil. However, on sites with poor or very poor ground bearing class (class 4 and 5) even lower ground pressure is required.

Beside ground pressure from the machine weight, traction and other forces, peak lads from tracks or wheels etc. contribute to the total "ground load".

The Terri ATD forwarder is one of the most environmentally friendly forwarders available. The mean ground pressure is only 25 kPa, and the machine width is only 170 cm. However, there are several machine characteristics that could be improved to get an even more environmental friendly machine:

- Tracks with steel ribs and sharp edges causing high point loads and damages on roots close to the earth surface
- Conventional tracks often have bad characteristics in stony terrain
- A rigid transmission that causes damage to ground when both turning and high traction is required
- Limited possibilities, due to stability and power requirement, to be used as tool carrier for a harvesting head
- Relatively long tracks on operator section (not bogie) and a frame steering without "fixation" between front and rear vehicle section causing ground damages when turning and whole body vibrations for the operator

The Terri ATD forwarder is in conventional forestry in most cases not economically compatible against larger conventional forwarders (at least on a short time base excluding future wood losses). Gullberg (1991) concludes that an old Terri (smaller and simpler than the Terri ATD) gives a transport cost that is about 10 SEK/m^3 higher at short transport distance (100 m) and about 25 SEK/m^3 higher at long transport distance (600m) compared to a conventional forwarder. However, on very small objects Terri is competitive due to low moving and starting cost.

The relatively high off-road transport cost makes the old Terri in many cases to a relatively limited niche machine that is only used when it is absolutely necessary by for example environmental reasons. Although better biological result using Terri will lead to future advantages it is hard to convince forest owners to pay a much higher prize using Terri.

If a more environmentally friendly machine shall reach success it therefore must also have sufficient short time economy. Low transport cost in combination with a light and small machine is difficult as the operator costs the same driving various machine sizes. To reach a better economy several alternatives exist, used single or in combination:

- Increased (and flexible) load capacity, but still acceptable machine width and ground pressure
- Multiple machine use, base machine used for both cutting and off-road transport
- A complete logging machine, making cutting and forwarding simultaneously
- Increased income from forestry by more flexible harvesting methods (adaptation to wood market and biology)

Increased (and flexible) load capacity

Load size is one major factor regarding transport productivity. The Terri ATD has a load area of 1,3 m^2, which leads to a maximum load of about 3,8 m^3 solid for normal log lengths (4,5 m). A conventional forwarder for thinning conditions loads about 7,9 m^3 solid. Below are shown some estimations of the importance of load size on productivity based on Gullberg (1997). For the new machine the same crane cycle time and mowing time is assumed as for the conventional harvester. For the Terri ATD crane cycle time is slightly higher and starting time for mowing substantially higher due to stabilising legs. Other basic conditions and assumptions for the machines are shown in table 1. The forest conditions are a conventional first thinning on easy terrain (removal 50 m^3/ha, pilesize 0,3 m^3, 3 assortments, average log length 4,5 m).

Table 1. Machine data

	Terri ATD	New machine (as forwarder)	Conventional forwarder (small) (Timberjack 810B with 22.5 X 600 tires)
Prize, SEK	550 000	1 000 000	1 350 000
Machine weight, tonne (unloaded)	2,9	3,6	10,0
Allowed load, tonne	3,5	6,0	8,5
Practical load for 4,5 m logs, m^3solid	3,8	4,4-6,7	7,9
Practical load weight for 4,5 m logs, tonne (density 0,85)	3,23	3,73-5,7	6,7
Ground pressure loaded (mean) , kPa	25,1	22,3-28,3	58,3
Machine width, cm	170	160-200 (adjustable)	252 (with 600 tires) 228 (with 500 tires)
Load size (load area, m^2)	1,3	1,5-2,3	2,7 (3,4 for short logs)
Driving speed, m/min	50	50	50
Grapple size (area, m^2)	0,15	0,20	0,26
Crane reach, m	4,6	5,5	6,7

The new machine has a high load weight compared to machine weight. This is good from an environmental point of view (low ground pressure and fuel consumption), but will also result in high forces on machine material and components. Therefore a well designed chassis and high quality on material is essential.

One other factor that might cause problem is stability contrary to machine direction. Narrow width of ground contact in combination with a light chassis and relatively high payload will most likely result in a relatively low maximum angel of side slope before the machine turn over. The possibility to utilise the maximum load capacity is therefore limited to relatively easy terrain or very careful driving and planning of strip-roads.

As can be seen in figure 1 the new machine will get substantial lower time consumption compared to the Terri ATD, especially when the load is wide. This is based on the assumption that driving speed is the same for all machines. If driving speed have to be reduced due to low stability the effect on productivity of greater load size will be lower.

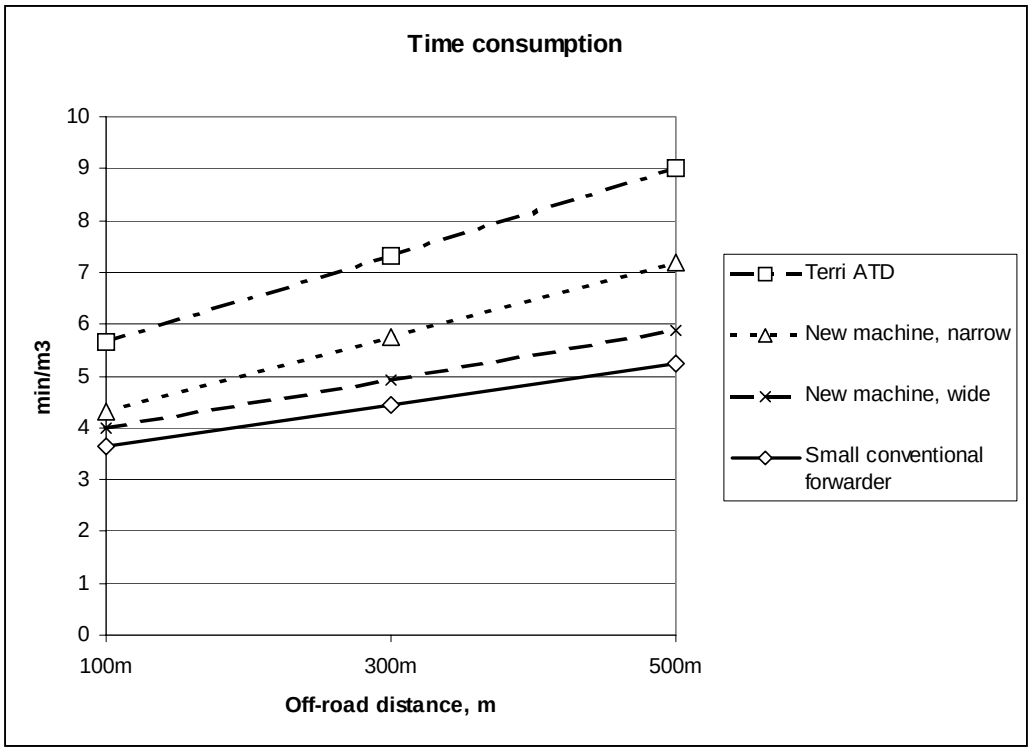

Figure 1. Estimated time consumption (effective time) in first thinning conditions.

Machine cost for the three machines are shown in table 2. Especially for the new machine the cost is a rough estimation. Cost for capital and maintenance is set proportional to machine investment for all hauling machines. There is a risk for higher maintenance and/or shorter pay-off time for the smaller machines due to weaker construction.

Table 2. Machine cost

	Terri ATD	**New machine forwarder**	**New machine combination**	**Forwarder small**	**Harvester small**
investment, tot, SEK	550000	1000000	1500000	1350000	2100000
base machine, SEK	550000	1000000	1000000	1350000	1550000
aggregate, SEK			500000		550000
hours per year, total	2700	2700	2700	2700	2700
TU, %	90	90	85	90	81
G15-hours/year	2430	2430	2295	2430	2187
Interest rate, %	7	7	7	7	7
Pay-off time, base machine, year	6	6	6	6	6
Pay-off time aggregate, year		4	4		4
Restvärde, %	20	20	15	20	15
Maintenance-factor	0,05	0,05	0,07	0,05	0,07
Pay-off, SEK/year	79450	144455	260704	195015	354278
Interest, SEK/year	21815	39664	38498	53547	59672
Capital cost, SEK/year	101266	184120	299202	248562	413950
Fuel and lubrication, SEK/G15	35	40	50	45	60
Maintenance, SEK/G15	28	50	105	68	147
Taxes and insurance, SEK/year	12000	12000	16000	12000	16000
Wage incl. 65% additional costs, SEK/hour	150	150	150	150	150
Addition to wage due to overlapping shifts, %	33	33	33	33	33
Driver cost SEK/year	538650	538650	538650	538650	538650
Costs per hour, SEK/G15-tim					
Investment	41,7	75,8	130,4	102,3	189,3
Driver	221,7	221,7	234,7	221,7	246,3
Operational cost	67,4	94,9	162,0	117,4	214,3
Sum	**330,8**	**392,4**	**527,0**	**441,4**	**649,9**
Mowing cost, 15 km					
Way of transportation	own	own	own	own	own
Driving speed, km/hour	16	16	16	16	16
Starting time (tire chains, instructions etc.), hour	1,3	1,3	1,3	1,3	1,3
Machine cost during mowing, SEK/G15	330,8	392,4	527,0	441,4	649,9
Total cost, SEK/move	740	878	1179	988	1454

Hauling cost for the various machines is shown in figure 2. Note that the figures are mainly for relative comparisons. The new machine is estimated to get almost the same hauling cost as the conventional forwarder when using the maximum loading space. At minimum width, the new machine will get a higher hauling cost, but lower than the Terri ATD.

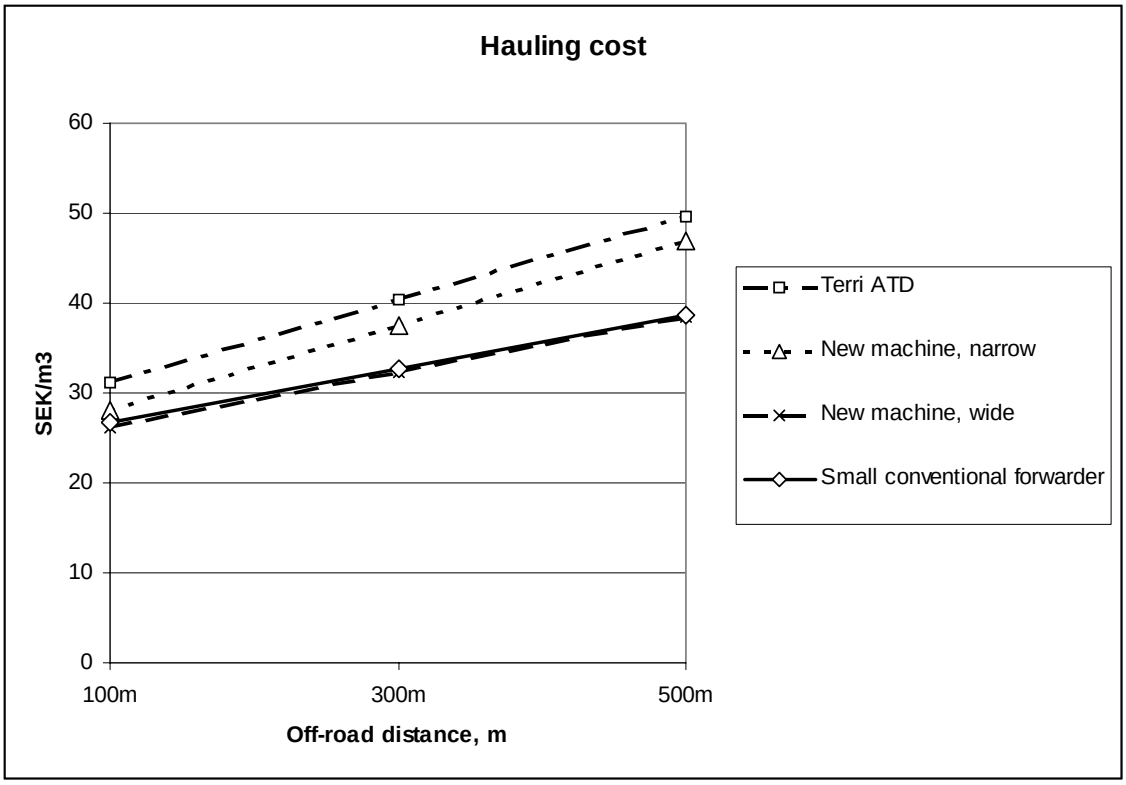

Figure 2. Direct hauling cost excluding moving between objects.

Multiple machine use, base machine used for both cutting and off-road transport

For small objects, machine moving- and starting costs often result in high costs per cubic metre. Therefore, a system where only one machine is involved is interesting. The new machine will give possibility to shift between harvesting with a harvester head and forwarding. Moving cost for a conventional system of one harvester and one forwarder is about 2500 SEK (see table 2) while the moving cost for a new combination machine is only about 1200 SEK. However, in addition the cost for changing between harvester and forwarder must be added. If changing takes 30 min per shift (two shifts per object) the additional cost is about 400 SEK. The increase in harvesting cost per cubic metre due to starting and moving cost for a conventional machine system and the new single combination machine is shown in figure 3. Drawbacks with a combination machine may be:

- lower performance compared to specialised machines
- higher machine prize (compared to equal one-purpose machine)
- need to change between harvesting and forwarding more than one time per object on large objects to not get to old timber before delivery

It is difficult to estimate all the differences, however the new combination machine can be judged to be favourable on objects up to at least 100 m3.

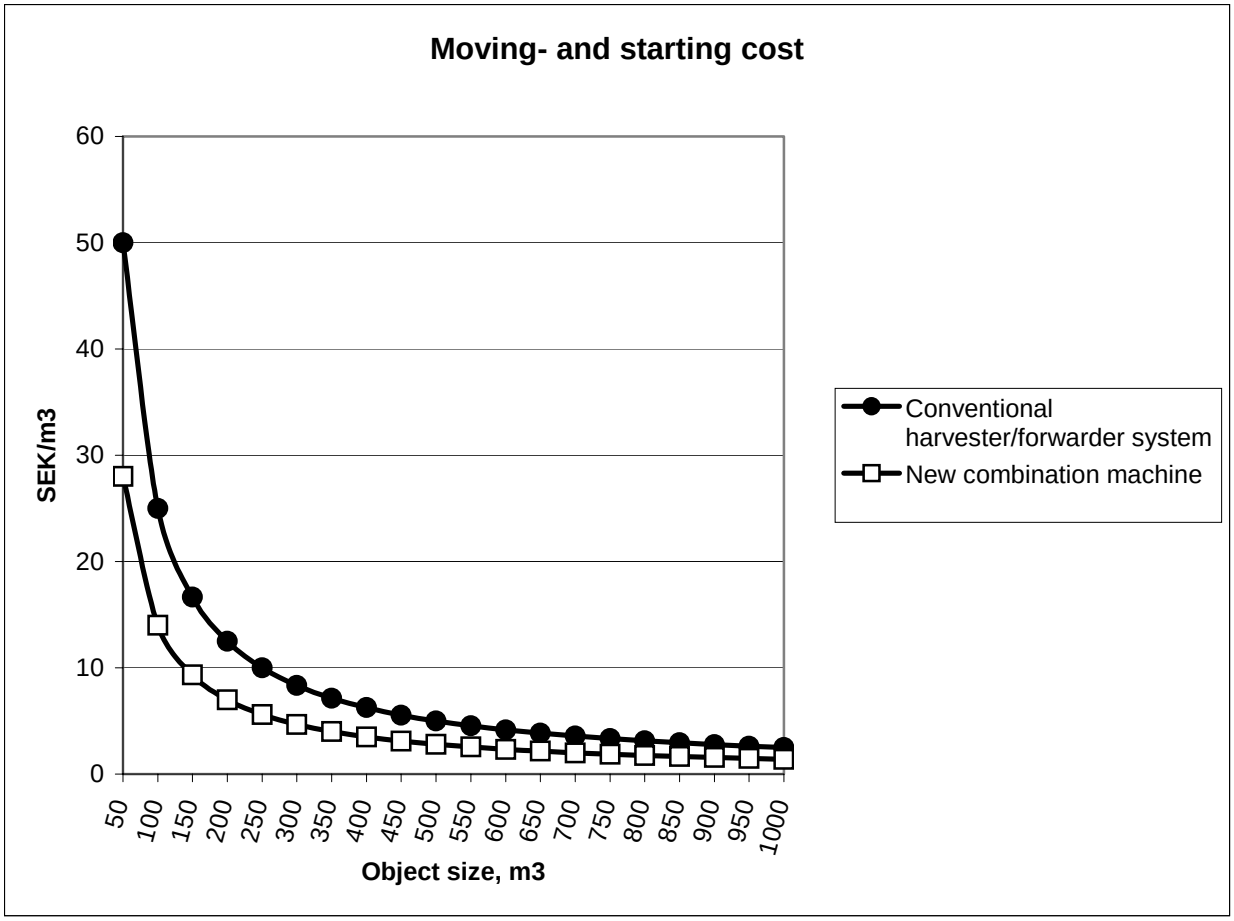

Figure 3. Cost for moving and starting dependent on object size.

A complete logging machine, making cutting and forwarding simultaneously

Beside the advantages on small objects connected with the use of only one machine, an integrated logging machine may get some extra possibilities:

- reduced time consumption for picking logs (directly loaded)
- reduced number of machine passes
- reduced risk for loading wrong assortment
- reduced time from cutting to landing
- no time for shifting between grapple and harvesting head

To facilitate direct loading the loading section must be directed in nearly the same direction as the tree is felled, either by driving and turning the machine rear section and/or turning the load on the machine frame. The new machine is planned to have a turnable loading section as option. However, there may also be some possible drawbacks:

- low unloading (and loading from ground) capacity
- difficulties when using several assortments
- high machine price
- heavy machine (especially if load is booth changeable in width and turnable)
- need for wide strip-roads

Increased income from forestry by more flexible harvesting methods

Moore flexible and environmentally friendly harvesting methods with low moving- and starting cost make it possible to treat the forest in a biologically and economically better way compared to conventional harvesting methods. For example, it gives possibilities to:

- make harvesting well adopted to market demand for special dimensions and qualities
- make harvesting well adopted to biological need of thinning
- reduce risk for windfalls etc. by narrow strip roads, little ground and root damage, small volumes removed etc.

This kind of benefits connected with the use of environmentally friendly and flexible harvesting systems with low fixed costs are discussed in Eriksson (1997) and Hagner (1999).

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