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Applying the Activity-Based Costing to Cut-to-Length Timber Harvesting and Trucking

Tuomo Nurminen, Heikki Korpunen and Jori Uusitalo

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The supply chain of the forest industry has increasingly been adjusted to the customer's needs for precision and quality. This has changed the operative environment both in the forest and on the roads. As the total removal of timber is increasingly divided into more log assortments, the lot size of each assortment decreases and the time consumed in sorting the logs increases. In this respect, the extra assortments have made harvesting work more difficult and affected the productivity of both cutting and forest transport; this has thus increased the harvesting costs.

An activity-based cost (ABC) management system is introduced for timber harvesting and long-distance transport, based on the cut-to-length (CTL) method, in which the logistic costs are assigned to timber assortments and lots. Supplying timber is divided into three main processes: cutting, forest transport, and long-distance transportation. An ABC system was formulated separately for each of these main operations. Costs were traced to individual stands and to timber assortment lots from a stand. The cost object of the system is thus a lot of timber that makes up one assortment that has been cut, forwarded, and transported from the forest to the mill. Application of the ABC principle to timber harvesting and trucking was found to be relatively easy. The method developed gives estimates that are realistic to actual figures paid to contractors. The foremost use for this type of costing method should be as a tool to calculate the efficiency of an individual activity or of the whole logistic system.

Keywords logistics, bucking, cutting, forest transport, long-distance transportation, trucking, time consumption, timber assortment, cost driver
Addresses *Nurminen*, Metsätoimisto Tuomo Nurminen, Joensuuntie 5 B 8, FI-41800 Korpilahti, Finland; *Korpunen* and *Uusitalo*, Finnish Forest Research Institute, Parkano Research Unit, Kaironiementie 54, FI-39700 Parkano, Finland **E-mail** jori.uusitalo@metla.fi
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1 Introduction

In the last ten to fifteen years, remarkable changes have occurred in the timber procurement that is based on mechanised cut-to-length (CTL) harvesting. This supply chain of the forest industry has increasingly been adjusted to the customer's needs for precision and quality (Uusitalo 2005), while the cost-efficiency and flexibility of upstream logistics have been emphasised. In Finland, the forest industry has outsourced a great deal of its operative timber procurement actions. Timber harvesting and long-distance transportation are carried out almost completely by private entrepreneurs; who, as the timber suppliers, are then responsible to fulfil the requirements of the primary wood processing industry.

The private entrepreneurs and their employees, who conduct harvesting and long-distance transportation operations, are responsible not only for actual work processes, but also for issues relating to timetables, the quality of the raw material, the silvicultural result, and various environmental aspects. There are also some indications that even more comprehensive responsibility for raw wood deliveries will be given to these timber suppliers in the future (Palander and Väätäinen 2005). For example, in the near future, timber suppliers could also carry out, timber purchasing and the regional planning of all timber logistics.

Coinciding with these developments in timber procurement, the entire cut-to-length based environment has become more complex, as product-based bucking has increased the number of timber assortments (Uusitalo 2005, Nurminen et al. 2006, Nurminen and Heinonen 2007). This has changed the operative environment both in the forest and on the secondary transportation routes. As the total removal of timber is increasingly divided into several assortments, the lot size of each assortment decreases while time consumption for sorting the logs increases (Bjurulf 1992, Bjurulf 1993, Brunberg 1993, Berg et al. 1996, Poikela and Alanne 2002, Nurminen et al. 2006). In this respect, extra assortments have made harvesting work more difficult and affected the productivity of both cutting and in forest transport (Väkevä ym. 2001, Poikela and Alanne 2002, Nurminen et al. 2006), and thereby increased the harvesting costs (Brunberg and Arlinger 2001, Poikela and Alanne 2002).

Since the lot (i.e. shipment) size of an assortment in storage at a roadside landing has decreased, the logs for a full shipment have to be collected from several storage points. This has increased the absolute level and the variation in the time consumed (Väkevä et al. 2000, Nurminen and Heinonen 2007) and has thus affected the transportation costs. In this respect, product-based bucking should be seen as an important variable, among others, affecting the productivity and unit costs of timber logistics (Arce et al. 2002).

Product-based bucking combined with the impending and existing responsibilities of timber suppliers have lead to increasing demands for cost management. The planning, profitability calculations, and pricing of products should be based on accurate information about the performance and costs of logistics. Since stand conditions, transportation routes, and bucking can vary greatly, information about average costs may be insufficient. In the pricing of deliveries, the logistic costs should be traced and assigned to each product (i.e. timber assortment) in the wood supply chain based on their real production cost. Product related costing is also needed when the net revenues of processing industries are calculated by comparing the post processing value of a raw material with its procurement costs.

A way for timber suppliers to adjust and improve their cost management may be activity-based costing (ABC). Since its development in the late 1980's, the ABC system has become very popular not only among manufacturing companies, but also with other types of organisations including: financial services, utilities, telecommunications, government agencies, defence, health care, and logistics (Turney 1991, Pirttilä and Hautaniemi 1995, Lere 2000). The basic idea of ABC is to assign a cost to a product according to the actual resources, both material and service, utilised to make it.

In a traditional cost accounting system, the final cost of a manufactured product is calculated first by identifying the fixed costs and variable costs. The basic principle of traditional costing is that the fixed costs and the variable costs are assigned to products according to a measure of the units produced. This method works well as long as the final share of the combined variable costs is big and the number of units manufactured

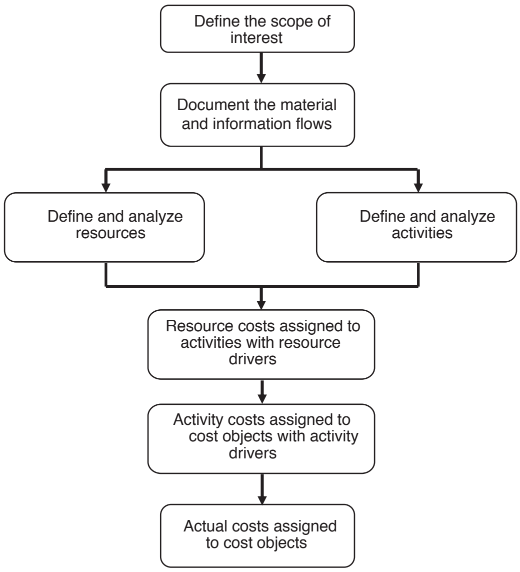

Fig. 1. Steps for designing an activity-based costing (ABC) system (modified from Pirttilä and Hautaniemi 1995).

is relatively low. However, modern manufacturing requires high fixed costs in the form of more capital-intensive production facilities, in addition, the number of products produced has increased markedly; there has thus been a great demand for a more sophisticated costing system (Turney 1991, Lere 2000).

In general, to produce products or services, there is a need for certain activities that consume the resources of a company. The need for specific activities and resources may, however, vary between individual products. The principle of ABC is to trace the costs that originate from a specific product (Turney 1991, Kaplan and Anderson 2004).

Even if the ABC system is designed for each individual case, its structure can be divided into a few general steps (Fig. 1). First, the scope and the type of cost information needed should be evaluated; this sets requirements for accuracy on the input data (Pirttilä and Hautaniemi 1995, Lere 2000). Next, to identify relevant resources (e.g. personnel and machinery) and activities (e.g. work processes) the material and information flows should be recognized. At this phase, existing costing systems can be utilized (Pirttilä and Hautaniemi 1995). The actual assignment of costs is conducted in two stages. First, the costs of resources are assigned to activities by the means of "resource drivers" and secondly, the activity costs are assigned to cost objects (e.g. products) by the means of "activity drivers" (Turney 1991, Pirttilä and Hautaniemi 1995). In many cases it is simpler only to talk about one driver, the resource or "cost" driver that links the resources, activities, and product together in a meaningful way.

The basic aim and advantage of ABC is to indicate the function of business processes and provide information on the origin and causality of costs. In addition to providing pure cost reports, it also reveals the efficiency or inefficiency of operations (Turney 1991). Two main applications of this costing system are: (1) estimating forthcoming costs or (2) assigning real costs after production. The desired application determines the type of information used: cost estimates are usually based on either theoretical data or earlier experience, whereas the definition of real activities and costs is usually based on a company's accounting system and follow-up statistics.

In the field of timber logistics, few applications of ABC are reported. One example by Oijala and Terävä (1994) suggested a method for allocating harvesting costs to timber assortments. Recently, general guidelines for applying ABC to road transport were given by the Ministry of Transport and Communications Finland (Oksanen 2003). There are also a few rather good examples of how ABC has been implemented in sawmills (Wessels and Vermaas 1998, Rappold 2006).

Here an activity-based cost (ABC) management system is introduced and demonstrated for timber harvesting and trucking based on the cut-to-length (CTL) harvesting method. Within this management system, logistic costs are assigned to timber assortments and timber lots. The act of supplying timber to a mill is divided into three main processes: cutting, forest transport (i.e. forwarding), and long-distance transportation (i.e. trucking). A costing system is formulated separately for each of these processes. Costs are traced to individual stands and the lots of timber assortments from that stand; the system's cost object is therefore a lot of timber from a specific assortment that is cut, forwarded, and trucked to a mill.

The ABC management system may be used

either to estimate future costs or to assign true costs after production. The scope of the system includes cutting, forest transport, and timber trucking. Examples were calculated based on information describing common CTL timber logistics in Finland, which use a mechanised harvester, forwarder, and specialised timber truck with removable truck mounted crane. The management system is explained through examples that have been based on theoretical costs and resource consumption. Information was gathered from recent studies and from the trade associations of the harvesting and trucking entrepreneurs. The examples are presented to help readers more easily comprehend and use the equations presented.

2 Timber Supplier's ABC System

2.1 Resources and Cost Factors

Resources relevant to a timber supplier include: labour, machinery, other equipment, and real estate. In general, the annual use of resources can be measured in terms of work time or output, and is presented for each machinery unit of a company (Table 1). The use of resources is based on either follow-up statistics or theoretical cost estimates.

The division of costs and single cost factors for cutting and forest transport typically includes three categories: (i) fixed costs, (ii) labour costs, and (iii) operational costs (Table 2) while the costs for long-distance transport are divided into (i) time-dependent costs and (ii) distance-dependent costs (Table 3). For this use of the ABC system, the relocation costs for a harvester and forwarder are analyzed separately from other operational costs. In practice, when applying cost factors the following equations may be found useful:

$$SL_y = \frac{SL_h}{OH_a} \tag{1}$$

$$SV = PP * \left(1 - \frac{DP}{100}\right)^{SL_y} \quad \text{Nurminen (2003)} \tag{2}$$

$$c_{drwl} = 59.928 d_{drwl}^{-0.0857} + 1.8 \quad \text{Väkevä et al. (2004)} \tag{3}$$

$$c_{drfl} = 83.445 d_{drfl}^{-0.0587} \quad \text{Väkevä et al. (2004)} \tag{4}$$

Table 1. Example of the annual use of a single-grip harvester, forwarder, and timber truck. Time estimations for a harvester and forwarder are presented according to the Nordic Forest Study Council (Samset et al. 1978) and time estimations for trucking are based on the study of Nurminen and Heinonen (2007).

	Harvester		Forwarder		Truck		
Work shift arrangements							
One shift	6	months/year	6	months/year		2	months/year
Two shifts	5	months/year	5	months/year		9	months/year
Total time	52	weeks/year	52	weeks/year		52	weeks/year
Unutilized time	4	weeks/year	4	weeks/year		4	weeks/year
Total working time	48	weeks/year	48	weeks/year		48	weeks/year
Length of work shift	8	hours	8	hours		10	hours
Number of work days	22	days/month	22	days/month		21	days/month
	239	days/year	239	days/year		231	days/year
Operational time[a)]	2361	hours/year	2500	hours/year	Transportation time	3360	hours/year
Repair, service, delays	417	hours/year	278	hours/year	Repair, service	840	hours/year
Total work place time	2778	hours/year	2778	hours/year	Total work time	4200	hours/year
Relocation time	200	hours/year	200	hours/year	Transportation output	44160	m^3/year
Total work time	2978	hours/year	2978	hours/year		110588	km/year
						912	loads/year

a) = Gross-effective time (incl. delays < 15 min)

$$c_{drd} = \frac{\left(59.928 s_{drwl}^{-0.0857} + 1.8\right) + \left(83.445 d_{drfl}^{-0.0587}\right)}{2} \quad (5)$$

Modified after Väkevä et al. (2004)

where

SL_y expected service life in years,
SL_h expected service life in operational hours (harvester and forwarder), or in driven kilometres (tractor and trailer), or in number of loads (crane),
OH_a Annual operational hours (harvester and forwarder), or annual driven kilometres (tractor and trailer), or annual number of loads (crane),
SV salvage value: €,
PP purchase price: €,
DP annual depreciation: %,
c_{drwl} fuel consumption when driven unloaded: litres/100 km (crane is carried),
d_{drwl} distance driven unloaded: km,
c_{drfl} fuel consumption when driven fully loaded: litres/100 km,
d_{drfl} distance driven loaded: km, and
c_{drd} fuel consumption when driven partially loaded between landings: litres/100km.

Generally, the fixed costs for cutting and forest transport comprise: (i) depreciation of machinery (Eq. 6), (ii) interest (Eq. 7), and (iii) assorted other fixed costs. Labour costs include the base wage, any wage premium for special working hours (e.g. evenings, holidays, etc.), and indirect wage costs. Travel and meal compensation are included with labour costs. Operational costs include fuel, lubricants, other minor consumable equipment, repairs, and maintenance. The total resource cost per operational hour is calculated by means of Eq. 8.

$$AC_{dep} = \frac{PP - SV}{SL_y} \qquad \text{Nurminen (2003)} \quad (6)$$

$$AC_{\mathrm{int}} = \frac{I}{100} * \frac{PP + SV}{2} \qquad \text{Nurminen (2003)} \quad (7)$$

$$HC = \frac{AC_{fix} + AC_{lab} + AC_{ope}}{OH_a} \quad (8)$$

where

AC_{dep} straight-line depreciation cost (separate groupings of the base machinery with the harvester head and of the forwarder with its trailer and crane): €/a,
AC_{int} interest cost (average invested capital): €/a,
I interest rate: %,
HC total cost per operational hour: €/h,
AC_{fix} fixed costs: €/a,
AC_{lab} labour costs: €/a, and
AC_{ope} operational costs: €/a.

For long-distance transport, in this case only by trucking, the total resource cost is a sum of (i) the time-dependent costs (i.e. depreciation, interest, insurance, traffic tax, administration, maintenance, and labour), (ii) the distance-dependent costs (i.e. fuel, lubricants, repair, and tires), and (iii) the crane costs (i.e. fixed and operational). Depreciation and interest are calculated in the same way as for cutting and primary transport (Eqs. 6 and 7). Time-dependent costs are calculated per year and per transportation hour. However, the distance-dependent costs are calculated per load according to the time consumed and other characteristics of a complete trip (Nurminen and Heinonen 2007).

2.2 Activities

The harvesting and secondary transport activities should be explicitly recognizable for each stand and complete trip, and they should be as similar as possible in the division of work to time elements commonly used in work studies. The divisions of activities for the described management system are similar to those used by Nurminen et al. (2006) in their time studies of the mechanized CTL harvesting system and of those used by Nurminen and Heinonen (2007) to study timber trucking (Table 4).

2.3 Activity Costs of the Cost Objects

2.3.1 *Cutting and Forest Transport*

At the stand level the machinery resource cost, or machinery cost per hour (*HC*), for cutting and forest transport is constant. The cost per operational hour of a machine is assigned to the main phases of the work cycle according to their time consumption.

Table 2. Cost factors for a single-grip harvester and forwarder system (mid-weight class) coupled with example values. Costs are given excluding value-added tax (VAT). Purchase prices include normal forest and data processing equipment. The price levels are based on the situation in Finland in 2005. Sources: [1] Väätäinen et al. (2006a); [2] Rieppo and Örn (2003); [3] Nurminen (2003); and [4] Väätäinen et al. (2006b).

Cost factor	Harvester	Forwarder	Unit	Source
Fixed costs				
Purchase price of base machine	283667	221333	€	[1]
Service life in operational hours	15000	15000	h	[1]
Service life in years	6	6.0	a	Eq. 1
Annual depreciation of purchase price	27	27	%	[1]
Salvage value	38411	33491	€	Eq. 2
Purchase price of harvester head	50000		€	[1]
Service life in operational hours	7000		h	[1]
Service life in years	3		a	Eq. 1
Annual depreciation of purchase price	27		%	[1]
Salvage value	19667		€	Eq. 2
Interest rate	5	5	%	[1]
Insurance (traffic, fire, etc.)	2200	1750	€/year	[1]
Administrative and maintenance costs (e.g. ADP, phone, accounting, electricity, water)	5500	5500	€/year	[1]
Labour costs				
Hourly wage for total working time	10.9	10.1	€/h	[1]
Shift premium (evenings)	0.75	0.75	€/h	[1]
Indirect wage costs, share of the taxable salary	63	63	%	[1]
Travel compensation	0.38	0.38	€/km	[1]
Travel distance (roundtrip)	60	60	km/shift	[1]
Meal compensation	6.4	6.4	€/day	[1]
Meal compensation	20	20	days/year	[1]
Operational costs				
Fuel consumption	12.79	10.76	litres/h	[2]
Fuel price	0.55	0.55	€/liter	[1]
Motor oil consumption	0.10	0.10	litres/h	[1]
Motor oil price	1.30	1.30	€/liter	[1]
Transmission oil consumption	0.10	0.10	litres/h	[1]
Transmission oil price	2.00	2.00	€/liter	[1]
Hydraulic oil consumption	0.20	0.20	litres/h	[1]
Hydraulic oil price	1.35	1.35	€/liter	[1]
Chainsaw oil consumption	0.43		litres/h	[1]
Chainsaw oil price	1.35		€/liter	[1]
Chainsaw chain consumption	0.06		pcs/h	[1]
Chainsaw chain price	15.00		€/pcs	[1]
Chainsaw disc consumption	0.02		pcs/h	[1]
Chainsaw disc price	53.00		€/pcs	[1]
Marking paint consumption	0.30		litres/h	[1]
Marking paint price	1.07		€/liter	[1]
Repair and maintenance (incl. spare parts and maintenance equipment)	9.66	5.06	€/h	[3]
Relocation cost with truck (excluding labour costs)	1.62	1.62	€/km	[4]
Annual relocation distance	8649	8649	km	[4]

Table 3. Cost factors for a timber truck (three-axel, 6×4 power configuration; a removable hydraulic crane; and a four-axel trailer. The total vehicle mass limit was 60 tons). Sources: [1] SKAL 2006.; [2] Väkevä et al. (2004); [3] Salo and Uusitalo (2001); and Eqs. 1–5.

Cost factor	Value	Unit	Source
Time-dependent costs			
Purchase price of tractor	128500	€	[1]
Service life in kilometres	667000	km	[1]
Service life in years	6.0	a	Eq. 1
Annual depreciation of purchase price	22	%	[1]
Salvage value	28713	€	Eq. 2
Purchase price of trailer	44060	€	[1]
Service life in kilometres	1000500	h	[1]
Service life in years	9.0	a	Eq. 1
Annual depreciation of purchase price	25	%	[1]
Salvage value	3264	€	Eq. 2
Purchase price of crane	42000	€	[1]
Service life	3975	loads	[1]
Service life in years	4.4	a	Eq. 1
Annual depreciation of purchase price	25	%	[1]
Salvage value	11993	€	Eq. 2
Interest rate	5	%	[1]
Insurance (motor vehicle, comprehensive, liability, etc.	8270	€/year	[1]
Regulation fees (taxes, safety inspection, etc.)	2690	€/year	[1]
Administration (ADP, phone, accounting, training, etc.)	4340	€/year	[1]
Maintenance (electricity, water, etc.)	2190	€/year	[1]
Hourly wage for total work time of drivers	11.94	€/h	[1]
Shift premium (evening)	0.75	€/h	[1]
Indirect wage costs, share of the taxable salary	68	%	[1]
Distance-dependent costs			
Fuel consumption unload[a)]	e.g. 43.1	litres/100 km	Eq. 3
Fuel consumption fully loaded[a)]	e.g. 65.6	litres/100 km	Eq. 4
Fuel consumption between storage points for partial load [a)]	e.g. 58.6	litres/100 km	Eq. 5
Fuel consumption, other driving (to service hall, etc.)[a)]	e.g. 5.6	litres/load	Eq. 3
Fuel consumption when stopped and idling	7.8	litres/load	[2]
Fuel price	0.87	€/liter	[1]
Motor oil consumption	200	litres/year	[1]
Motor oil price	1.38	€/liter	[3]
Transmission fluid consumption	40	litres/year	[1]
Transmission fluid price	2.07	€/liter	[3]
Repair and maintenance of tractor and trailer	0.154	€/km	[1]
Repair and maintenance of crane	0.022	€/km	[1]
Service life of tires[b)]	80000	km	[1]
Number of remoulds (i.e. retreads) during service life	1.5	pcs/tire	[1]
Tire price, tractor	500	€/pcs	[1]
Tire price, trailer	390	€/pcs	[1]
Remould (i.e. retread) price	250	€/pcs	[1]

[a)] Dependent on distance driven.
[b)] Number of tires: tractor 10, trailer 16.

Table 4. Timber supply activities used for development of the ABC system. For exact definitions see Nurminen et al. (2006) and Nurminen and Heinonen (2007).

Cutting	Forest transport	Trucking
Travel within a stand	Driving unloaded	Unloaded
Positioning-to-cut	Driving fully loaded	Storage activities
Felling	Driving while loading	Partial load between landings points
Delimbing and cross-cutting	Loading	Fully loaded
Sorting	Unloading	Unloading
Boom retraction	Delays	Loading
Clearing	Relocation	Other driving
Moving logs, tops, etc.		Delays
Delays		
Relocation		

Time consumption for cutting: felling, delimbing, and crosscutting of a stem into sorted piles, is employed as both a resource and cost driver. Assignments of time consumption and costs are at the stem-level. The time consumptions for the use of a mechanised single-grip harvester include: travel within a stand; positioning-to-cut; felling; boom retraction; clearing; and moving logs, tops, etc.; these are jointly assigned at the stem level for all timber assortments bucked from a stem. Whereas, the time consumptions for delimbing and cross-cutting, as well as sorting are assigned directly to the timber assortments.

If i is a log from any stem j, and k is any assortment to be taken from a stand, then the costs related to the use of a mechanised single-grip harvester for cutting a single stem that includes assortment k is calculated as follows

$$\hat{C}_{cs} = \left(\left(t_{mo} + t_{pc} + t_{fe} + \sum_{i=1}^{n_i} t_{dc} + t_{so} + t_{bi} + t_{cl} + t_{ml} \right) a_c \right) \left(\frac{HC_c}{60} \right) \tag{9}$$

where

$\hat{C}_{cs}$ cost of cutting a stem that includes assortment k: €,

t_{mo} time consumption for travel within a stand: min/stem,

t_{pc} time consumption for positioning-to-cut: min/stem,

t_{fe} time consumption for felling: min/stem,

t_{dc} time consumption for the delimbing and cross-cutting of one log in assortment k: min/log,

i log form stem j,

n_i number of logs from stem j,

k an assortment from a stand,

t_{so} time consumption for sorting: min/stem,

t_{bi} time consumption for boom retraction: min/stem,

t_{cl} time consumption for clearing: min/stem,

t_{ml} time consumption for moving logs, tops, etc.: min/stem,

a_c coefficient that converts the effective time (E_0) of cutting into gross-effective time, and

HC_c total resource cost of cutting per operational hour: €/h.

When n_j is the number of stems in a stand l where assortment k is cut, then C_{cut} is the unit cost for the cutting of assortment k from stand l. This cost is calculated as the sum (Eq. 10) of the cutting costs for n_j stems divided by the sum of the timber volume V_k removed from stand l that is included into assortment k.

$$C_{cut} = \frac{\sum_{j=1}^{n_j} \hat{C}_{cs}}{V_k} \tag{10}$$

where

C_{cut} unit cost for the cutting of timber in assortment k from stand l: €/m^3,

V_k removal volume from a stand l that is in assort-

ment k: m^3/stand, and
n_j number of stems in a stand l where assortment k is cut.

Combining equations 9 and 10 produces:

$$C_{cut} = \frac{\sum_{j=1}^{n_j}\left(\left(t_{mo} + t_{pc} + t_{fe} + \sum_{i=1}^{n_l} t_{dc} + t_{so} + t_{bi} + t_{cl} + t_{ml}\right)a_c\right)\left(\frac{HC_c}{60}\right)}{V_k} \quad (11)$$

For forest transport, the movement of timber from where it was cut to the roadside, the assignments of time consumption and costs are conducted at the level of the timber lot (i.e. the removal volume V_k from a specific stand that is then included into assortment k (m^3/stand)). When using a forwarder for forest transport, timber assortments are hauled to a roadside either as single loads (i.e. a load is made-up of logs from only one timber assortment) or as mixed loads (Nurminen et al. 2006).

In the case of single loads, time consumption is employed as both a resource and cost driver. The unit cost for hauling an assortment k from a stand to the roadside as single loads is calculated as follows

$$C_{forw\_single} = \left(\left(t_{de} + t_{dl} + t_{dw} + t_{lk} + t_{ulk}\right)a_f\right)\left(\frac{HC_f}{60}\right) \quad (12)$$

where

C_{forw_single} unit cost for forest transport of logs in assortment k from a specific stand carried out in single loads: €/m^3,
t_{de} time consumption for driving unloaded: min/m^3,
t_{dl} time consumption for driving loaded: min/m^3,
t_{dw} time consumption for driving while loading: min/m^3,
t_{lk} time consumption for the loading of assortment k: min/m^3,
t_{ulk} time consumption for the unloading of assortment k: min/m^3,
a_f coefficient that converts effective time (E_0) of forwarding into gross-effective time, and
HC_f total resource cost of forest transport per operational hour: €/h.

For mixed loads (i.e. the hauling of logs from several assortments in the same load) there is an increase in the time consumed in loading and unloading (Nurminen et al. 2006). Before the forest transport costs can be assigned to individual assortments that were transported as mixed loads, a general unit cost, C_{fm}, for all portions of all assortments hauled as mixed loads is determined. When n_k is the number of assortments that are hauled as mixed loads, then the unit cost for forest transport of mixed loads for n_k assortments is calculated as follows

$$C_{fm} = \left(\left(t_{de} + t_{dl} + t_{dw} + t_{lm} + t_{ulm}\right)a_f\right)\left(\frac{HC_f}{60}\right) \quad (13)$$

where

C_{fm} unit cost for forest transport carried out in mixed loads: €/m^3,
t_{lm} time consumed in loading of n_k assortments: min/m^3, and
t_{ulm} time consumed in unloading of n_k assortments: min/m^3.

The cost of mixed loads is assigned to the assortments in question by comparing it to the situation where the same removal of timber as included in n_k assortments was hauled as single loads. The difference between these costs is called the sorting cost, C_{fs}, this is then assigned to the respective assortments by using the number of assortments as a cost driver (Eq. 14).

$$C_{fs} = \frac{\left(C_{fm} - C_{forw\_single}\right)V_m}{n_k V_k} \quad (14)$$

where

C_{fs} unit cost for sorting an assortment k: €/m^3,
V_m removal volume that was hauled as mixed loads: m^3/stand, and

n_k number of assortments carried as mixed loads.

Thus the unit cost for hauling a portion of assortment k from a stand to the roadside as mixed loads, is calculated as follows

$$C_{forw\_mixed} = C_{forw\_single} + C_{fs} \quad (15)$$

where

C_{forw_mixed} unit cost of forest transport of assortment k carried out in mixed loads: €/m^3.

The unit cost for forwarding all the logs that are part of assortment k from a specific stand is then calculated as

$$C_{forw} = \frac{C_{forw\_mixed} * V_{fload} * n_{ml} + C_{forw\_single} * V_{fload} * n_{sl}}{V_k} \quad (16)$$

where

C_{forw} unit cost for the forest transport of assortment k from a specific stand: €/m^3,

V_{fload} forwarding load size: m^3,

n_{ml} number of loads hauled as mixed loads, and

n_{sl} number of loads hauled as single loads.

2.3.2 Trucking

The unit cost for long-distance transport using a timber truck with truck mounted crane is dependent on time, distance, and operational costs of the crane. The cost driver for the time-dependent costs is a load´s transportation time. For distance-dependent costs, the cost drivers are the distances for those work phases that determine fuel consumption, the maintenance and lubrication costs of the truck, and tire cost. The cost driver for the crane is the volume of the load, since this determines its variable (i.e. repair and hydraulic oil) costs. Using the ABC system these costs are assigned to the assortments by dividing them into transportation lots.

At a roadside storage, the total removal volume of an assortment, forms a storage lot. When hauling these storage lots to the mills that ordered the assortments they compose, it may be necessary to divide them into transportation lots, which correspond to a truck's load capacity; this of course depends on the volume of the storage lot. The majority of these lots are trucked as single-sourced, full loads. However, at least one of these lots, typically the final one transported, is a residual lot that is smaller in volume than a truck's capacity (Nurminen and Heinonen 2007). This lot is trucked as a multi-sourced, full load, often together with other residual lots collected from the necessary number of other storage points to create a full load. Compared to a roundtrip for a single-source load, a multi-source roundtrip includes the additional activity of driving between storage points and the repetition of some auxiliary activities at each storage landing (Nurminen and Heinonen 2007). Since the resource consumption for loads that are multi-source differ from those that are single-source, the unit cost for the long-distance transportation of any storage lot is calculated with the ABC system in two separate stages: all timber of an assortment that was trucked as single-source loads and any timber of the assortment that was trucked as residual lots in multi-source loads.

For every storage point s there is a volume V_s that is loaded and trucked from that point. For a multi-source load, the number of storage points, n_s, comprises a full load, V_{load}, with multiple storage points s (i.e. $s = 1, 2, \ldots, n_s$) (Eq.18).

$$V_{load} = \sum_{s=1}^{n_s} V_s \quad (17)$$

The time consumed doing log deck activities were assessed by dividing the activities into those for loading at a roadside landing and those for unloading at a log yard. The truck mounted crane may not be used for all loading and unloading; for example, at some log yards special cranes or front-end loaders are used for unloading. As a simplification, the equations shown here assume that only the truck's crane is used for the loading and unloading of all loads.

The t_{ld_s} is the time consumed at the storage point s. It is a sum of the time consumed by the actual loading and by the auxiliary activities (e.g. setting up the crane, securing the crane, securing the load, etc.), which is calculated as follows:

$$t_{1d\_s} = t_{lo\_s} + t_{al\_s} \quad (18)$$

where

t_{ld_s} total time consumed at a storage point s: min,

t_{lo_s} actual loading time at storage s: min, and

t_{al_s} time consumed by auxiliary activities at a storage s: min.

The time consumed at the terminal log yard, t_{unl}, is a sum of the time consumed in queuing and other waiting, actual unloading, and for auxiliary activities (e.g. removing any securing binders, weight scaling, etc.), which is calculated as follows:

$$t_{unl} = t_{ul} + t_q + t_{aul} \quad (19)$$

where

t_{unl} time consumed at the terminal log yard: min,

t_{ul} actual unloading time: min,

t_q queuing and other waiting: min, and

t_{aul} time consumed by auxiliary activities at the terminal log yard: min.

The time consumed by the actual use of the truck mounted crane, t_{cr}, is calculated as

$$t_{cr} = \sum_{s=1}^{n_s} t_{lo\_s} + t_{ul} \quad (20)$$

where

t_{cr} time consumed in the use of the truck mounted crane: min.

The total time consumed in a long-distance roundtrip with a single-source load is calculated as follows

$$t_{load\_single} = t_{drwl} + t_{1d\_s} + t_{drfl} + t_{unl} + t_{odr} + t_{del} \quad (21)$$

where

t_{load_single} time consumed by the roundtrip of a specific single-source load: min,

t_{drwl} time consumed when driving unloaded: min,

t_{ld_s} time consumption by log deck activities at a storage point s: min

t_{drfl} time consumed when driving fully loaded: min,

t_{odr} time consumed by other driving: min, and

t_{del} time consumed by delays: min.

Similarly the total time consumed in a long-distance roundtrip with a multi-source load is calculated as follows

$$t_{load\_multi} = t_{drwl} + t_{drd} + \sum_{s=1}^{n_s} t_{1d\_s} + t_{drfl} + t_{unl} + t_{odr} + t_{del} \quad (22)$$

where

t_{load_multi} time consumed by a roundtrip for a specific multi-source load: min and

t_{drd} time consumed when driving between roadside landings: min.

Since part of the trucking costs are distance-dependent the total distance driven to collect and deliver a load, d_{load}, is calculated as follows

$$d_{load} = d_{drwl} + d_{drd} + d_{drfl} + d_{odr} \quad (23)$$

where

d_{load} total distance driven to collect and deliver a load: km,

d_{drwl} distance driven unloaded: km,

d_{drd} distance driven between roadside landings: km,

d_{drfl} distance driven fully loaded: km, and

d_{odr} other distance driven: km.

For single-source loads the cost of trucking is assigned to an assortment at the load-level. Based on the roundtrip characteristics that determine the resource consumption, the unit cost of long-distance transportation of a storage lot as a single-source load is calculated as a sum (Eq. 27) of the time-dependent (Eq. 24), distance-dependent (Eq. 25), and operational costs of the truck mounted crane (Eq. 26).

$$\hat{C}_{dd\_load\_single} = \Big(\big(c_{drwl} * d_{drwl} + c_{drfl} * d_{drfl} + c_{odr} * d_{odr}\big) * p_{fue}\Big) + \big(UC_{rep} + UC_{\mathrm{lub}} + UC_{tir}\big) * d_{load} \tag{24}$$

$$\hat{C}_{dd\_load\_single} = \Big(\big(c_{drwl} * d_{drwl} + c_{drfl} * d_{drfl} + c_{odr} * d_{odr}\big) * p_{fue}\Big) + \big(UC_{rep} + UC_{\mathrm{lub}} + UC_{tir}\big) * d_{load} \tag{25}$$

$$\hat{C}_{cr\_load\_single} = \big(c_{cr} * p_{fue}\big) + \left(\frac{V_{load}}{V_{annual}}\right) * AC_{rmh\_cr} \tag{26}$$

$$C_{truck\_single} = \frac{\hat{C}_{td\_load\_single} + \hat{C}_{dd\_load\_single} + \hat{C}_{cr\_load\_single}}{V_{load}} \tag{27}$$

where

C_{truck_single} unit cost of long-distance transportation of storage lot in single-source loads: €/m^3,
$\hat{C}_{td\_load\_single}$ time-dependent costs of a truck and crane for a roundtrip with a single-source load: €,
$\hat{C}_{dd\_load\_single}$ distance-dependent costs of a roundtrip with a single-source load: €,
$\hat{C}_{cr\_load\_single}$ operational costs of a crane for a roundtrip with a single-source load: €,
V_{load} load volume of a timber truck: m^3/load,
t_{annual} total annual time timber truck and crane are used: min/a,
AC_{int} capital costs for a truck and crane: €/a,
AC_{dep} straight-line depreciation costs for a truck and crane: €/a,
AC_{ins} insurance and traffic tax costs: €/a,
AC_{adm} administration and maintenance costs: €/a,
AC_{lab} labour costs: €/a,
c_{drwl} fuel consumption of truck without a load: l/km,
c_{drfl} fuel consumption of truck with a full load: l/km,
c_{odr} fuel consumption of truck for other driving: l/km,
c_{cr} fuel consumption of truck during stops: litres/load,
p_{fue} fuel price: €/litre,
UC_{rep} unit cost for truck repairs: €/km,
UC_{lub} unit cost for truck lubrication: €/km,
UC_{tir} unit cost for truck tires: €/km,
V_{annual} annual volume transported: m^3/a, and
AC_{rmh_cr} repair, maintenance, and hydraulic oil costs for a crane: €/a.

To find out the unit costs for the long-distance transportation of a residual lot that is transported as a part of a multi-source load, the transportation costs should be assigned to each lot collected along the route of the load. Time- and distance-dependent costs as well as operational crane costs are calculated for each activity of the load. The costs for transport unloaded, fully loaded, other driving, unloading, and for delays are jointly assigned to all the lots making up a full load, whereas the costs for storage activities and transport between storage points are individually assigned to each lot. The unit cost for long-distance transportation of a multi-source transport lot is then the sum (Eq. 35) of those jointly assigned time-dependent (Eq. 28), distance dependant (Eq. 29) and unloading costs (Eq. 30), with the individual transport lot costs for loading (Eq. 31), auxiliary activities at its roadside landing (Eq. 32), and those that are time (Eq. 33) and distance (Eq. 34) dependent.

$$\hat{C}_{td\_load\_multi} = \left(\frac{t_{drwl} + t_{drfl} + t_{unl} + t_{odr} + t_{del}}{t_{annual}} \right) * \left(AC_{dep} + AC_{\text{int}} + AC_{ins} + AC_{adm} + AC_{lab} \right) \tag{28}$$

$$\hat{C}_{dd\_load\_multi} = \left(\left(c_{drwl} * d_{drwl} + c_{drfl} * d_{drfl} + c_{odr} * d_{odr} \right) * p_{fue} \right) + \left(UC_{rep} + UC_{\text{lub}} + UC_{tir} \right) * \left(d_{drwl} + d_{drfl} + d_{odr} \right) \tag{29}$$

$$\hat{C}_{unl\_cr\_multi} = \left(\frac{t_{ul}}{t_{cr}} \right) * \left(\left(c_{cr} * p_{fue} \right) + \frac{V_{load}}{V_{annual}} * AC_{cr\_rmh} \right) \tag{30}$$

$$C_{lo\_cr} = \left(\frac{t_{lo\_s}}{t_{cr}} \right) * \frac{\left(\left(c_{cr} * p_{fue} \right) + \frac{V_{load}}{V_{annual}} * AC_{cr\_rmh} \right)}{V_s} \tag{31}$$

$$C_{\log deck} = \frac{\left(\left(\frac{t_{1d\_s}}{t_{load}} \right) * \hat{C}_{td\_load} \right)}{V_s} \tag{32}$$

$$C_{td\_drd} = \left(\frac{\frac{t_{drd}}{n_m}}{V_{load}} \right) * \left(\frac{\hat{C}_{td\_load\_multi}}{t_{load\_multi}} \right) \tag{33}$$

$$C_{dd\_drd} = \frac{\left(\left(c_{drd} * p_{fue} \right) + UC_{rep} + UC_{\text{lub}} + UC_{tir} \right) * d_{drd}}{V_{load}} \tag{34}$$

$$C_{truck\_multi} = \frac{\hat{C}_{td\_load\_multi} + \hat{C}_{dd\_load\_multi} + \hat{C}_{cr\_unl\_multi}}{V_{load}} + C_{td\_drd} + C_{dd\_drd} + C_{\log deck} + C_{lo\_cr} \tag{35}$$

where

$\hat{C}_{td\_load\_multi}$ time-dependent costs of a truck and crane for a roundtrip with a multi-source load: €,

$\hat{C}_{dd\_load\_multi}$ distance-dependent costs for a roundtrip with a multi-source load: €,

$\hat{C}_{cr\_unl\_multi}$ operational costs of a crane for a roundtrip with a multi-source load: €,

C_{td_drd} time-dependent unit costs of driving between all the storage points of a multi-sourced load: €/m^3,

C_{dd_drd} distance-dependent unit costs of driving between all the storage points of a multi-sourced load: €/m^3,

$C_{logdeck}$ unit costs of log deck activities for a single transport lot *m*: €/m^3,

C_{lo_cr} unit cost of a crane for the loading of a single transport lot m: €/m^3,
c_{drd} fuel consumption of driving between all the storage points of a multi-sourced load: l/km,
d_{drd} distance driven, and
C_{truck_m} unit cost for long-distance transportation of a transport lot m as a part of a multi-sourced load: €/m^3.

Let n_f be the number of those transport lots that are being trucked as single-source loads. The unit cost for the whole storage lot is then calculated as:

$$C_{truck} = \frac{C_{truck\_single} * V_{load} * n_f + C_{truck\_multi} * V_s}{V_k} \tag{36}$$

where
n_f number of single-source transport lots from storage lot k, and
C_{truck} unit cost for long-distance transport of timber storage lot k.

3 Example Application of the ABC System

3.1 Data and Methods

The example data comes from a clearcut final felling performed on 3 ha of a typical Finnish pine-dominated stand. The total volume of the pines was 411 m^3; this was 64 % of the stand's total volume. The mean volume for a pine stem from the stand was 0.454 m^3. In order to make exact time estimates for each activity, a total tree list of species and sizes was needed; in this case the tree list was processed and stored in exchange streaming media (stm) file format by the mechanised harvester that cut the stand in the Summer of 2004. The pines from the stand were bucked and delivered to five different production plants as specific assortments. The assortments SAW1 and SMALL each went to two different sawmills, assortment JOINERY went to a joinery factory, assortment LOGHOUSE went to a log house factory, and PULP went to a pulpmill (Table 5).

The time consumption for cutting and forwarding was estimated mainly using the mean values and models presented by Nurminen et al. (2006). The example cost of cutting was based on the use of a normal single-grip harvester under the typical conditions that existed in Finland, in 2005. The machinery cost of the harvester (HC_c) was 84.15 €/h; calculation of this value is based on the annual machine utilisation presented in Table 1 and the cost factors presented in Table 2. The average time consumptions for cutting with a mechanised harvester in seconds per stem (s/stem) were set as: 4.6 for travel within a stand (t_{mo}); 6.0 for positioning-to-cut (t_{pc}); 2.8 for boom retraction (t_{bi}); 1.3 for clearing (t_{cl}); and 0.7 for moving logs, tops, etc. (t_{ml}). The time consumption for felling was dependent on the stem volume according to the following:

$$t_{fe} = 0.068 + 0.142 V_j \tag{37}$$

where
V_j stem size: m^3.

Table 5. Definitions and volumes for the timber assortments from the example stand.

Factory	Timber assortment	Length (mm) min	Length (mm) max	SED (mm) min	SED (mm) max	Removal: V_k (m^3)
Sawmill1	SAW1	370	580	150	380	261
Sawmill2	SMALL	430	460	120	150	30
Joinery mill	JOINERY					16
Loghouse factory	LOGHOUSE	370	760	240	285	54
Pulpmill	PULP	250	600	60	700	50
Total						411

Since Nurminen et al. (2006) presents a time consumption model for the combination of delimbing and cross-cutting with a mechanised single-grip harvester only for whole trees, a new model was created to estimate the time consumption for a single log. This model is based on the same final felling data used by Nurminen et al. (2006), which includes: 1,141 pine logs, 904 spruce logs, and 291 birch logs. The model has the following form:

$$t_{dc} = 2.952 + 0.013V_i + 0.425d \tag{38}$$

where

t_{dc} time consumption for delimbing and cross-cutting a log: s/log,

V_i log volume: dm^3, and

d dummy variable: $d = 0$ for pine or spruce, $d = 1$ for birch.

The coefficient of determination (R^2) for this model is 0.27 and the standard error of the residuals is 2.20 seconds.

The combined bunching and sorting time (t_{so}) depends on the number of timber assortments from a stem; it is zero seconds for one assortment, 1.5 seconds for two assortments, 2.3 seconds for three assortments, and 3.3 seconds for four assortments. The cutting calculations also used a gross-effective time coefficient of 1.527, which was based on investigations by Kuitto et al (1994). This is a product of the gross-effective time coefficient of 1.197, which converts delay-free effective time (E_0) to gross-effective time (E_{15}), and of the follow-up coefficient of 1.276, which converts gross-effective time (E_{15}) so that it corresponds with long term productivity levels. Based on these time estimates and other parameters presented for the example, the C_{cut}, or unit cost for the cutting of an assortment k from the example stand, can then be calculated using Eq. 11.

The example cost for forest transport was based on the use of a normal forwarder under the typical conditions that existed in Finland, in 2005. The machinery cost of the forwarder (HC_f) was 61.10 €/h; this is based on the annual machinery utilisation figures presented in Table 1 and cost factors presented in Table 2. The time consumption for forest transport depends on stand characteristics, driving speed, and load size. The average transport distance (x_d) was set at 250 m, and the load capacities for forwarding (V_{fload}) were 11 m^3 for pulpwood and 14 m^3 for all other logs.

Time consumptions for different work phases were calculated using models (i.e. Models 14–26) presented by Nurminen et al. (2006). It was assumed that assortment SAW1, LOGHOUSE, and PULP were forwarded as single loads, while assortments SMALL and JOINERY were forwarded as mixed loads. The time consumption estimates based on these assumptions for the SAW1, PULP and mixed SMALL/JOINERY loads as well as the variables used to calculate these estimates are presented in Table 6.

The forest transport calculations used a gross-effective time coefficient of 1.327, which was based on investigations by Kuitto et al (1994). This gross-effective time coefficient is a product of the gross-effective time coefficient of 1.084, which converts delay-free effective time (E_0) to

Table 6. Time consumption estimates for the example created with Models 14–26 presented by Nurminen et al. (2006).

Time element	Quantity	SAW1	PULP	MIXED SMALL/JOINERY	MIXED SMALL/JOINERY AS SINGLE
Driving empty (t_{de})	min/m^3	0.383	0.746	0.686	
Driving loaded (t_{dl})	min/m^3	0.315	0.169	0.133	
Driwing while loading (t_{dw})	min/m^3	0.332	1.728	1.859	
Loading (t_{lk}), (t_{lm})	min/m^3	0.707	1.607	0.846 (t_{lm})	0.786 (t_{lk})
Unloading and driving while unloading (t_{ulk}), (t_{ulm})	min/m^3	0.547	0.564	0.630 (t_{ulm})	0.547 (t_{ulk})
Total (E_o)	min/m^3	2.284	4.814	4.154	4.011

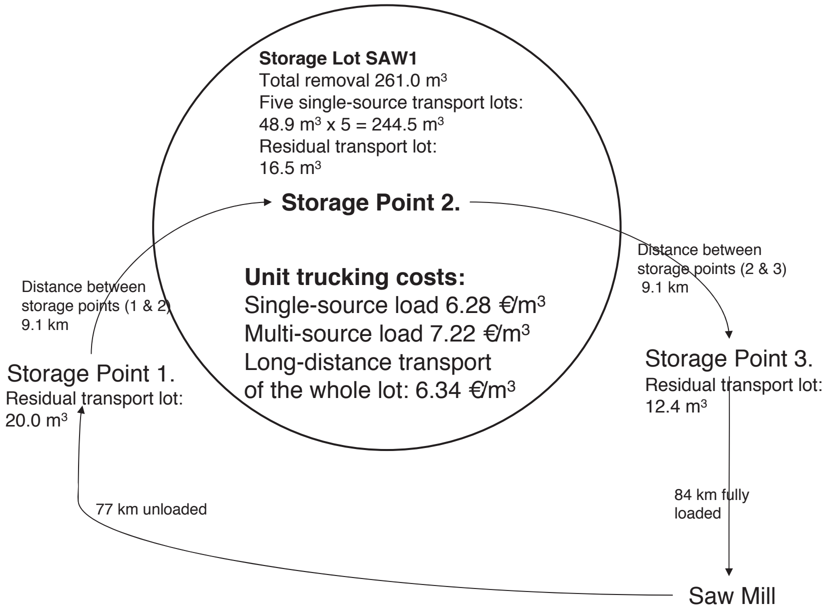

Fig. 2. Trucking figures and calculated unit costs for example assortment SAW1 with a diagram of the multi-source trucking route and its variables.

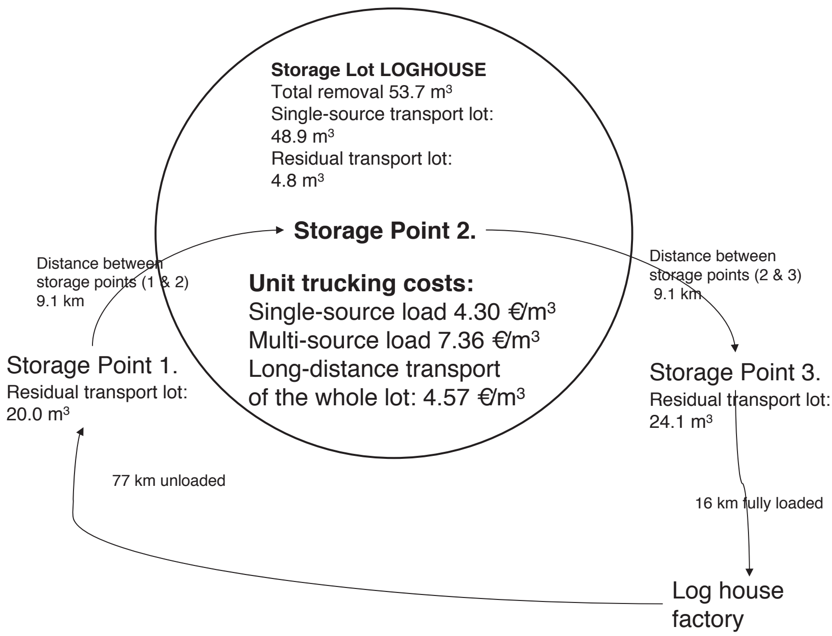

Fig. 3. Trucking figures and calculated unit costs for example assortment LOGHOUSE with a diagram of the multi-source trucking route and its variables.

Table 7. Time estimates and auxiliary parameters, for the example assortments SAW1 and LOGHOUSE, which were used to complete calculations with models presented by Nurminen and Heinonen (2007).

Time element	Quantity	SAW1 Single-source	SAW1 Multi-source	LOGHOUSE Single-source	LOGHOUSE Multi-source
Driving unloaded (t_{drwl})	min/load	75.9	75.9	75.9	75.9
Driving between storage points (t_{drd})	min/load		42.0		42.0
Lock deck activities (t_{ld_s})		32.7	41.1		
Loading (t_{lo_s}), $\left(\sum_{i=1}^{n_s} t_{lo\_s}\right)$	min/load	21.5	21.5	21.5	21.5
Auxiliary activities ($t_{al}s$), $\left(\sum_{i=1}^{n_s} t_{al\_s}\right)$	min/load	11.2	19.6	11.2	19.6
Driving fully loaded (t_{drfl})	min/load	83	83		
Unloading (t_{unl})	min/load	34.9	34.9	34.9	34.9
Actual unloading time (t_{ul})	min/load	17.5	17.5	17.5	17.5
Other driving (t_{odr})	min/load	12.8	12.8	12.8	12.8
Delays (t_{del})	min/load	7.8	7.8	7.8	7.8
Roundtrip in total (t_{lload_single}), (t_{lload_multi})	min/load	297	247		
Auxiliary parameters					
Distance driven unloaded (d_{drwl})	km	77	77	77	77
Distance driven between landings (d_{drd})	km		9.1/9.1		9.1/9.1
Distance driven fully loaded	km	84	84	16	16
Distance driven for other purposes (d_{odr})	km	30	30	30	30

gross-effective time (E_{15}), and of the follow-up coefficient of 1.224, which converts gross-effective time (E_{15}) so that it corresponds to long term productivity levels. The C_{forw}, or unit cost of forest transport of the whole of an assortment k from the example stand is divided into those portions of the assortment transported as single loads, C_{forw_single}, which are calculated with Eq. 12 and those portions that are transported as mixed loads, C_{forw_mixed}, which are calculated with equations 12–15. The C_{forw} is then calculated with Eq. 16.

The example cost for long-distance transport is based on the use of a normal timber truck with a three-axel, 6x4 power configuration; a removable hydraulic crane; and a four-axel trailer. The truck's crane is used for all loading and unloading. The calculation is based on annual use figures presented in Table 1 and cost factors presented in Table 3. The truck's single-source load size was set at 48.9 m^3.

For the two multi-source examples (i.e. LOGHOUSE, SAW1), a full load was assumed to consist of individual lots sourced from three roadside storage landings (Figs. 2 & 3). The residual transport lots from the example stand were located along the multi-source truck routes at the second landing in the sequences. At the first storage landing on each multi-source route a residual transport lot of 20 m^3 was loaded as a component of the load. For the SAW1 storage lot example (Fig. 2), most of the storage lot (i.e. 244.5 m^3 of the total 261 m^3) was transported as single-source loads and only a residual lot of 16.5 m^3 was transported as a multi-source load. Similarly, the example storage lot LOGHOUSE (Fig. 3) was transported as a single-source load and a multi-source load.

Time consumption for each work phase for long-distance transport is calculated by equations presented by Nurminen and Heinonen (2007) in their Table 9. The example variables that are needed for these models and the results of these equations are given here in Table 7. The C_{truck_single}, or unit costs for each single-source

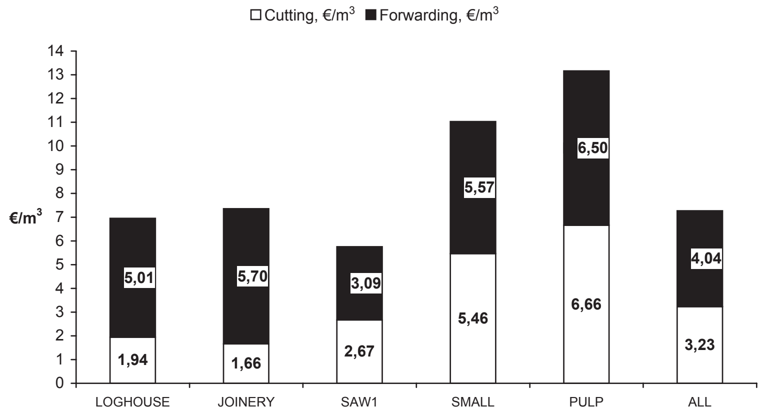

Fig. 4. Unit harvesting costs for each example assortment calculated using the activity based costing (ABC) method and a calculated average for the combination of all the assortments (i.e. ALL). The costs are divided into those for cutting and forest transport.

load were calculated with equations 24–27 and the C_{truck_multi}, or unit costs for the multi-source load with equations 28–35. The C_{truck}, or unit cost for the trucking of the whole storage lot is then calculated with Eq. 36.

3.2 Results

There are marked differences between the harvesting costs of the example timber assortments when costs are apportioned to each assortment by the activity-based costing method (Fig. 4). The costs of cutting special logs (i.e. LOGHOUSE, JOINERY) are very cost-effective, but their forwarding costs are rather high when compared to the same costs for normal sawlogs (i.e. SAW1, SMALL); this is due to the considerably smaller volumes of the special assortments. The costs for the cutting of the small piece-size assortments (i.e. SMALL, PULP) were naturally higher than for the larger piece-size assortments due to a lower level of productivity. The higher costs for the forwarding of pulpwood were mostly attributed to the smaller load size. The last bar in Fig. 4 (i.e. ALL) represents the averages of the harvesting costs when all the timber assortments are considered together as has been done with traditional costing systems. This example clearly shows that the traditional way of apportioning the harvesting costs equally to each assortment is flawed.

The unit costs for the long-distance transport of assortment SAW1 with the example timber truck are presented in Fig. 2 and those for assortment LOGHOUSE are in Fig. 3. The apportioning of these costs is also illustrated.

4 Discussion

In the past fifteen years, the timber logistics working environment has become more complex. Quality requirements are now stricter than earlier and the number of assortments has increased considerably. It should be questioned, whether it is desirable to cut so many different products from a single stand, since it implies so many loading and transportation operations. It might be that the gains achieved with better product characteristics are then lost due to increased logistical costs.

The basic principle of activity-based costing (ABC) is very simple – to allocate costs to products according to the actual resources consumed in processing them. Applying this principle to timber harvesting and trucking was found to be relatively easy. The application of ABC is helped by earlier research that has provided established practises for evaluating the work done with modern harvesters and forwarders. There are also rather widely used methods for the evaluation of timber procurement that aid with the application, by defining activities and providing guidelines for time studies and cost calculations for machinery.

The work of Oijala and Terävä (1994) follows the same principle as the system reported here. Their system operated using the spreadsheet, Microsoft Office Excel, but only the basic principle has been documented. However, earlier time studies did not take into account the influence of the number of assortments on cutting and loading, which means that these also were not included in the costing system of Oijala and Terävä.

It is always important to compare results of a simulation to actual figures paid on a market. In view of this, the costing system presented here appears to give realistic numbers when contrasted with statistics collected from Finnish forest companies (Kariniemi 2006) for the same period (i.e. 2005) and situation on which the simulation was based. According to the company statistics the average costs, or sums paid to entrepreneurs in southern Finland for mechanised final felling and forwarding with a harvester and a forwarder were 4.11€/m^3 and 3.10 €/m^3 respectively. The sum of these average harvesting, (i.e. cutting and forwarding) activities is 7.21 €/m^3, which is nearly equal to the value of 7.27 €/m^3 determined by the theoretical case (Fig. 2). However, the theoretical calculations gave values of 3.23 €/m^3 for cutting and 4.04 €/m^3 for forwarding. It is thought that the main reason for this difference is the actual structure of the payment system used for harvesting. It is a widely believed that the current payment system compensates the costs for low productivity thinnings with high productivity clear fellings, and that forwarding is under compensated.

For trucking, the ABC costing system example suggested slightly higher costs than the sums paid in reality. The costing system gave costs of 6.34 €/m^3 for SAW1 (distance to the mill 77 km) and 4.57 €/m^3 for LOGHOUSE (distance to the mill 16 km). According to statistics for 2005 the average cost of transportation by road to a mill in Finland was 5.68 €/m^3 with the average distance being 105 km (Kariniemi 2006).

Comparing the cost of an individual assortment determined by ABC to the average cost of harvesting (Fig. 4) proves that it is very important to develop new methods that meaningfully assign the costs to the different assortments. The traditional approach to costing seems quite inappropriate for timber harvesting, while the method developed and presented here appears much more suitable, is rather straightforward, and quite strictly adheres to the principle of activity-based costing.

The principle of ABC was originally developed for factories that have separate departments and several product lines. Following this product line division, is it right to divide costs for pulpwood logs from the upper stem from those costs for the lower stem's larger sawlogs? Since they are from the same stem, should all of the logs have the same costs since the whole stem is utilized anyway? It might be wise not to strictly follow this type of costing when the costs for timber procurement are divided between different products in terms of wood payments. It certainly gives higher costs to timber assortments with smaller quantities. Who is responsible for the cost of a specific volume of one assortment that is collected from numerous stands? Do these assortments have special characteristics, which mean that they can be found only in a stand only in small amounts, or is this smaller amount caused by the complexity of the timber procurement system, with its high number of assortments? It seems clear that if an assortment has unique special characteristics that are found only in small quantities in a stand, it is right to allocate all costs to that product. But, if an assortment could be cut in large quantities from many similar stands, it should be understood that it is undesirable to cut many products from the same stand, since this then requires too many loading and transportation operations. Thus the foremost use of the ABC method should be as a tool to calculate the efficiency of activities or the efficiency of a whole logistic system. However, only precise information on a cost structure enables comparison of logistic systems in various areas or of the efficiency of whole business branches. It is clear that costing is a necessity when optimal wood allocation problems are to be assessed.

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Total of 31 references

Symbols

AC_{adm}	administration and maintenance costs: €/a
AC_{int}	interest costs: €/a
AC_{dep}	straight-line depreciation costs (separate for base machine, harvester head, tractor, trailer, and crane): €/a
AC_{fix}	fixed costs: €/a
AC_{ins}	insurance and traffic costs: €/a
AC_{lab}	labour costs: €/a
AC_{rmh_cr}	repair, maintenance, and hydraulic oil costs for crane: €/a.
AC_{ope}	operational costs: €/a
a_c	coefficient that converts the effective time (E_0) for cutting into gross-effective time.
a_f	coefficient that converts the effective time (E_0) for forwarding into gross-effective time
$\hat{C}_{cr\_load\_single}$	operational costs of a crane for one roundtrip in the case of a single source load: €
$\hat{C}_{cr\_unl\_multi}$	operational costs of a crane for one roundtrip in the case of a multi-source load: €
$\hat{C}_{cs}$	cost of cutting a stem that includes assortment *k*: €
$\hat{C}_{dd\_load\_multi}$	distance-dependent costs for one roundtrip in the case of a multi-source load: €
$\hat{C}_{dd\_load\_single}$	distance-dependent costs for one roundtrip in the case of a single-source load: €
$\hat{C}_{td\_load\_multi}$	time-dependent costs of a truck and crane for one roundtrip in the case of a multi-source load: €
$\hat{C}_{td\_load\_single}$	time-dependent costs of a truck and crane for one roundtrip in the case of a single-source load: €
C_{cut}	unit cost for the cutting of assortment *k*
C_{dd_drd}	distance-dependent unit costs of driving between the storage points: €/m^3
C_{fm}	unit cost of forest transport that is carried out with mixed loads: €/m^3
C_{forw}	unit cost for the forest transport of assortment *k* within a stand: €/m^3
C_{forw_m}	unit cost for the forest transport of assortment *k* that is carried out with mixed loads: €/m^3
C_{forw_single}	unit cost for the forest transport of assortment *k* carried out with single loads: €/m^3
C_{fs}	unit cost for the sorting of assortment *k*: €/m^3
C_{lo_cr}	unit cost of a crane for loading: €/m^3 .
$C_{logdeck}$	unit costs for log deck activities: €/m^3
C_{td_drd}	time-dependent unit costs for driving between storage points: €/m^3
C_{truck_multi}	unit cost for long-distance transportation as a multi-source load: €/m^3
C_{truck_single}	unit cost for the long-distance transportation of the storage lot r_k as a single source load: €/m^3
c_{cr}	fuel consumption during stops: litres/load
c_{drd}	fuel consumption for driving between the decks: l/km
c_{drfl}	fuel consumption for driving with a full load: l/km
c_{drwl}	fuel consumption for driving without a load: l/km
c_{odr}	fuel consumption for other driving: l/km
DP	annual depreciation: %

d	dummy variable; $d=0$ for pine or spruce, $d=1$ for birch
d_{drd}	distance driven between storage points: km
d_{drfl}	distance driven fully loaded: km.
d_{drwl}	distance driven unload: km
d_{load}	total distance a load driven: km
d_{odr}	distance driven for other purposes: km.
HC	total cost per operational hour: €/h
HC_c	total resource cost of cutting per operational hour: €/h
HC_f	total resource cost of forest transport per operational hour: €/h
I	interest rate: %
i	a log from stem j
j	a stem in stand l
k	an assortment (product) that is cut from stem j
l	a stand
n_d	number of storage points visited to complete a load V_{load}
n_f	number of those truck loads that are being trucked as single-source loads
n_i	number of logs in a stem
n_j	number of stems in a stand where assortment a is cut
n_k	number of assortments in a mixed load
n_{ml}	number of loads forwarded as multiple loads
n_{sl}	number of loads forwarded as single loads
OH_a	Annual operational hours (harvester and forwarder) or annual driving kilometres (tractor and trailer) or annual number of loads (crane)
PP	purchase price: €
p_{fue}	fuel price: €/liter
SL_h	expected service life in operational hours (harvester and forwarder) or in driving kilometres (tractor and trailer) or in number of loads (crane)
SL_y	expected service life: years
SV	salvage value: €
t_{al_s}	auxiliary activities at storage s: min
t_{annual}	annual transportation time: h/a
t_{aul}	auxiliary activities at log yard (preparation, scaling, etc): min.
t_{bi}	time consumption for boom-in: min/stem
t_{cl}	time consumption for clearing: min/stem
t_{cr}	time consumption for actual use of the crane: min
t_{dc}	time consumption for delimbing and cross-cutting of one log of assortment k: min/log;
t_{de}	time consumption for driving empty: min/m^3
t_{del}	time consumption of delays: min
t_{dl}	time consumption for forwarder driving loaded : min/m^3
t_{drd}	time consumption of truck driving between the storage points: min.
t_{drfl}	time consumption of truck driving with a full load: min
t_{drwl}	time consumption of truck driving without a load: min
t_{dw}	time consumption for forwarder driving while loading: min/m^3
t_{fe}	time consumption for felling: min/stem
t_{ld_s}	time consumption of log deck activities in storage point s: min
t_{lk}	time consumption for forwarder loading of assortment k: min/m^3
t_{lm}	time consumption for forwarder loading of all n_k assortments: min/m^3
t_{load_multi}	time consumption of a roundtrip in multi-source loads: min

t_{load_single}	time consumption of a roundtrip in single-source loads: min
t_{lo_s}	actual loading time in storage *s*: min
t_{ml}	time consumption for moving logs, tops etc.: min/stem
t_{mo}	time consumption for moving (machine): min/stem
t_{odr}	time consumption of other driving: min
t_{pc}	time consumption for positioning-to-cut: min/stem
t_q	queuing and waiting: min
t_{so}	time consumption for sorting: min/assortment *k*
t_{ul}	actual unloading time: min
t_{ulk}	time consumption for unloading of assortment *k*: min/m^3
t_{ulm}	time consumption for unloading of n_k assortments: min/m^3
t_{unl}	time consumption of unloading: min
UC_{lub}	unit cost of lubricants: €/km
UC_{rep}	unit cost of repair: €/km
UC_{tir}	unit cost of tires: €/km
V_{annual}	annual transportation output: m^3/a
V_{fload}	load size of forwarder: m3
V_{load}	load volume of timber truck: m^3/load
V_a	volume of removal from a stand that is assortment *k*: m^3/stand
V_i	log volume: dm^3
V_j	stem volume: m^3
V_m	volume of removal hauled as mixed load: m^3/stand
V_s	volume loaded from a storage point *s*