Cost analysis of thinning and supply systems for small-diameter trees

D 2.2 Cost analysis of thinning and supply systems for small-diameter trees

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1. Abstract:

Besides defining forest operations performance, also cost analysis is of importance when deciding on best practices. In the Smallwood project, the aim was to perform a cost analysis of the different machinery time studied and to perform a systems analysis to compare the performance between different systems options. A sub-aim was also to calculate net cost (income – cost) profit compared to different treatment choices. We conclude that, under the studied conditions, mechanized thinning with the removal of whole tree biomass for, e.g. energy purposes, shows great potential to turn negative net cost (only cost) into a positive income in many cases. The analysis also shows that the main driver for investment in new technologies is to obtain high harvesting productivity to increase cost-effectiveness and thus profitability.

2. Introduction

Both technical and socioeconomic factors must be considered when analyzing the cost-effectiveness of harvesting systems in and between different countries (Di Fulvio et al. 2017). Major factors typically considered in operational cost analysis are productivity (dry t/SMh), machine/tool investment cost (€), annual utilization time (h/year), interest rate (%), diesel fuel and maintenance cost (€/SMh), operator salary (€/SMh), etc. There are several published guidelines and on-line tools to be used when performing forest operations cost analysis (Ackerman et al. 2014, Di Fulvio et al. 2017, Bell et al. 2017, Kaleja et al. 2018, Triplat and Krajnc 2020). Differences between methods are minor and mainly concern the level of detail in parameters.

In the Smallwood project, different harvesting operations were time studied in the field. In Sweden, Finland, Slovenia, and Spain, a Komatsu 901.4 thinning harvester equipped with the Bräcke Forest C16.c felling and bunching head were studied in selective thinning (ST) and boom-corridor thinning (BCT) (Bergström et al. 2022, Herguido-Sevillano et al. submitted ms). In Slovenia, also motor-manual cutting was time studied. In Spain, also the BioBaler and the Retrabio were time studied. In order to perform harvesting and supply systems cost analysis also, literature data on other machinery performance and costs were used.

The objective was to calculate the operative and supply cost per unit harvested (€/dry t or m^3 or ha) for some of the time studied operations in different conditions – in this case, Slovenia and Spain. A sub-aim was also to relate the operative cost to revenues from sales of the biomass, i.e. net cost.

3. Systems analysis – the Slovenian case

Time studies of motor manual thinning work were conducted in 15 study plots of young dense beach pole stands (Fig 1). In 7 plots, the method of selective thinning (ST) was conducted with the aim of thinning out 1400-1600 trees/ha. In 8 plots, the minimizing (situation) thinning (MT) method was conducted with the aim of thinning out 400 trees/ha. The stand age was 20 years and on average, for the 15 plots, the tree species distribution was 99% beach pole and 1% other broadleaves, the diameter at breast height (DBH) was 3.6 cm, the tree height was 4.7 m, and the stand density for trees ≥ 1cm DBH were 11565 trees/ha, with a range of 4200 – 20300.

Time studies of fully mechanized thinning work were conducted in 10 study plots of young dense beach pole stands (Fig 1.). In 5 plots, ST was conducted and in 5 plots boom-corridor thinning (BCT). The stand age was 20 years, and on average, for the 10 plots, the tree species distribution was 99% beach pole and 1% other broadleaves, the DBH was 3.6 cm, the tree height was 6.2 m, and the stand density for trees ≥ 1cm DBH were 11565 trees/ha, with a range of 8000 – 14900, and stand density for trees ≥ 4 cm DBH were 3430 trees/ha, with a range of 2000-5400. The mean standing volume was 110 m^3/ha.

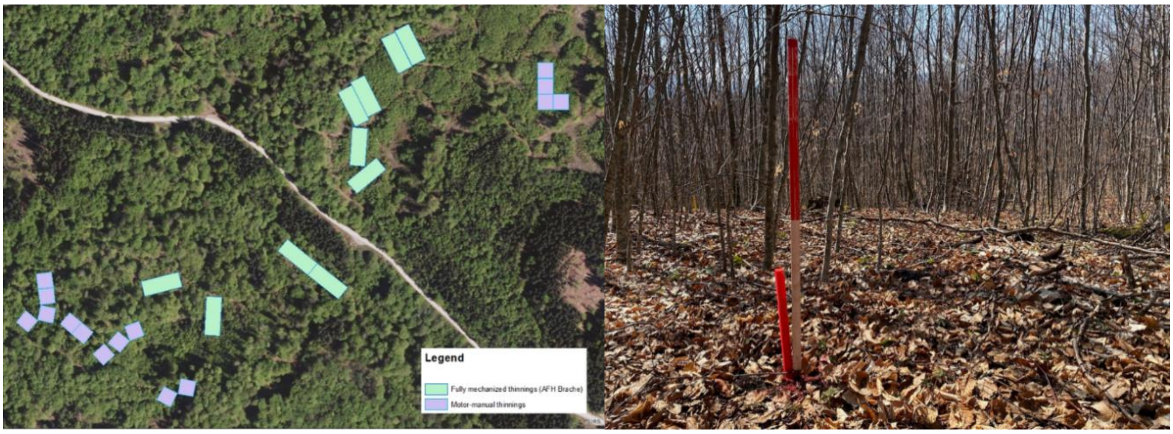

Figure 1. View over time study area with time study plots marked out and an in-stand view including inventory marking.

In the motor manual (chain-saw) thinning work, trees were cut, delimbed and bucked, and then left in a forest stand, i.e. no biomass extraction was conducted (Fig 2.).

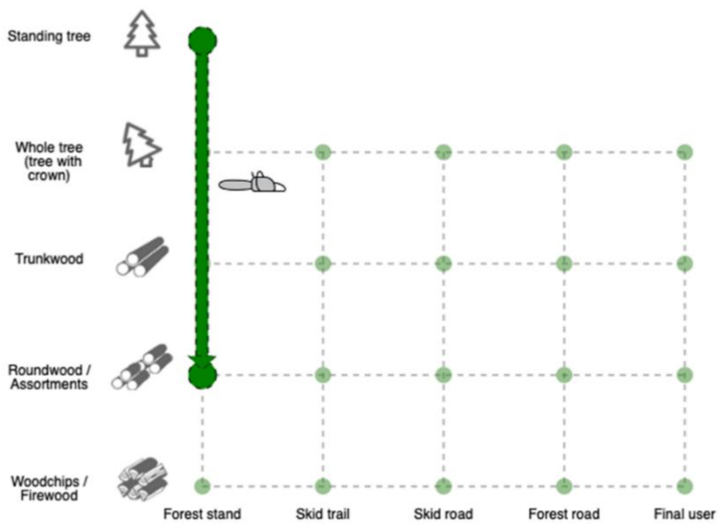

Figure 2. Sketch over work phases of the motor manual thinning work.

Table 1. Data for costing of motor manual chain-saw work.

Meth-od	Equip-ment	Fixed costs (€ / Depreciation period)	Fixed costs (€/h)	Variable costs of fuels and lubric-ants (€/h)	Variable costs of mainten-ance (€/h)	Total material costs of the selected machine (€/h)	Labo-ur costs (€/h)	Total costs of work processes (€/h)	Total costs of work processes (€/m3)
ST	**Chainsaw (4 kW)**	315,00	2,86	1,36	2,4	6,62	**17**	**23,62**	**113,12**
	Small tools and personal protective equip.	236,00	2,15		2,57	0,98			
MT	**Chainsaw (4 kW)**	315,00	2,86	1,36	2,4	6,62	**17**	**23,62**	**102,12**
	Small tools and personal protective equip.	236,00	2,15		2,57	0,98			

In the mechanized thinning work, whole trees were felled and bunched along strip roads in both ST and BCT treatments. The biomass was then forwarded to forest roadside (Fig. 3)

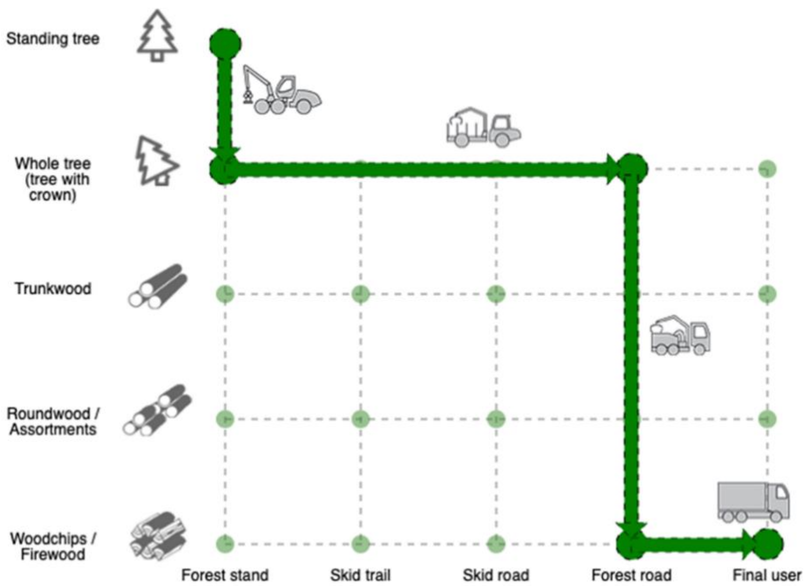

Figure 3. Sketch over work phases of the mechanized thinning work in stand and subsequent work included in systems analysis.

Results showed that, for the mechanized thinning, and both treatments (ST and BCT), the biomass removal was on average 30 dry t/ha, the basal area removal was 47%. The productivity was on average 3.3 dry t/PMh for ST treatment and was on average 15% higher for the BCT treatment (Fig. 4).

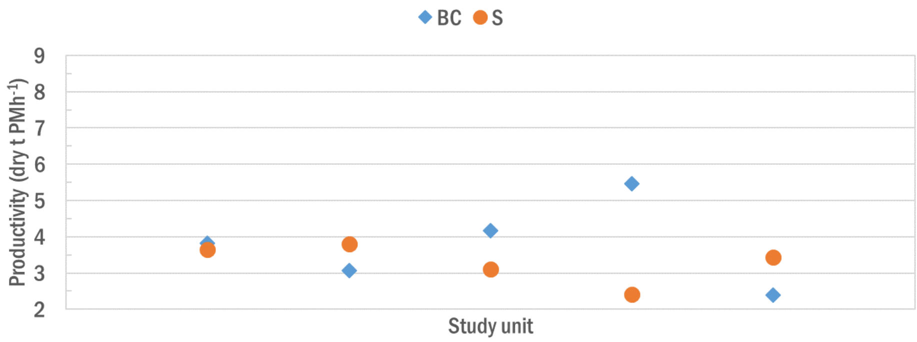

Figure 4. Productivity of mechanized thinning for the different study units and treatments. (BC=boom-corridor thinning, S=selective thinning).

The supply cost for the system, including ST work, was 58.9 €/m^3 (82.72 €/dry t), and was 9.2% lower for the supply system with BCT treatment (Table 2).

Table 2. Operational cost for thinning work with the two methods, BCT and ST.

Machine	Fixed costs (€ / Depreciation period)	Fixed costs (€/h)	Variable costs of fuels and lubricants (€/h)	Variable costs of maintenance (€/h)	Total material costs of the selected machine (€/h)	Labour costs (€/h)	Total costs of work processes (€/h)	Total costs of work processes (€/m3)	
								BCT	ST
Harvester	57160	63.5	33.9	39.9	137.3	20	**157.3**		
+ Bräcke C16.c	8388	9.3	0	5.9	15.2	20	**35.2**		
Forwarder	48000	53.3	33.9	30.0	117.2	20	**137.2**	**53.5**	**58.9**
Woodchipper	48000	53.3	64.7	30.0	148.1	17	**165.1**		
Woodchips truck	33300	47.6	72.7	14.8	135.0	20	**155.0**		

The operational cost of the mechanized harvesting and supply systems show exponential cost increases below an annual use of approx. 700 h/year (Fig. 5).

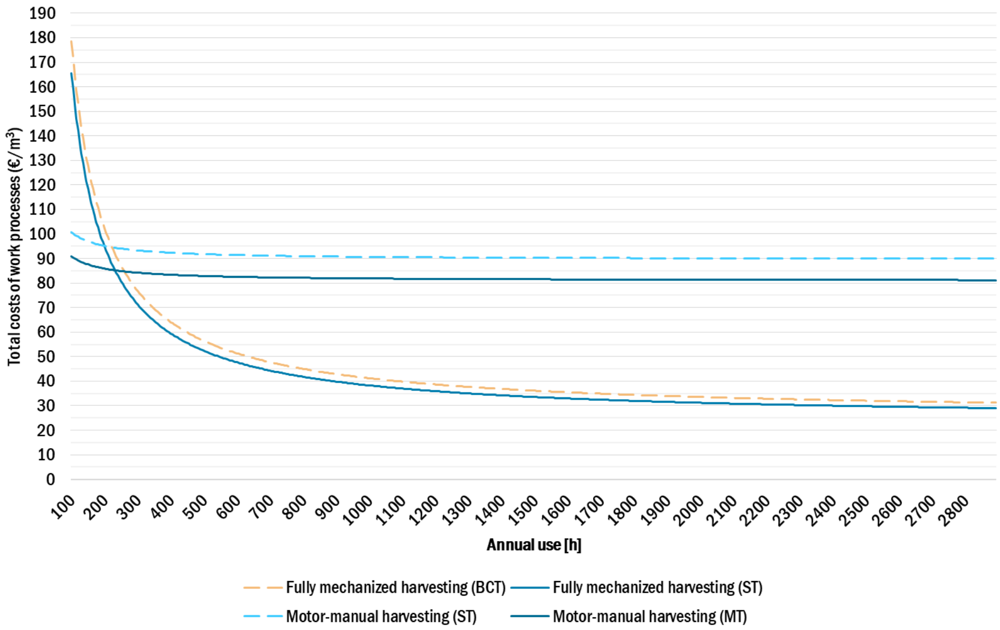

Figure 5. Effect of annual use of machinery on the operational cost for the different treatments.

Analysis of net cost (revenues-cost) shows a cost of 389 €/ha for motor manual ST and 259 €/ha for motor manual MT, a 33% lower cost (Table 3). The tinning-based supply systems show a positive result, where the net cost was 258 €/ha (3.9 €/t) for the ST based system and was 27% higher per ha for the BCT based system, due to lower operational cost and higher biomass removal/ha. The corresponding profit per extracted ton was 44% higher for the BCT system.

Table 3. Net cost analysis for the different systems

	Reference system			
	Motor-manual thinning (ST)	**Motor-manual thinning (MT)**	**Fully mechanized thinning (BCT)**	**Fully mechanized thinning (ST)**
Costs (in €)	108.83 €	82.92 €	1,749.66 €	1,944.26 €
Harvesting (in €)	108.83 €	82.92 €	857.45 €	926.82 €
Haulage (in €)	0.00 €	0.00 €	440.78 €	476.44 €
Wood chipping (in €)	0.00 €	0.00 €	255.18 €	275.83 €
Wood chips transport (in €)	0.00 €	0.00 €	196.26 €	265.17 €
Revenue from sales (in €)	/	/	1,913.18 €	2,067.98 €
Price of wood chips (EUR per fresh ton)	/	/	65	65
Quantity of wood chips (fresh ton)	/	/	29.434	31.815
Time consumtion (PMH per ha)	9.0	6.0	8.2	8.9
Worksite area (m²)	2800	3200	5000	4800
Net revenue (in €)	**-108.83 €**	**-82.92 €**	**163.52 €**	**123.72 €**
Net revenue (€ per ha)	-388.67 €	-259.11 €	327.04 €	257.75 €
Net revenue (i€ per ton)	/	/	5.56 €	3.89 €

4. Systems analysis – the Spain case

In Spain, time studies of a Komastu 901.4 harvester equipped with the Bräcke C16.C felling and bunching head were performed in *Quercus pyrenaica* coppice thinnings (Herguido-Sevillano et al. submitted ms). The harvester work with two methods (BCT and ST) and its productivity and cost was then compared to 1) mechanized felling and bunching with a John Deere 643J heavy feller-buncher equipped with a JD FD 45 disc saw felling head and 2) motor-manual felling and bunching by a team of three forest workers.

The productivity equations were based on Tolosana et al. (2018), Tolosana et al. (unpublished ms) and Herguido-Sevillano et al. (submitted ms) and were applied using the average values in the studied sites (6.0 dry kg/tree and basal area removal of 46%) (Herguido-Sevillano et al. submitted ms).

Results show the lowest cost for the mechanized work and were on average 34.8 €/dry t for the BCT treatment, 12% lower than the ST treatment (Table 4). The unit costs are not competitive in the present market conditions but are clearly smaller using the tried technology.

Table 4. Cost analysis of the different thinning systems

		Hourly cost (€·ProdH^{-1})	Estimated Productivity (odt·ProdH^{-1})	Unit cost (€·odt^{-1})
3 forest workers w/chainsaws		72	1.438	50.1
Heavy Feller Buncher JD643J w/JD FD45 sawdisc felling head		120	1.105	108.6
Komatsu 901.4 w/Bracke C16c felling head	ST	135	3.243	39.4
	BCT		3.874	34.8

The Retrabio mulcher-collector was studied in systematic mulching of willow coppice with 36000 trees/ha (average DBH around 2 cm, average maximum height around 5 m and 50% cover of shrubs) (Fig. 6). Its base machine was a forwarder. The Retrabio is equipped with a rotor with hammers rotating upward on the machine front to mulch shrubs or very small trees and sending the shredded material, by means of a flywheel and discharge spout, to a 24 m^3 container on the rear (Fig. 6).

Figure 6. The Retrabio mulcher-collector harvesting system

The collection efficiency of the Retrabio was 45% and its productivity reached 1.86 dry t/PMh (or 1.64 dry t/SMh). The net cost (for a roadside biomass price of 20 €/fresh t) was -205.6 €/ha, similar to the alternative conventional hammer mulcher system.

The Retrabio mulcher-collector was also studied in systematic mulching in strips of post-wildfire regenerated maritime pine stands, followed by selective clearing on the untreated strips. The stand had 4100 trees/ha (2.9 cm DBH and 1.9 m average height, with shrubs covering 23%) The collection efficiency of the Retrabio was 35-40% and the average productivity was 2.3 dry t/SMh (0.67 ha/SMh).

The productivity was linearly correlated with extracted basal area. The net cost (including revenues from the biomass) was -95 €/ha, saving 91 €/ha when compared to the conventional treatment with hammer mulcher.

The mulcher-bundler BioBaler was time studied in two sites for systematic mulching in a post-wildfire regenerated young and dense maritime pine stand (around 1.5 cm DBH and less than 2 m height). The BioBaler collects woody material from 1 to 10 cm in diameter, using a continuous technology of mulching and bundling in bales of 1.2 m wide and 1.2 m in diameter.

The efficiency of the BioBaler was positively correlated to pine biomass volume. The collection efficiency was on average 32%. Results show that the BioBaler on average reached a productivity of 1.4 dry t/SMh (0.75 ha/SMh).

In two sites, the BioBaler was compared to the alternative conventional chain mulcher system. Although the BioBaler areal based productivity was slightly greater, the operational cost was almost twice the chain mulcher system. The selective motor-manual treatment with clearing saws was less efficient in the areas treated with BioBaler, due to the higher stumps. As the biomass price was low, the net cost of the BioBaler treatment (cost-incomes) was 475 €·ha-1, compared to 350 with chain mulcher (both with the same selective motor-manual clearing afterwards).

5. Conclusions

We conclude that the Bräcke C16.C head render higher cost efficiency in the felling and bunching work in thinning's compared to conventional harvesters, which in turn render lower biomass supply cost. This is true for all studied stand conditions.

Boom-corridor thinning render higher harvesting cost efficiency than selective thinning. This is true for all studied stand conditions. Motor manual felling, delimbing and bucking work using the minimizing (situation) thinning method render lower treatment cost per ha compared to the conventional selective thinning method in pole beech stands. Thinning out biomass for energy use renders a positive net revenue, compared to clearing work, in pole beech stands

The Retrabio allowed a similar cost to the alternative treatment in the willow coppice, while its use in post-wildfire maritime pine regeneration led to a saving of 91 €·ha-1 (48.9%) compared to the alternative treatment with hammers mulcher. It is well-worthen to extend the studies about this technology to a wide range of small tree stands and shrublands as it can allow cheaper wildfire preventive treatment than the usual means.

The BioBaler was slightly more efficient, in terms of surface treated by workhour than the alternative treatment (chain mulcher), but its net cost of the treatment per hectare was 35.7% more expensive, because of four reasons: the higher hourly cost of BioBaler, the low price of the produced biomass – because its poor quality -, the low efficiency of biomass collection (32%) and the lower productivity of the further selective motor-manual treatment in the area treated with BioBaler, due to the high stumps that difficulted the work with clearing saws. The mulching technology of BioBaler should be improved in order to increase its efficiency and leave lower stumps on the terrain to be competitive with commonly used technologies.

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