Time consumption functions for harvester and forwarder

Project: Applikationer

Revisions

Version	Date	Description	Author
1.0	2008-03-11		Peder Wikström
1.1	2008-05-26	Corrected error section 4.2 – L and S should be multiplied with 0.1 instead of divided by 0.1	
1.2	2008-05-29	Corrected misstyping in table in section 4.2: "S" should be "Y"	

Contents

1. About this document

Model	Time consumption functions for harvesting and forwarding (SkogForsk)
Purpose and description	The functions are used to compute time consumption for harvesting and forwarding. The result can then be multiplied with the per-hour cost for a certain machine to obtain total cost. The functions are applied at treatment unit level.
References	[1] Brunberg, T, 1995. Underlag för produktionsnorm för stora engreppsskördare i slutavverkning. Redogörelse nr 7, SkogForsk. [2] Brunberg, T, 1997. Underlag för produktionsnorm för engreppsskördare i gallring. Redogörelse nr 8, SkogForsk. [3] Brunberg, T, 2004. Underlag till produktionsnorm för skotare. Redogörelse nr 3, SkogForsk.
Type of model	Additive/multiplicative
Program code	Fortran 95 (Peder Wikström), supplied by request
Revisions	1.0: 2008-03-11, Peder Wikström

2. Model results

The functions compute time consumption for harvesting and forwarding in thinning and clearcutting. The results should be multiplied with a per-hour cost for the machine used to obtain the cost (per ha).

3. Variables

Variable	Unit	Min/Max	Description
v	m^3 fub	Clearcutting: [0, 3] Thinning: [0, 0.2]	Mean tree volume of harvested trees (treatment unit level) = harvested volume in the stand divided by the number of harvested trees in the stand.
L	integer	1-5	Slope (lutning), Definition according "SkogForsk terrängtypschema" 1-flat, 5-steep NOT THE SAME AS RIS-codes
Y	integer	1-5	Surface (Ytstruktur), 1-Mkt jämn, 5-Mkt ojämn, SAME AS RIS-codes
N_{harv}	trees/ha	Truncated depending on function	
V_{harv}	m^3 fub/ha		Extracted volume
N_{res}	trees/ha	[0, 2000]	Number of trees left after harvest, used only in function for thinning harvester
D	m	>0	Terrain transport distance (one way average). Default = 300 m
W	m	>0	Tree striproad width (width of strips between striproads, for ex. 16 m if distance between striproads is 20 m and striproad width is 4 m)
ThinningSystem	enum		STRIPROAD = Standard thinning (Vanlig gallring utan stråk) STRIPROAD_WITH_MIDFIELD_MACHINE = Thinning with midfield (stråkmetod, skördare kör mellan I stråket mellan stickvägar och slingra sig fram) STRIPROAD_WITH_MIDFIELD_CHAINSAW = Stråkmetod med motormanuell avverkning i mellanzonen istället för maskin
thinningNumber	enum		1^{st}, 2^{nd} or later thinning (1^{st} thinning = first thinning ever, young stands)

Variable	Unit	Min/Max	Description
rd	real	>0	Relative diameter = mean diameter of harvested trees divided by mean diameter of residual trees (basal area weighted mean diameters)
$p_{init,Spruce}$	proportion	[0, 1]	Proportion spruce trees before harvest of total number of stems
$P_{harv,\ broadLeaves}$	proportion	[0, 1]	Proportion broadleaved trees of harvested trees

4. Time consumption functions for harvester

The functions for harvesting time are divided into driving time (t_1), time for felling and processing (t_2), and additional time (t_3). The functions return time per tree, given as centiminutes[a] per tree.

4.1 Total time, clearcutting and thinning

Routine name: `HarvesterTotalTime_SkogForsk`

1) Compute total time per tree:
$t = t_1 + t_2 + t_3$

2) Then multiply t with a correction factor c (=1.3): correction from study time to actual time (see Brunberg).

$t = c \cdot t$

3) Multiply time per tree with number of harvested trees to get total time. Divide by 6000 to convert from cmin to hours:

$$T_{harvesting} = \frac{t \cdot N_{harv}}{6000}$$

If $T_{harvesting}$ is multiplied with the per-hour cost for the machine, the total cost (per ha) is obtained.

4.2 Driving time, clearcutting and thinning (t_1)

Routine name: `HarvesterDrivingTime_SkogForsk`

The following default values are used for the variables S and K included in the function unless the user has supplied another set of values:

Harvest type/thinning system	**K**	**S**
Clear cutting	25.9	13.3
STRIPROAD	15.6	W
STRIPROAD_WITH_MIDFIELD_MACHINE	15.4	2/3*W
STRIPROAD_WITH_MIDFIELD_CHAINSAW	20.2	2/3*W

[a] Note that 100 cmin = 1 min and 6000 cmin = 1 hour.

Functions applicable to following variable ranges:

Variable	Function	Min	Max	Action
N_{harv}	Clearcutting	200	1500	Truncate
	Thinning	400	2000	Truncate
v	Clearcutting	0	3	Truncate
	Thinning	0	0.2	v > 0.2: Use function for clearcutting
N_{res}	Thinning	0	2000	Truncate
L	Clearcutting	1	2*	Truncate
	Thinning	1	2*	Truncate
Y	Clearcutting	1	2*	Truncate
	Thinning	1	2*	Truncate

*Functions may be applicable to classes 3-5 too, but this has not been tested.

$$T_1 = \frac{10^6}{S \cdot N_{harv} \cdot K \cdot \left[1 + \frac{50}{N_{harv}} - 0.1 \cdot Y - 0.1 \cdot L\right]}$$

Truncate result (T_1) to interval [2, 20]

4.3 Felling and processing time, clearcutting ($t_{2,\ clearcutting}$)

Routine name: `HarvesterClearcutFellProcessTime_SkogForsk`

$$t_2 = 27.3 + 56 \cdot v + 28 \cdot p_{doublesawed} + 15 \cdot p_{hindrance} + 37 \cdot p_{difficult}$$

Local variables $p_{doublesawed}$, $p_{hindrance}$ and $p_{difficult}$ are obtained from creating function based on data in figures 4-6 in reference [1]:

Variable	Range	Description	Value
$p_{hindrance}$	[0, 1]	Proportion of trees where hindrance occur when felling.	$p_{hindrance} = \frac{0.35}{1 + e^{2.5(1.9 - v)}}$
$p_{doublesawed}$	[0, 1]	Proportion of trees where more than one felling cut was needed.	$p_{doublesawed} = \frac{1}{1 + e^{3.5(1.6 - v)}}$
$p_{difficult}$	[0, 1]	Proportion of difficult trees to fell or process due to… (klykor etc).	$p_{difficult} = \frac{0.7}{1 + e^{4.4 - 2v}}$

4.4 Felling and processing time, thinning ($t_{2,\ thinning}$)

Routine name: `HarvesterThinningFellProcessTime_SkogForsk`

1) If v > 0.2, then use function for clear cutting (1.4.3) and STOP

2) Set local variable *p* according to the following and compute t_2:
If *thinningNumber* = 1 then 1st thinning: set $p = p_{init,Spruce}$
If *thinningNumber* = 2 then 2nd thinning: set $p = 0.5 * p_{init,Spruce}$
If *thinningNumber* > 2 then 3rd thinning or later: set $p = 0$

$$t_2 = v(78p + 89) + N_{res}(0.0025p + 0.0019) + 20.3$$

Comment 1: p reflects visibility in the stand, which is assumed proportional to spruce occurrence (since spruce trees limit sight)
Comment 2: The number of thinnings should be tracked. Thinning history at the start of the planning horizon is needed.

3) Corrections

Broad-leaves
Correct t_2 for proportion of harvested broad-leaves (these trees are more time-consuming):

$t_2 = t_2 + 2.3 p_{harv,BroadLeaves}$

Thinning type
If uniform thinning or thinning from above, there is a time reduction, compared to thinning from below.

If $rd > 1$ (thinning from above):
Let x = argmin{ *rd*, 1.1 }
$t_2 = t_2 - 16(x - 1)$
(This is fuzzification of the original function, time reduction can be at most 1.6)

If $0.95 < rd \leq 1$ (uniform thinning):
$t_2 = t_2 - 1.3$

Thinning system:
Addition when thinning with midfield (stråkkörning)
If ThinningSystem = STRIPROAD_WITH_MIDFIELD_MACHINE:
Default: $p_{not\ reached} = 0.3$ (assume 30 % of trees not reached from striproad)

$t_2 = t_2 + 3.4 p_{not\ reached}$

Addition when thinning with midfield and using chainsaw in midfield instead of machine:
If ThinningSystem = STRIPROAD_WITH_MIDFIELD_CHAINSAW

Default: $p_{chainsaw}$= 0.17 (assume 17 % of trees felled with chainsaw)

$t_2 = t_2 + 8.3p_{chainsaw}$

4.5 Additional time in harvesting (t_3)

Routine name: `HarvesterAdditionalTime_SkogForsk`
Clearcutting: 1.6 cmin/tree
Clearcutting: 4.3 cmin/tree

5. Time consumption functions for forwarder

The functions for forwarding time (skotning) are divided into terminal time (t_4), driving time (t_5), assortment time (t_6), sorting time (t_7), and additional time (t_8). The functions compute time in total number of minutes (G15-minutes) per cubic meter harvested tree (m^3 fub), not in cmin/tree as the functions for harvester.

5.1 Total time

Routine name: `ForwarderTotalTime_SkogForsk`

Total time (minutes/ha)

$$T_{forwarding} = V_{harv} \sum_{i=4}^{7} t_i + t_8 \qquad \text{(minutes, divide by 60 to get hours)}$$

Comment: Note that t_8 is not multiplied with the harvested volume, since it is based on the number of loads and is computed in 1.5.6

If $T_{forwarding}$ is multiplied with the per-hour cost for the machine, the total cost (per ha) is obtained.

5.2 Terminal time (t_4)

Routine name: `ForwarderTerminalTime_SkogForsk`

Comment: Terminal time (min/m^3 fub) include time for loading, driving during loading, and unloading.

Constants

Treatment	**Machine size***	***a***	***b***	K_1	K_2
Clearcutting	Small	5.7	11.45	1	1.04
	Medium	5.7	11.45	1	0.86
	Large	5.7	11.45	1	0.73
Thinning	Small	-43	25.9	1	1.18
	Medium	-43	25.9	1	0.67
	Large	-43	25.9	1	0.67

*Machine size should be user-defined, and be dependent on harvest object
Default values: Clearcutting: Large machine, Thinning: First thinning: small, Second thinning and later: Mediium

Functions applicable to following variable ranges:

Variable	Function	Min	Max	Action
V_{harv}	Clearcutting	50	350	Truncate
	Thinning	25	125	Truncate

$$t_4 = K_1\left[\frac{a + K_2 V_{harv} + b\sqrt{V_{harv}}}{V_{harv}}\right]$$

5.3 Driving time for forwarder (t_5)

Routine name: `ForwarderDrivingTime_SkogForsk`

Comment: The function ccmputes the time for driving (min/m^3 fub). Time depends on speed and capacity.

Clearcutting:
$speed = 75 - 8.2Y - 1.4L^2$

Thinning:
$speed = 0.85\ (75 - 8.2Y - 1.4L^2)$

Machinesize/tonnage	*c* (capacity, m^3 fub)	Treatment (default, used unless user-defined specifies differently)
Small (9 ton)	9.5	First thinning
Medium (12.9 ton)	13.6	Second thinning and later
Large (17 ton)	17.9	Clearcutting

$$t_5 = \frac{2D}{speed \cdot c_{machinesize}}$$

5.4 Assortment dependent time (t_6)

Routine name: `ForwarderAssortmentDependentTime_SkogForsk`

Comment: Time is dependent on timber/pulpwood ratio, and tree volume is used as an indicator for this.

Truncate v to interval [0, 0.5]

$t_6 = 0.05 - v$

5.5 Sorting time (t_7)

Routine name: `ForwarderSortingTime_SkogForsk`

Comment: Time consumption depends on the number of assortments handled (=no. of qualities and species)

$t_7 = -0.1 + 0.1 nbAssortments$

nbAssortments is user-defined (default value =4)

5.6 Additional time in forwarding (t_8)

Routine name: `ForwarderAdditionalTimePerLoad_SkogForsk`

Comment: Additional time including for example marking of wood. Basic function returns minutes per load. Here multiplied with the number of loads to get total driving time (minutes per ha).

$t_8 = 1.5 nbLoads$

where *nbLoads*

$$nbLoads = \text{int}\left[\frac{V_{harv}}{c_{machinesize}} + 0.99\right]$$

int rounds down to nearest integer. 0.99 is added to add a tolerance of 0.1 cubic meter.

Example 1: Assume V_{harv} = 39.9 and capacity = 20
Then 39.9/20 = 1.995
1.995 + 0.99 = 2.985.
int(2.985) = 2

Example 2: Assume V_{harv} = 40.1 and capacity = 20
Then 40.1/20 = 2.005
2.005 + 0.99 = 2.995
int(2.995) = 2 (hence, only two loads are needed since 40.1 is so close to 40)

Example 2: Assume V_{harv} = 40.2 and capacity = 20
Then 40.1/20 = 2.01
2.01 + 0.99 = 3
int(3) = 3 (hence, three loads are needed since 40.2 violates the tolerance for two loads)

6. Test data

Function 4.1, Harvester, clearcutting:

Variable	**Test data 1**	**Test data 2**	**Test data 3**	**Test data 4**
Mean tree volume (v)	0.8 m^3	0.4	1.5	0.7
Number of harvested trees (N_{harv})	500 trees/ha	600	700	500
Y	1	1	1	2
L	1	1	2	2
W	default	default	default	default
Result (h)	9.0519	7.540	20.685	8.5607

Function 4.1, Harvester, thinning:

Variable	**Test data 1**	**Test data 2**	**Test data 3**	**Test data 4**
Mean tree volume (v)	0.1	0.1	0.3	0.2
Number of harvested trees (N_{harv})	500	500	500	500
Number of residual trees N_{res}	1200	1200	1000	1000
Y	1	1	1	1
L	1	1	1	1
W	16	16	16	16
$p_{init,Spruce}$	0.7	0.7	0.5	0.5
$P_{harv,\ broadLeaves}$	0.2	0.2	0	0
rd	1.0	**1.1**	1.1	1.1
thinningNumber	2	2	3	3
thinningSystem	STRIPROAD	STRIPROAD	STRIPROAD	STRIPROAD
Result (h)	10.894	10.876	15.21	10.273
Time per m3 fub	0.21788	0.21752	0.1014	0.10273

Function 5.1, Forwarding, clearcut and thinning:

Variable	**Test data 1**	**Test data 2**	**Test data 3**	**Test data 4**	**Test data 4**
Treatment	Clearcutting	Clearcutting	Thinning	Thinning	Thinning
Mean tree volume (*v*)	1	2	0.2	0.1	0.2
Number of harvested trees (N_{harv})	700	700	700	600	600
Y	1	1	1	2	2
L	1	1	1	2	2
nbAssortments	4	4	3	2	2
D	300	300	500	600	600
Machinesize	3 (big)	3 (big)	1 (small)	2 (medium)	2 (medium)
Result (h)	21.076	30.08	12.266	5.43	9.39