A step towards optimal wood supply chain: A case study on optimal tree bucking in Central Finland

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Abstract:
In this paper we estimate how large a net profit can be achieved provided that a forest-level tree bucking optimum can be achieved within a normal Finnish wood supply chain. We demonstrate a holistic system where all costs and revenues within the wood supply chain are calculated. The forest-level optimum of the complete processing chain is then solved with the GA-based algorithm. We calculate both the maximum and minimum net profit for the forest-level bucking optimization problem and find out what could be the maximum difference between the maximum and minimum net profit. The system is demonstrated and validated with the aid of case study material collected from Central Finland. The GA-based stand level allocation system seems to produce logical solutions. There are no clear differences in logistics costs between the best and the worst feasible solution, but there needs to be an explanation of the differences in processing costs and revenues. It seems that there is a possibility to increase the net income of the wood supply chain by at least 50 per cent by better allocation decisions.

Keywords: genetic algorithm, logistic costs, wood processing, wood supply chain management

1 Introduction

The activity of cutting tree stems into shorter logs is usually called tree bucking. The resulting logs are suitable for further processing as saw logs, pulp logs, poles and other products. The process of producing logs from tree stems attaining the highest value is known as the bucking optimization problem (Pickens et. al 1997). Laroze (1999) has stated that bucking optimization problems occur at stem, stand and forest-level. At stem level, the bucking pattern that maximizes the stem value should be determined. At stand level, the bucking pattern for each dbh class should be established, maximizing the aggregate production value. At forest-level, a bucking program should be determined for each stand, maximizing the global fit.

The classical dilemma in tree bucking optimization is that in order to achieve the best possible result at stand level it is to some extent necessary to compromise on the principle of optimizing individual stems. Moreover, a global maximum to the forest-level problem requires us to compromise on the principle of optimizing individual stands. The first forest-level optimization procedures were presented by Laroze in 1999 and Arce et al. in 2002. Both suggested a two-stage hierarchical optimization model to find the most suitable solution. More recently, Kivinen (2004, 2006) has introduced a genetic algorithm (GA)-based system for finding an optimal log demand matrix set to solve the forest-level optimization problem. The system for the control of log demand distributions has three main parts (Fig. 1): 1) a module for the loading and preprocessing of stem data and demand matrices; 2) a bucking simulator for the optimal conversion of tree stems into logs of various sizes and qualities; and 3) a GA module for the search for stand-specific log demand distributions. The advantage of the system is that the data structures and the bucking simulator mimics the procedures used by modern harvesters. This means that in the ideal case the system should give realistic values and demand matrices for practical use.

Disregarding whether we consider tree, stand or forest-level problems, bucking control can be divided into two main tasks: 1) which products (wood assortments) in what quantities we cut from each stand (wood allocation problem) and 2) what kind of logs in terms of small-end diameter and log length we cut within each product (product fine-tuning problem).

In the Nordic countries, significant progress in both tree bucking control and transportation allocation has been achieved in practice, but these two processes are still handled separately. Thanks to heavy investments in research and training, harvester operators are today more skillful in controlling the bucking in such a way that the log demand distributions for individual sawmills can be fulfilled. Although the number of different wood products has been growing rapidly, wood procurement companies do not have any decision-support system for how to react to the wood allocation problem. In most cases it is undesirable to cut many products from the same stand, since this requires too many loading and transportation operations. Therefore, it would be necessary to choose which products in what quantities may be cut from each stand. This means that tree bucking control and the wood transportation problem should not be considered separate tasks; they should be optimized as a whole. If they are considered separate processes the potential gain from the better product characteristics will be lost due to increasing transportation costs.

In this paper we estimate how large a net profit can be achieved provided that a forest-level tree bucking optimum can be achieved within a normal Finnish wood supply chain. We demonstrate a holistic system where all costs and revenues within the wood supply chain are calculated. The forest-level optimum of the complete processing chain is then solved with the GA-based algorithm proposed by Kivinen (2006). We calculate both the maximum and minimum net profit for the forest-level bucking optimization problem and find out what could be the maximum difference between the maximum and minimum net profit. The system is demonstrated and validated with the aid of case study material collected from Central Finland.

2 Material and Methods

2.1 Study stands and wood processing mills

The case study comprises one large wood processing industry consortium that owns two sawmills and one pulp mill. The wood raw material provided to the mills is supplied by the consortium’s own wood procurement department. In addition to that the wood procurement department also has delivery agreements with two additional wood processing factories; one joinery and one logging factory that are not owned by the consortium (later referred to as delivery mills).

The case study attempts to mimic real harvesting, transportation and tree conversion scenarios. The data is based on harvesting sites that were marked for felling and harvested by a local wood harvesting entrepreneur. The calculations concentrated on optimizing the production flows of pines (*Pinus sylvestris*).The study material comprise 15 mature pine and mixed pine-spruce (*Picea abies*) forest stands (Table 1). The study stands were measured prior to harvest by the systematic sampling procedure proposed by Uusitalo 1997 and the sample data was converted to complete descriptions of the stems with the method proposed by Uusitalo & Kivinen (1998, 2000). It was estimated that wood raw material cut from the study stands amounts to a total of roughly 5,100-5,200 m^3. This volume was proportioned to the annual demand of roughly 300,000m^3 of raw wood that the local wood procurement district supply to the mills in total in real life. This means that the volume of 15 study stands meets the approximate demand of the mills in one week. The log specifications and the proportional demands of each factory are given in Table 2. The sum of the proportional demands is 4,830m^3. Therefore, within the allocation process, the demand of all the factories will be fulfilled but a small amount of wood would remain unallocated to any factory and left as surplus until the next period.

Table 1: Mean characteristics of the 15 study stands

Stand No	Area Ha	Shares of pine trees from volume %	Total volume of pine trees m^3	Mean volume of pine stems m^3
1	3.0	64	386	0.454
2	7.0	62	872	0.905
3	5.1	69	513	0.467
4	1.3	48	77	0.507
5	3.2	98	568	0.457
6	2.8	53	347	0.785
7	2.0	51	177	0.461
8	5.1	46	560	0.463
9	6.8	34	505	0.589
10	2.0	29	149	1.049
11	2.0	38	168	0.828
12	1.2	31	87	0.604
13	1.5	12	39	0.394
14	4.0	30	323	1.170
15	3.6	46	466	0.908

Table 2: Specifications of the log products and the proportional usage (=demand) of roughly one week

Factory	Ownership	Log product	Length (cm) min	max	SED (mm) min	max	Proportional demand (min) m^3
Sawmill1	Own mill	SAW1	370	580	150	380	3,420
Sawmill2	Own mill	SAW2	370	550	150	240	450
		SMALL	370	460	120	150	150
Joinery	Delivery mill	JOINERY	370	580	290	600	170
Logging factory	Delivery mill	LOGGING	370	760	240	285	170
Pulp mill	Own mill	PULP	250	600	60	700	470
All							4,830

2.2 Problem definition and optimization

Let i be the diameter (i=1, 2,…, n), j the length of the log (j=1,2,,…, m), k the log product and s the stand from which the log has been cut. Suppose we have r Scots pine stands to be harvested and p Scots pine log assortments k (k = 1, 2,..., p) can be cut in each stand s (s = 1, 2,..., r). For each log there are individual costs (€/m^3) for each log class i, length class j, log product class k and stand s defined in a four-dimensional matrix $\mathbf{C}_{tot}^{sk} = \left(c_{ij}^{sk}\right)$. Moreover, total volumes of log class i, length class j, log product class *k* that are actually being cut from stand *s*, v_{ij}^{sk} (m[3]), are given in a four-dimensional matrix $\mathbf{V}_{ij}^{sk} = (v_{ij}^{sk})$. The total costs (€) of each individual alternative can then be calculated as $tc_{ij}^{sk} = c_{ij}^{sk} \times v_{ij}^{sk}$ and total costs (€) of the wood supply chain as $\mathbf{TC}_{tot}^{sk} = \mathbf{C}_{ij}^{sk} \times \mathbf{V}_{ij}^{sk}$ or $TC_{tot}^{sk} = \sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{s=1}^{r}\sum_{k=1}^{p} tc_{ij}^{sk}$.

We define revenues of the wood supply chain to be only income that comes directly from selling the main products (logs, sawn goods, pulp, etc.) and associated by-products (woodchips, sawdust, turpentine oil, etc.) sold on the open market. Production revenues received from processing certain logs in certain processes is therefore defined as $\mathbf{R}_{tot}^{sk} = \left(r_{ij}^{sk}\right)$ (€/m[3]), revenues (€) of each individual alternative that have actually being cut as $tr_{ij}^{sk} = r_{ij}^{sk} \times v_{ij}^{sk}$ and total revenues (€) of the wood supply chain as $\mathbf{TR}_{tot}^{sk} = \mathbf{R}_{ij}^{sk} \times \mathbf{V}_{ij}^{sk}$ or $TR_{tot}^{sk} = \sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{s=1}^{r}\sum_{k=1}^{p} tr_{ij}^{sk}$.

The ultimate goal of forest-level tree bucking optimization would then be to determine the wood assortment palette along with the matrices for each stand so that the maximum overall profit $Max\left[\mathbf{TR}_{tot}^{sk} - \mathbf{TC}_{tot}^{sk}\right]$ (or $Min\left[\mathbf{TR}_{tot}^{sk} - \mathbf{TC}_{tot}^{sk}\right]$) can be achieved.

Tree bucking is controlled in modern harvesters with two matrices that are similar in size and structure: 1) a value matrix and 2) a demand matrix. The goal of the bucking optimization procedure is to find a solution that assigns the most suitable value and demand matrices in each stand so that the net profit of the wood supply chain will be maximized. The search for the most suitable value and demand matrices was executed with the genetic algorithm (GA) presented by Kivinen (2006). The algorithm is exactly the same as was introduced in the previous study by Kivinen, with the only exception being that the goodness of fit-based objective function of the previous study was replaced with the net profit objective function. The basic principle of the algorithm is presented in Figure 1 and the core of the algorithm is thoroughly described in Kivinen (2006). It was agreed that the algorithm would run 1,000 iterations towards both optimization targets (maximum and minimum). With both cases there were restrictions that the minimum volume of wood cut must exceed 5,080m[3].

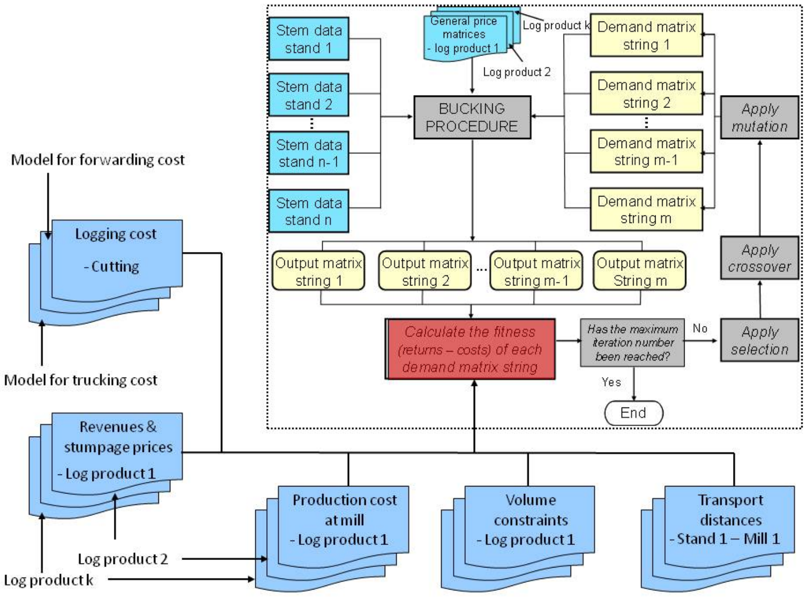

Figure 1: Basic structure of the genetic algorithm (GA)-based system for forest-level bucking optimization.

2.3 Calculation of costs and revenues for each log

In general, costs in the wood supply chain from the forest to the final product can be expressed as:

$$C_{tot} = C_{stumpage} + C_{cut} + C_{forw} + C_{truck} + C_{woodcapital} + C_{wscm} + C_{proc}$$

where

C_{tot} = Total wood supply chain costs from forest to final product, €/m^3
$C_{stumpage}$ = Stumpage price, €/m^3
C_{cut} = Cutting costs, €/m^3
C_{forw} = Forwarding costs, €/m^3
C_{truck} = Timber trucking costs, €/m^3
$C_{woodcapital}$ = Capital costs of wood, €/m^3
C_{wscm} = Wood supply chain management costs, €/m^3
C_{proc} = Processing cost of timber from round wood to final products, €/m^3

and revenues as:

$$R_{tot} = R_{final\_prod} + R_{\log\_prod}$$

where

R_{tot} = Total wood supply chain revenues, €/m^3
R_{final_prod} = Revenues of final products processed by own mills, €/m^3
R_{log_prod} = Revenues of log products sold to other factories (delivery mills), €/m^3

Revenues and costs are calculated in different ways for the consortium's own mills and the delivery mills. With regard to the consortium's own mills, revenue comes from selling the final products (R_{final_prod}) and in the case of the delivery mills, it is generated from the delivery and sale of a log (R_{log_prod}). Accordingly, in the case of delivery mills, the costs associated with the logs do not include processing costs (C_{proc}). The cost matrix (four-dimensional array) $\mathbf{C}_{tot}^{sk} = \left(c_{tot\,ij}^{sk}\right)$ can be calculated by summing up four-dimensional cost matrices (€/m^3) related to each individual process along the supply chain

$$\mathbf{C}_{tot}^{sk} = \mathbf{C}_{stumpage}^{sk} + \mathbf{C}_{cut}^{sk} + \mathbf{C}_{forw}^{sk} + \mathbf{C}_{truck}^{sk} + \mathbf{C}_{woodcapital}^{sk} + \mathbf{C}_{wscm}^{sk} + \mathbf{C}_{proc}^{sk},$$

the costs of the individual log classes (€/m^3) by summing up

$$c_{ij}^{sk} = c_{stumpage_{ij}}^{sk} + c_{cut\,ij}^{sk} + c_{forw_{ij}}^{sk} + c_{truck\,ij}^{sk} + c_{woodcapital_{ij}}^{sk} + c_{wscm\,ij}^{sk} + c_{proc_{ij}}^{sk},$$

and total costs of the wood supply chain (€) by summing up

$$TC_{tot}^{sk} = TC_{stumpage}^{sk} + TC_{cut}^{sk} + TC_{forw}^{sk} + TC_{truck}^{sk} + TC_{woodcapital}^{sk} + TC_{wscm}^{sk} + TC_{proc}^{sk}$$

where footnotes *stumpage*, *cut*, *forw*, *truck*, *woodcapital*, *wscm* and *proc* refer to stumpage price, cutting, forwarding, timber trucking, wood capital, wood supply chain management and processing costs.

For practical reasons, some of the cost matrices are not purely four-dimensional; there are three, two or one-dimensional arrays or, in some cases, even one constant value (scalar) for all logs. A certain cost matrix may disregard the size of the logs and therefore have the same cost for all logs in each product-stand combination. Similarly, some processing costs are regarded as independent of stand properties or log dimensions.

The costing of cutting and forwarding was calculated according to the activity-based cost (ABC) calculation procedure proposed by Nurminen et al. (2009), utilizing the time study models of Nurminen et al. (2006). The cost of the cutting of an individual log is dependent on the properties of each log (diameter and length), the properties of each stem (dbh and height) in which the log is being cut, the number of stems in stand *s* where log product *k* is cut, the total volume of log product *k* that is being cut from stand *s*, and the total resource cost of the harvester per operational hour (€/h). The procedure calculates one general unit cost (€/m^3) for the cutting of the log product *k* from stand *s*.

The cost of forwarding is dependent on the properties of the stand (hectare of logging site and average forest haulage distance), cutting method (clear cut or thinning), the total volume of log product *k* that is being cut from stand *s*, the average timber volume per load, and the total resource cost of the forwarder per operational hour (€/h). The procedure calculates one general unit cost (€/m^3) for the forwarding of log product *k* from stand *s*. The resource cost per operational hour of the harvester and the forwarder were €91.57/hr and €66.59/hr, respectively. The total length of the strip road network was 769 m/ha in final fellings (based on an average strip road spacing of 13 m) and 500 m/ha in thinnings (based on an average strip road spacing of 20 m. For all other assumptions, see Nurminen et al. (2006, 2009).

The cost of timber trucking is dependent on the transportation distance between stand and mill, the average driving distance between storage points, the total volume of log product *k* that is being cut from stand *s* (V_{sk}), the load size of the timber truck and the unit cost of trucking. The calculation for the timber trucking cost for each individual product was based on the time studies of Nurminen and Heinonen (2007) and the ABC calculation procedure presented by Nurminen et al. (2009). The unit cost of timber trucking is dependent on time (€/h) and distance-dependent costs (€/km) which must be calculated individually for each load. Finally, the procedure calculates one general unit cost (€/m^3) for the forwarding of the log product *k* from stand *s*.

The capital costs of wood are dependent on the amount of days during which a company's money is tied up in the raw material, the stumpage price and the interest rate. It was assumed that the wood purchaser (the company) pays a deposit of 30 per cent of the total price of the wood upon the sale of the timber, and keeps the stand as a stumpage reserve for three months before harvesting begins. The remaining part of the stumpage price has to be paid later. Moreover, it was assumed that it takes two months from the beginning of the harvesting operation until the logs have been processed into final products and the company has received payment for the delivered wood. Stumpage prices for sawlogs, small sawlogs and pulp wood were €54, €25, and €15 respectively, and the interest rate was 3 per cent. Wood supply chain management costs were kept at a constant €3.51/m^3 for all logs

It was assumed that processing costs are independent of stand properties. Instead, processing costs were calculated individually for each diameter class, on the assumption that each sawlog had a mean length of 4.9 meters. Calculations of sawmilling costs were based on the ABC calculation procedure presented by Korpunen et al. (2010) and the pulping cost on the ABC calculation procedure by Korpunen et al. (2011). Processing costs are presented in Table 3. All cost parameters utilized in the costing models were derived according to cost levels for 2010.

Table 3: Processing costs for log products SAW1, SAW2, SMALL and PULP, €/m3

Log product	**Small-end diameter mm**												
	70-110	**120**	**130**	**140**	**150**	**170**	**190**	**210**	**230**	**250**	**270**	**290**	**310**
SAW1					29.3	27.3	23.8	23.0	20.3	20.5	19.3	17.8	17.2
SAW2					27.2	25.5	22.7	22.8					
SMALL		29.0	29.0	29.0	29.0								
PULP	21.99	21.99	21.99	21.99	21.99	21.99	21.99	21.99	21.99	21.99	21.99	21.99	21.99

Revenues from the sawing process comprise sawing goods, woodchips, bark, and sawdust. Proportions of A, B, and C grades for each log grade were derived individually for each stand and diameter class . Moreover, separate values were given to butt logs and logs cut from upper parts of the stem (hereafter referred as top logs). The prediction of the quality distribution of sawing goods for each stand, diameter class and log type were based on pre-harvest sampling procedures and related wood quality prediction models (Uusitalo 1997, Uusitalo & Kivinen 1998). The proportions of sawn goods, woodchips, bark and sawdust were derived from Heiskanen and Riikonen (1976), Hakala (1992) and Uusitalo (1997). The prices of A, B and C-grade battens were €220/m^3, €160/m^3 and €110/m^3, the prices of A, B and C-grade boards €310/m^3, €180/m^3 and €80/m^3 and the prices of woodchips, bark and sawdust were €35/m^3, €10/m^3 and €10/m^3, respectively.

Revenues from products sawn from products SAW1, SAW2 and SMALL can be expressed by two two-dimensional matrices, $\mathbf{R}_{Saw\_butt}$ for butt logs and $\mathbf{R}_{Saw\_top}$ for top logs, which includes both the variation of value related to the dimension of logs (12 diameter classes 120…310 as expressed in Table 3) and the variation related to quality differences between the 15 stands. Matrices can be calculated with the following matrix operations

$$\mathbf{R}_{saw\_butt} = \mathbf{d}_{butt} \times \mathbf{s}_{butt} \times v_{butt}$$

$$\mathbf{R}_{saw\_top} = \mathbf{d}_{top} \times \mathbf{s}_{top} \times v_{top}$$

where $\mathbf{d}_{\text{butt}}$ and $\mathbf{d}_{\text{top}}$ are row vectors indicating the value differences between the dimensions, $\mathbf{s}_{\text{butt}}$ and $\mathbf{s}_{\text{top}}$ are column vectors indicating value differences between the stands, and v_{butt} and v_{top} are the base values (scalars) indicating the general level of revenues in that category (€/m^3). The following values were used in our calculations: $\mathbf{d}_{\text{butt}}$=[0.73 0.75 0.76 0.80 0.89 0.95 1.00 1.07 1.10 1.11 1.12 1.09], $\mathbf{d}_{\text{top}}$=[0.75 0.80 0.81 0.81 0.90 0.95 1.0 1.04 1.07 1.08 1.09 1.09], $\mathbf{s}_{\text{butt}}$=[1.06 1.21 1.11 1.06 1.19 1.25 1.00 1.10 1.25 1.25 1.16 1.16 1.06 1.28 1.28], $\mathbf{s}_{\text{top}}$=[1.00 1.04 1.01 1.00 1.01 1.05 1.00 1.02 1.07 1.06 1.01 1.02 1.00 1.09 1.07] and v_{butt} = v_{top}=89€/m^3.

Revenues from the pulping process comprise pulp, bark, oil, turpentine and black liquor. Basic density (kg/m^3) has the biggest influence on revenues. The higher the basic density, the less wood is needed to get a pulp tonne. Basic density estimates for each diameter class were derived from Hakkila (1979) and bark estimates from Heiskanen and Riikonen (1976). The prices of pulp, oil, turpentine and black liquor were

€600/Adt pulp, €200/t, €200/t and €213/Adt pulp, respectively. The market price of black liquor was derived from its value as a source of energy. Revenues from the pulping process are presented in Table 4.

Table 4: Revenues from pulping process (product PULP), €/m³

Stand	Small-end diameter mm												
	70	**90**	**110**	**130**	**150**	**170**	**190**	**210**	**230**	**250**	**270**	**290**	**310**
Butt logs	133	135	135	144	144	147	147	147	150	156	156	156	156
Top logs	138	140	140	150	150	153	153	153	156	162	162	162	162

When calculating the revenues from log products (i.e. prices) sold to delivery mills (customer mills), it is assumed that the difference in quality between the logs are to a certain extent being taken into account in pricing. This prevents the optimization system from returning all the good logs to the consortium's own mills and the bad logs to the delivery mill. The basic price for the log is calculated by summing up stumpage price, mean harvesting cost, mean transportation costs, capital costs of wood, wood supply chain management costs and five per cent profit. Revenues from JOINERY butt logs are seen as being independent of diameter and length but dependent on stand properties. Value differences can be expressed as a column vector $\mathbf{r}_{Joinery\_butt} = \mathbf{s}_{butt} \times v_{\log prod}$

where $v_{log\ prod}$ is the basic price of the log and $\boldsymbol{S}_{butt}$ is the same column vector used to indicate value differences between the stands with the consortium's own sawn products.

The prices of LOGGING and the top logs of JOINERY are seen as being independent of stand properties, providing the dimensional criteria of the product are fulfilled. A constant value of €77/m^3 was used as the basic price for all three categories (JOINERY butt logs, JOINERY top logs and LOGGING (top/butt).

3 Results

The results of the wood allocation problem (which products we cut from each stand) is presented in table 5 and figure 2. The allocation of cutting with the best net income ($Max\left[\mathbf{TR}_{tot}^{sk} - \mathbf{TC}_{tot}^{sk}\right]$) and worst net income ($Min\left[\mathbf{TR}_{tot}^{sk} - \mathbf{TC}_{tot}^{sk}\right]$) are somewhat different. It is however very difficult to come up with any clear solutions, since the problem space is so complicated. To a certain extent it seems that it is more affordable to allocate logs from good quality stands to the consortium's own sawmills, but the consistency of that conclusion is unclear. Both solutions produce on average 3.7 log products per stand.

Table 5: Stand level allocation of the best feasible (A) and worst feasible (B) solutions

Log products	Stand														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
LOGGING				A	B			A	B			B	AB	AB	
JOINERY	B		AB	AB	B		AB	A		AB		A	B	AB	
SAW1	AB	AB	A	B	AB	B	AB	AB	AB	B	B	A	A	B	AB
SAW2	A	A	B	A	A	A		A		AB		AB	AB	A	
SMALL	AB	B	AB	B	B	AB	AB	AB	B		A	AB	A	B	AB
PULP	AB	AB	AB	AB	AB	AB	AB	AB	AB	AB	AB	AB	AB	AB	AB

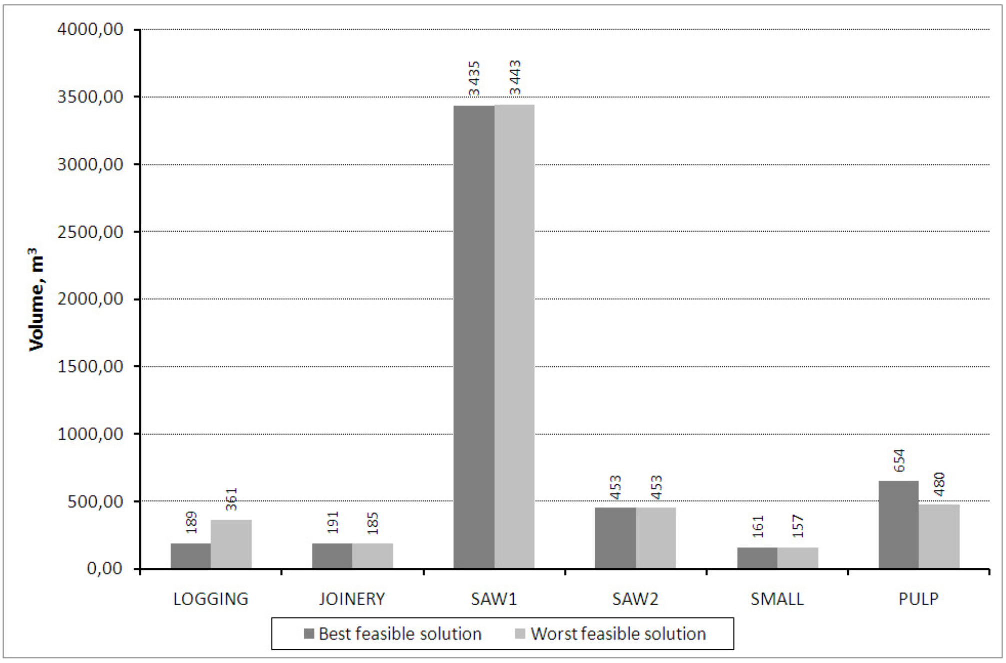

Figure 2: Differences between the volumes produced between the best and worst feasible solutions by log product

Both the best and the worst solutions fulfill the minimum demands of the mills, the sum of which is 4,830m^3. Both solutions exceed the minimum requirement of 5,080m^3 that has to be cut and allocated. The best solution allocates 5,083 m^3 and the worst solution 5,081m^3 to the wood processing mills. Therefore, there is surplus of 250 m^3 that the system has to allocate to wood processing mills. With the best solution, the surplus of 191 m^3 is allocated to the pulp mill and with the worst solution the surplus of 184 m^3 to the logging factory. It is rather obvious that the net incomes are the best in the pulping process and the worst in delivering logs to the logging factory.

Both solutions produce on average 3.7 log products per stand, so the net value differences cannot be explained by the differences in the logistics costs, as can also be seen in Table 6. The difference between the best and the worst feasible solution is €15,801 (€24,181 and €8,380).

Table 6: Differences between the total cost and total net income between the best and worst feasible solutions

Optimization target	Cutting costs $TC_{cut\,ij}^{sk}$		Forwarding costs $TC_{forw\,ij}^{sk}$		Trucking costs $TC_{truck\,ij}^{sk}$		Management costs $TC_{wscm\,ij}^{sk}$	Total net income $\mathbf{TR}_{tot}^{sk} - \mathbf{TC}_{tot}^{sk}$
	€	€/m^3	€	€/m^3	€	€/m^3	€	€
Minimum	23716	2.98	23716	4.67	38291	7.54	17831	8380
Maximum	23190	2.98	23190	4.56	38564	7.59	17838	24181

4 Discussion

The GA-based stand level allocation system seems to produce logical solutions. There are no clear differences in logistic costs between the best and the worst feasible solutions; the differences can be explained by the differences between processing costs and revenues. Different kinds of logs have different values in each process. Providing the average solution in reality is the average of the best (€24,181) and the worst (€8,380) solution, €16,280, there is the possibility of increasing the net income by at least 50 per cent through better allocation decisions. This equals the increase in net income by 1.5 to €3/m^3 per logs produced. In our case study area that would mean an increase in annual net income by €500,000 to €1,000,000. The case study outlined here had rather tight restrictions that did not allow for very broad alternatives for allocation decisions. The allocation problem was dominated by one sawmill. The quality of the logs was also evaluated with the same principle in three different sawmills. It is clear that many allocation problems can be found in real life, whilst there is the potential to multiply the net income compared to the results obtained here. The system seems to be very sensitive to the price of pulp. Since pulpwood can be cut from any part of the wood, the system starts to turn expensive sawlogs to pulpmills even with at price of €600€/Adt pulp, provided that quantity restrictions are relaxed.

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