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SUPPLY CHAIN PLANNING FOR A TIMBER HARVESTING PLUS SALE TENDER

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Abstract

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Since 2010, the Czech State Forest Enterprise has been inviting timber-harvesting tenders while insisting on the forestry company purchasing the timber from the felled trees as well. To win, a tender must offer the greatest difference between the price of the timber purchased and the cost of the operations. Thus, the forest companies are now facing new problem: apart from minimizing the logging costs they are searching for a cross-cutting and mill-distribution strategy that maximizes the selling price of the harvested timber.
The optimization model devised by the present paper provides support for finding an optimal timber selling strategy and, as an important contribution, include a detailed plan for cross-cutting the logs and assign them to the particular customers. We keep the support accessible via common office software and the cross-cutting and customer-assigning problem is formulated as a linear programming model for EXCEL, a particular real-world problem is solved and, using expert comparison, the model appears to provide very good results.

Keywords: linear programming, forestry supply chain, cross-cutting, timber-harvesting tender

INTRODUCTION

All over the world, decision-making-support systems have been extensively used to support the forest products industry and public forestry organizations. The methods of operations research and especially the optimizations techniques appeared to be a valid and helpful quantitative support for planning activities concerning the flow of wood fibre from forest to the customer (see, Clark, 2010; D'Amours, 2008; Usenius, 2007; Segura, 2014).

To a considerable extent, the supply chain process is specific for each country depending on its environmental and business conditions. For this reason, the optimizations models and decision-making-support systems are inherently only locally applicable, being built specifically for each forestry business chains (see Salo, 2011 and Knoke, 2005).

This paper is concerned with a particular process of the Czech forest business supply chain. The aim is to optimize the sale of the harvested timber to several customers. In this problem, the decision maker is a private forestry company logging under timber-harvested tender with the Czech State Forest Enterprise obliging it to buy the resulting timber as well. Having a number of potential customers that have different requirements concerning the length of logs and quality of timber purchased, offer different prices for the same length of logs and that are being at various distances from the harvest area, the complex optimization problem is to be solved. Thus, the forestry companies are facing an entirely new comprehensive decision-making problem for which a suitable quantitative tool is desirable (see an opinion poll among forestry managers Lindnerová, 2010). The aim is to create an optimization model solvable by MS EXCEL, which is available to forestry managers.

In the Problem Description part, the system of inviting timber-harvesting tenders in the Czech Republic is detailed presenting a particular decision-making problem for which, subsequently, an optimization model is built. This is then solved in the Result part with a validation provided in the final part by comparing the results with a solution found by an experienced forestry worker using intuitive approach.

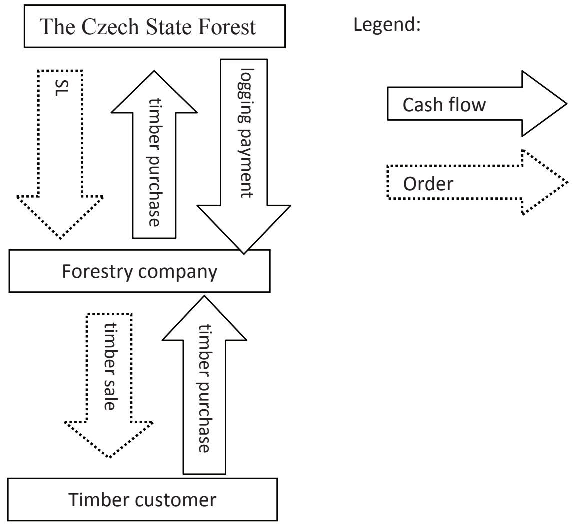
Problem Description

On a regular basis, forestry work orders are put out to tender by the Czech State Forest Enterprise. This involves timber harvesting, cultivation such as soil preparation and planting, weed and browsing control, fencing of reforested areas etc.

There are two types of timber-harvesting orders put out to tender. The first type is denoted by RS (road-side locality) and the second type by SL (stump locality). A RS order involves only services provided on-site without purchasing the resulting timber (the Czech State Forest Enterprise trade via their own timber dealers). In this case, the harvesting company is paid for logging and timber transport (if so stipulated in the contract). In addition, a RS order includes purchasing the resulting timber on-site, in this case, the Czech State Forest Enterprise only pay for logging with other costs being paid by the companies obliged to buy the timber and find a customer. When tenders for work are judged, the total price required for work is taken into consideration with the Czech State Forest Enterprise trying to push down the price as much as possible. With tenders including timber purchasing, the difference is important between the total price of timber purchase and the price of logging work.

Since 2010, only SL orders have been put out to tender. Thus, harvesting companies are facing new decision-making problems concerning the planning of timber-purchase activities. While, with a RS order, the costs of logging have to be minimized to push down the price offered to win the order (this problem was investigated by Janová, Lindnerová 2009), with a SL order (see Fig. 1), in addition, the sales of timber to customers must be optimised to maximize profit, that is, to make the timber purchase price as high as possible. This second comprehensive optimization problem is dealt with in this paper.

An optimization model will be built for a particular harvesting problem detailed by (Janová, Lindnerová, 2009). The harvesting takes place along the river Budišovka at the Kružberk reservoir, owned by the state and run by the Czech State Forest Enterprise. This is an area of about 1300 ha situated at an altitude from 440 m to 560 m above the sea level, covered with Norway spruce (*Picea abies* L., Karst.) with other tree species not exceeding 1 percent of the timber harvested.



1: *Cash flow diagram and order distribution in the forest business supply chain in question*

Optimization Model

Optimized should be the cross-cutting plan of each stem and the sale to given customers of the resulting logs for the *profit* z from the sale to be maximal. The profit z is defined as the difference between the sales to the customers and costs of harvesting and haulage to customers. Based on the maximum value z^* achieved, a harvesting company can then find the purchase price offered to the Czech State Forest Enterprise in the interval $[0, z^*]$ depending on its tender strategy.

Tab. I lists the number of trees existing in a given locality in each tree-volume class. For the purposes of solving the optimization problem, age classes are transformed into seven tree-volume classes discriminating between different lengths and diameters, and between logs and pulpwood. This transformation is necessary as the trees are cone- rather than cylinder-shaped. The timber volume is partitioned into tree-volume classes depending on length, diameter, and whether related to pulpwood or logs.

I: *Tree numbers in tree-volume classes*

tree-volume class k	diameter [cm]	length [m]	pulpwood/logs	harvest volume [m^3]	number of trees h_k
1	11	9	pulpwood	1,153	14,413
2	14	7	pulpwood	5,101	72,871
3	13	5	pulpwood	1,343	22,383
4	15	8	log	897	6,900
5	24	13	log	9,474	17,544
6	23	13	log	3,491	7,124
7	32	9	log	2,416	3,606

Source: Lindnerová 2011

II: *Structure of customers*

Customer *p*	Distance [km]	Specification		
Logs		Length in m	Diameter	
			min	max
1	167	4; 8	30	80
2	145	4; 5	30	65
3	159	4; 5; whole lengths	15	49
4	64	3; 5	12	39
Pulpwood				
5	202	2-4	8	50
6	64	2-4; whole lengths	8	80

Source: Lindnerová 2011

After the trees are harvested, the timber purchased from the Czech State Forest Enterprise is further delivered to customers. The characteristics of six customers are listed by Tab. II (average hauling distance and timber specifications). The length column lists the log lengths accepted by the customer. If the value is different from the entire log length, the timber distribution costs must, in addition to delivery, include the cross-cutting costs (see Tab. III). The diameter column of Tab. II shows the log diameter scope accepted by the customer. Customers listed in the Logs section, buy only timber of healthy trees while those in the pulpwood section accept timber of small diameter or worse quality.

The transport costs depend on the distance between the road-site and the end customer. The transport costs per lorry (only one type of timber truck is considered with a loading capacity of 30 m^3 of timber) to the customers are listed by Tab. IV along with the purchasing prices of 1 m^3 of timber as offered by the customers.

III: *Wood handling charges for tree-volume classes (in CZK per log)*

Tree-volume class k	Service charge [CZK/log] m_k
1	3.2
2	2.1
3	1.2
4	5.2
5	16.2
6	9.8
7	13.4

Source: Lindnerová 2011

IV: *Purchasing price c_p of wood and transport costs n_p*

Customer *p*	c_p [CZK/m^3]	n_p [CZK/ timber truck]
1	2,700	9,450
2	2,650	9,150
3	2,450	9,150
4	2,300	6,180
5	1,200	10,650
6	1,300	6,180

Source: Lindnerová 2011

Note that each customer only purchases logs cut to certain lengths, his/her options being also influenced by the current service charges and that all the timber of all the trees felled must be sold. Thus, the problem cannot be solved by simply selling the timber to the customer offering the most advantageous difference between the price offered and the transport costs.

The optimization problem will be solved by a linear-programming method. The objective function of profit z^* consists of the sales of timber diminished by the transport costs to the customers and the logging costs. In the model, the following denotation is used:

p ....customer, $p \in \{1; 2; \ldots; 6\}$;

l............log length, $l \in \{1; 2; \ldots; 6\}$; 1 = 2 m, 2 = 3 m, 3 = 4 m, 4 = 5 m, 5 = 8 m, 6 = whole stem log (whole log means log with more than 8 m length);

k ....tree-volume class of forest, $k \in \{1; 2; \ldots; 7\}$;

c_p..........customer *p's* price for 1 m^3 of wood;

d_{pkl} ....number of logs of length l tree-volume k sold to customer p;

V_{kl} ....volume of log of length l tree-volume k;

n_p ....transport costs per timber truck (capacity 30 m^3 of wood) to customer p;

Q_p ....number of timber trucks of wood for customer p;

m_k ....service charge for cross-cutting one log of tree-volume k;

$r_{k\alpha}$ ....number of logs of tree-volume class k cross-cutted using method α;

$D_{k\alpha l}$......number of logs of length l cut from log of tree-volume class k using method α;

h_k ....total number of logs of tree-volume class k.

The decision variables are d_{pkl} and $r_{k\alpha}$. Thus, the model results in determining the cross-cutting plan of each tree and deciding to which customers it should be dispatched. The optimization model has the following form:

$$z^* = \max\left\{\sum_{p=1}^{6} c_p \left(\sum_{l=1}^{6}\sum_{k=1}^{7} d_{pkl} \times V_{kl}\right) - \sum_{p=1}^{6} n_p \times Q_p - \sum_{k=1}^{7} m_k \times \sum_{\alpha=1}^{17} r_{k\alpha}\right\},$$

[CZK] (1)

$$Q_p = \left(\frac{\sum_{k=1}^{7} d_{pkl} \times V_{kl}}{30} \right), [pcs] \quad (2)$$

$$\sum_{p=1}^{6} d_{pkl} = \sum_{\alpha=1}^{17} r_{k\alpha} \times D_{k\alpha l}, [pcs] \quad (3)$$

$$\sum_{\alpha=1}^{17} r_{k\alpha} = h_k, [pcs] \quad (4)$$

$$r_{k\alpha} \geq 0, [pcs] \quad (5)$$

$$d_{pkl} \geq 0, [pcs] \quad (6)$$

$r_{k\alpha}$: integer,
d_{pkl} : integer.

Constraint (2) defines the number of timber trucks to be delivered to each customer. Constraint (3) defines the relationship between the total number of logs of a given tree-volume class cut to a given length and the way each log is cross-cutted. Constraint (4) expresses the logging requirement (cross-cutted or not) for each tree felled. Inequalities (5) and (6) require that the structural variables should be non-negative and the d_{pkl} and $r_{k\alpha}$ variables are required to be integers denoting the number of pieces. The model parameters are listed by Tabs. I–IV. The volumes V_{kl}, for which no tables of standardised values exist, were calculated using the above-mentioned age/tree-volume conversion with the resulting values shown in Tab. V.

Tab. VI shows the admissible cross-cutting plan for each tree length. Each cross-cutting plan is given by the lengths required by the customer and the lengths in the tree-volume classes. Each cross-cutting plan also lists the customers purchasing the resulting logs. In the last column are the tree-

V: *Volumes of logs*

k	V_{k1} [m³]	V_{k2} [m³]	V_{k3} [m³]	V_{k4} [m³]	V_{k5} [m³]	V_{k6} [m³]
1	0.018	0.027	0.036	0.044	0.071	0.080
2	0.020	0.030	0.040	0.050	0.080	0.070
3	0.024	0.036	0.048	0.060	0.096	0.060
4	0.033	0.049	0.065	0.081	0.130	0.130
5	0.083	0.125	0.166	0.208	0.332	0.374
6	0.075	0.110	0.151	0.188	0.302	0.339
7	0.149	0.223	0.298	0.372	0.596	0.670

Source: Lindnerová 2011

VI: *Cross-cutting plans*

Tree height in [m]	α	Cross-cutting plan in [m]	Customer	k
any	1	no cross-cutting	p = 3; 6	1; 4; 5*; 6*; 7
9	2	3 + 3 + 3	p = 5; 6	1
	3	2 + 3 + 4		
7	4	3 + 4		2
	5	2 + 2 + 3		
5	6	2 + 3		3
8	7	4 + 4	p = 3; 4	4
	8	8		
	9	3 + 5		
13	10	4 + 4 + 5		5, 6
	11	4 + 9		
	12	5 + 8		
	13	3 + 3 + 3 +4		
	14	3 + 5 + 5		
	15	3 + 10		
9	16	4 + 5	p = 1; 2	7
	17	3 + 3 + 3		

Source: Lindnerová 2011
/* no cross-cutting in tree-volumes-class 5 and 6 means log with 9 m length

volume classes assigned to each cross-cutting plan. Thus, to cross-cutting plan 1 (no cutting), all the tree-volume classes could be assigned, however, this is not possible because of the second tree-volume-class length, which is 7 m. Whole-stem logs are those longer than 8 m. Also, the lengths in the third tree-volume class are less than required.

RESULTS

This model is solved using the MS Excel solver. The results are summarized in Tab. VII with the optimum values of the structural variable d_{pkl}, denoting the numbers of logs of different lengths in each tree-volume class.

It can be seen in Tab. VII that two- and three-metre logs must only be cross-cutted in tree-volume classes two and three, thus these are considered pulpwood. Taking into account the transport costs, these should be sold to customer 6. In the first and second tree-volume class, four-metre logs should be cross-cutted selling them to customer 6 as well. Thus, all pulpwood should be sold to customer 6 leaving nothing for customer 5, which could have been expected due to its unfavourable cost/purchasing-price ratio.

The optimal customer for the four-metre logs in the seventh tree-volume class is the first one; because of the diameter required, timber from no other tree-volume class can be supplied. Again, the five-metre logs should only be produced in tree-volume class seven selling them to customer two. The four-metre logs of tree-volume classes four, five and six are bought by customer three, which will also buy whole-stem logs of tree-volume classes five, and six. Because of the unfavourable purchasing price and shipment costs, nothing should be sold to customer four.

In terms of the timber volume, all the trees in the tree-volume classes are portioned using a single cross-cutting plan, evaluated as the best by the model. Tab. VIII shows the assignment of the trees felled to cross-cutting plans.

A total of 36,796 two-metre logs will result, 109,667 three-metre logs, 129,358 four-metre logs, 3,606 five-metre logs, and 24,668 whole-length logs.

VII: *Summary of the results achieved: values of d_{pkl}, (in pieces)*

		Tree-volume class ***k***						
Customer *p*	**Log length *l* m**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1	4	0	0	0	0	0	0	3,606
	8	0	0	0	0	0	0	0
2	4	0	0	0	0	0	0	0
	5	0	0	0	0	0	0	3,606
3	4	0	0	0	13,800	17,544	7,124	0
	5	0	0	0	0	0	0	0
	whole length	0	0	0	0	17,544	7,124	0
4	3	0	0	0	0	0	0	0
	5	0	0	0	0	0	0	0
5	2	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0
	4	0	0	0	0	0	0	0
6	2	14,413	0	22,383	0	0	0	0
	3	14,413	72,871	22,383	0	0	0	0
	4	14,413	72,871	0	0	0	0	0
	whole length	0	0	0	0	0	0	0

Source: own work

VIII: *Resulting cross-cutting plans*

tree-volume class *k*	number of logs	cross-cutting plan α
1.	14,413	α = 3 (i.e. 1×2 m + 1×3 m +1×4 m)
2.	72,871	α = 4 (i.e. 1×3 m + 1×4 m)
3.	22,383	α = 6 (i.e. 1×2 m + 1×3 m)
4.	6,900	α = 7 (i.e. 2×4 m)
5.	17,544	α = 11 (i.e. 1×4 m + 1×9 m)
6.	7,124	α = 11 (i.e. 1×4 m + 1×9 m)
7.	3,606	α = 16 (i.e. 1×4 m + 1×5 m)

Source: own work

Thus 768 timber trucks will be dispatched to all the customers with a capacity of about 28,860 m^3 of timber. The total sales figure is 50,311,727 CZK, the total transport costs are 6,540,909 CZK and the total logging costs are 664,238 CZK. The optimal value of the model fitting function is $z^* = 43{,}106{,}580$ CZK.

Note that the fitting function does not include the purchasing price of timber paid by the forestry company to the Czech State Forest Enterprise. Thus, z^* cannot be taken for the final profit of a harvesting company. However, as this payment for timber to the Czech State Forest Enterprise is considered fixed in the model, its inclusion will not change the optimal solution arrived at.

The results calculated were compared with those obtained by an expert with some practical experience. As a senior employee of a company, he received as input the total harvest volume in each age class having to determine the sales to given customers (see Appendix for definition of this particular problem).

By intuitive approach, this senior employee calculated the company total sales to be 40,263,000 CZK. According to the model, these equal 50,311,727 CZK. The total costs by the employee's approach are 6,597,090 CZK while those according to the model reach 7,205,147 CZK. The total profit (its definition being identical with that defined by the fitting function of the optimisation model) was 33,665,910 CZK according to the senior employee and 43,106,580 CZK according to the model. Thus, in this particular case, the model produces better results than an individual approach with the difference in profit being 9,440,670 CZK for 23,875 m^3 of timber.

According to the model, the logging and transport costs are higher than those determined by an intuitive approach. Note that this difference may also be accounted for by the different calculation method used. Whereas the model uses transport costs per timber truck (30 m^3 of timber), the individual approach takes the transport price to be as per 1 m^3 of timber. Similarly, logging costs relate to individual logs in the model and to cubic m with the individual approach.

CONCLUSION

The optimal solution produced by the model seems to be better than the intuitive approach of an expert with practical experience. Thus, it is justified to assume that the model built can serve as a valid quantitative support for choosing a suitable cross-cutting plan and distribution to customers. Even this rather sophisticated optimization problem can be solved in MS EXCEL, which is readily available to forestry managers. Together with the model (Janová, Lindnerová, 2009), this model provides a decision-making support system for a new situation faced currently by the timber harvesting companies putting in tenders with the Czech State Forest Enterprise. The necessity to purchase the harvested timber, too, makes the working out of a tender a complicated job. Whereas a previous optimization model was designed to minimize the logging costs, this one provides support for timber pricing. In the current situation with many companies competing for orders from The Czech State Forest Enterprise, this model with a user-friendly interface offers a competition edge by making it possible to find exact limits for prices of timber that a forestry company can use in a tender.

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Appendices

Appendix: Optimisation problem as solved by an expert without any quantitative support.

Note that the expert only knew about the structure of trees in the forest in question, that is, about their distribution into age rather than tree-volume classes as with the optimisation model. For the timber volume in each tree-volume class, the expert carried out assignments to individual customers. In the tables, then, the total costs are calculated of transport and logging, yields on customer sales as well as the total profit for timber of each age class.

IX: *The third-age-class harvested timber as distributed to customers by the expert:*

Customer	Quantity [m^3]	Length [m]	Price [CZK/m^3]	Yield [CZK]	Costs [CZK]	Profit [CZK]
1	0	-	-	-	-	-
2	0	-	-	-	-	-
3	280	4	2,450	686,000	96,600	589,400
4	240	3	2,300	552,000	59,040	492,960
5	400	2	1,200	480,000	158,000	322,000
6	455	2.5	1,300	591,500	111,930	479,570
Total	1,375	-	-	2,309,500	425,570	1,883,930

The exchange rate 1€ ≐ 25.3 CZK in April 2010

X: *The fourth-age-class harvested timber as distributed to customers by the expert:*

Customer	Quantity [m^3]	Length [m]	Price [CZK/m^3]	Yield [CZK]	Costs [CZK]	Profit [CZK]
1	0	-	-	-	-	-
2	0	-	-	-	-	-
3	170	4	2,450	416,500	58,650	357,850
4	135	3	2,300	310,500	33,210	277,290
5	170	2	1,200	204,000	67,150	136,850
6	200	2.5	1,300	260,000	49,200	210,800
Total	675	-	-	1,191,000	208,210	982,790

XI: *The fifth-age-class harvested timber as distributed to customers by the expert:*

Customer	Quantity [m^3]	Length [m]	Price [CZK/m^3]	Yield [CZK]	Costs [CZK]	Profit [CZK]
1	0	-	-	-	-	-
2	0	-	-	-	-	-
3	3,900	4	2,450	9,555,000	1,345,500	8,209,500
4	2,840	3	2,300	6,532,000	698,640	5,833,360
5	3,100	2	1,200	3,720,000	1,224,500	2,495,500
6	4,360	2.5	1,300	5,668,000	1,072,560	4,595,440
Total	14,200	-	-	25,475,000	4,341,200	21,133,800

XII: *The sixth-age-class harvested timber as distributed to customers by the expert:*

Customer	Quantity [m^3]	Length [m]	Price [CZK/m^3]	Yield [CZK]	Costs [CZK]	Profit [CZK]
1	0	-	-	-	-	-
2	0	-	-	-	-	-
3	120	4	2,450	294,000	41,400	252,600
4	113	3	2,300	259,900	27,798	232,102
5	70	2	1,200	84,000	27,650	56,350
6	72	2.5	1,300	93,600	17,712	75,888
Total	375	-	-	731,500	114,560	616,940

XIII: *The seventh-age-class harvested timber as distributed to customers by the expert:*

Customer	Quantity [m³]	Length [m]	Price [CZK/m³]	Yield [CZK]	Costs [CZK]	Profit [CZK]
1	280	4	2,700	756,000	93,800	662,200
2	150	4	2,650	397,500	48,750	348,750
3	920	4	2,450	2,254,000	317,400	1,936,600
4	580	3	2,300	1,334,000	142,680	1,191,320
5	170	2	1,200	204,000	67,150	136,850
6	200	2.5	1,300	260,000	49,200	210,800
Total	2,300	-	-	4,052,000	576,430	3,475,570

XIV: *The eighth-age-class harvested timber as distributed to customers by the expert:*

Customer	Quantity [m³]	Length [m]	Price [CZK/m³]	Yield [CZK]	Costs [CZK]	Profit [CZK]
1	1,380	4	2,700	3,726,000	462,300	3,263,700
2	510	4	2,650	1,351,500	165,750	1,185,750
3	1,320	4	2,450	3,234,000	455,400	2,778,600
4	1,040	3	2,300	2,392,000	255,840	2,136,160
5	320	2	1,200	384,000	126,400	257,600
6	380	2.5	1,300	494,000	93,480	400,520
Total	4,950	-	-	6,504,000	931,120	5,572,880

Source: expert elaboration

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