The aftermath of implementing collaboration in a network of sawmills: A retrospective analysis on logistics costs

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Abstract. While usually collaborative logistics assures all partners are better off in coalition, a partner may in turn be composed by different sub-units. What is the effect of implementing collaboration for each of these sub-units? We study this problem motivated by a real-world case arising in a network of sawmills in Sweden. The sawmills are grouped in a single organization, which collaborates with an external company by wood bartering. Even if the organization as a whole benefits from the collaboration, the collaborative solution may leave some of the sawmills worse off, as the volumes they would use in absence of collaboration goes to the external company. By using an optimization model implemented in a decision support system, we analyze the logistics costs perceived by the organization in presence and absence of collaboration. We analyse the outcomes for the sawmills in several scenarios which can serve as basis to re-allocate the costs.

Keywords: Collaborative logistics; Forestry; Transportation; Optimization; Decision support system.

1 Introduction

Collaborative logistics has gained attention in theory and practice, due to its great potential to benefit companies. In forestry, for example, different companies can collaborate by performing their transport operations together, which helps them to reduce the total travelled distances and provides them cost savings. As reviewed by [1], an increasing body of literature has focused on calculating the cost savings and on how to allocate the savings among the collaborating partners. In particular, the forest sector has motivated several studies on collaboration, such as [3], [4], [5], [6] and [7]. While these are important problems foreseing the implementation of collaboration, an alternative problem, more absent in the literature, is to study the effect of collaboration in the outcome of different sub-units of the partners in a rather retrospective view. This is the view we adopt in this article, motivated by a real case in forestry arising in Sweden. In this case, collaboration between an organized network of sawmills and an external company takes place by means of wood bartering. The overall collaborative solution is better for the organization of sawmills, in the sense that the total logistics cost is reduced in comparison to the non-collaborative solution. However, the outcome of some of the sawmills in the network is worsened, because the wood they would use in the non-collaborative solution is assigned to the external company in the collaborative solution. In this article we describe the case and use an optimization model implemented in a decision support system in order to analyze several scenarios. These scenarios make use of real-world data, taken from the realized flows and invoiced costs of the implemented collaboration, and analyze the outcome of the sawmills in the organization. Some important aspects that we analyze in these scenarios concern the sawmills' geographic location and how much competition there is for supplies in different areas. Furthermore, we analyze the influence of wood bartering at both organizational and individual sawmills levels.

2 Background and problem description

We study an organized network of sawmills that belong to a number of owners. The owners have organized a common purchasing and transportation organization to improve their logistics operations. Each sawmill can be seen as an independent profit center within the whole organization. The sawmills demand wood by different assortments, which is used as raw material in their production process. The wood is procured from a number of supply areas. Several transport operations are involved in carrying the wood from the supply areas to the sawmills. When transports are done each sawmill is invoiced the actual cost of the truck transportation. Excess costs for train transport, loading at the terminal and transport to the terminal are charged evenly to at all volumes. The reason for this handling is to give some freedom in controlling the train flows.

The purchasing organisation re-distributes the actual costs of purchasing wood. If one sawmill must purchase an expensive volume and another a less expensive one, there is a model to compute the average cost. This average cost is then used to re-distribute the purchasing cost so that all sawmills pay the same price. There is an objective to process the logistic cost in a similar process.

The organization can collaborate with external companies by wood bartering. This is usually good for the organization seen as a whole, as such trading agreements often involves large savings. However, individual sawmills may be both victims and beneficiaries of wood bartering. Sawmills near the volumes made available from an external company tend to have shorter transport distances while sawmills near the removed swapped volumes tend to have longer transport distances. Our aim is to study this situation and discuss the outcomes of different sawmills within a network of a real-world organization in Sweden. This organization has full supply responsibility for nine sawmills in Sweden and partially for three sawmills in Norway. The purchasing areas for raw material comprises central Sweden from the Norwegian border in the west to the eastern coast. The industries are relatively scattered in the geography. The procurement involves approximately 4000 harvest areas annually.

The control of transports is based on a supply plan to the sawmills where the volumes from different suppliers are balanced against the demand quantities. Supply plans are worked out in the budget process through a dialogue with all suppliers. The supply plan is then broken down into monthly plans. The starting point for this planning is to minimize the total transportation cost.

Since each sawmill is an independent profit center, some questions naturally arise regarding the logistics costs. One of these is how each sawmill is affected by wood bartering. Another one relates to how well positioned is a sawmill with respect to the other ones and the supply areas. Ultimately, an answer to these questions may serve as basis for a fair re-distribution of the logistics costs among the network. As more firms or sub-units work together, it is important that common objectives and requirements are clear. Cooperation in logistics require a large transparency of information and description of how the distribution of cost reductions (or gains) occurs. Critical for a distribution is that it is seen as fair by all entities or owners.

To analyze the current situation, detailed data for one month has been collected. This includes journeys made by road and rail with information about the quality, volume, location of assets and costs. This applies to the organization of sawmills as well as for another main company involved in wood bartering. The data also include the invoiced amounts realized for all its twelve sawmills. We use the data as input for an optimization model and a decision support system (DSS) that we describe in the following section.

3 Optimization model and DSS

To analyze different scenarios and finding optimal plans, we use a decision support system called FlowOpt. FlowOpt, developed at the Forestry Research Institute, is used to optimize timber flows and allows for different means of transportation, such as lorry, train and boat. FlowOpt can also be used to coordinate the exchange of wood between several companies. The system utilizes the Swedish National Road Database (SNVDB) to calculate the correct distance between the regions, and the receiver terminals. As input are required also the transport cost functions for the input ranges, the network of terminals, train systems and costs.

The decision variables in the underlying linear programming model include the flows transported by both trucks and trains. Given the definition of sets of supply points, demand points and terminals, a very important aspect is what variables are included in the final model. Many variables are removed because they do not satisfy company rules or restrictions. Others are removed because they are unpractical. We can, for example, set up conditions like limit connections between supply points and demand points or limit connections between supply points and terminals.

The objective function minimizes the total cost, including cost of transportation and a penalty cost for undelivered demand. The constraints of the model include supply, demand, flow balances and capacity restrictions. In the case of wood bartering we need to control that swapping is limited and also to follow rules set up by participating companies. In some cases there might be specified quantities of wood bartering and then such quantity constraints are used to specify.
For a formulation of the model and a more detailed description of DSS FlowOpt we refer the reader to [8].

4 Case study

We use real-world data from a main Swedish organization accounting for a network of 12 sawmills. We will refer by N to the organization and by $N_1, \ldots, N_{12}$ to each of the sawmills in the network. The data comprise all logistics operations on a particular month. N collaborates with an external company which we will refer by E. The collaboration consists of wood bartering by different assortments. Table 1 shows these assortments and the corresponding flows involved in the operations by N. In total, these amounted to 281,624 m^3. About 14,000 m^3 of this volume was involved in the wood bartering with E.

Table 1: Volumes of different assortments.

Assortment	Volume (m^3)
Normal spruce sawlogs	98,833
Normal pine sawlogs	123,981
Stud wood pine	2,754
Small spruce sawlogs	9,182
Small pine sawlogs	46,874
Total	281,624

A volume of about 18,900 m^3 was transported by train. The transports of this volume came from a total of 330 different areas in central Sweden and five train terminals to three receiving sawmills. The optimization was able to use eleven terminals for the transfer from road to rail and eight receivers of train volumes, a total of 78 potential train alternatives. The transportation cost with trucks has an average cost of 42 SEK/m^3 for 50 km. Loading cost at the terminal ranged between 10 and 15 SEK/m^3 and unloading cost of the terminal ranged between 0 and 35 SEK/m^3. The cost of transport by rail varied between 58 and 99 SEK/m^3 depending on distance between the terminal and sawmill.

4.1 Scenarios

We used the decision support system described in Section 3 to solve different scenarios. A first scenario consists of taking the actual flows and optimizing them with our DSS. The other scenarios are built taking into account two aspects that the organization N considers as essential for a fair distribution of costs. The first is location which describes how well each sawmill is located in relation to the supplies. The other is competition, and describe how well each sawmill compete with other own sawmills. Both location and competition will be analyzed with and without collaboration. In total, we analyze the five scenarios described below.
Scenario 1: Actual flows. In this scenario, we optimize the flows keeping fixed most of the solution realized in practice. The only difference from the actual transport is that the optimization may choose a different allocation of truck and rail transportation.
Scenario 2: Integrated optimization without collaboration. We perform an optimization integrating all supply for the whole organization N, but without collaboration with E. We interpret a solution to this scenario describes how good each sawmill of N is in terms of competition with respect to the other sawmills in N. Also, as this scenario does not consider collaboration, its result can be used as an upper bound of the cost each sawmill should pay in the collaborative solution.
Scenario 3: Individual optimization without collaboration. For each sawmill, we run the optimization model assuming the corresponding sawmill has access to all assets of N without collaboration with E. Note

in this scenario the solutions to the optimization problems of two or more different sawmills may use the same volume, thus the overall solution is not necessarily implementable. The cost resulting from each solution provides an underestimation of the optimal cost. Thus, the solution may serve as a lower bound on the cost that should be paid by a sawmill in absence of collaboration. We interpret a solution to this scenario describes how well positioned a sawmill is in terms of geography.

Scenario 4: Integrated optimization with collaboration. Similarly to scenario 2, we perform a single run to optimize the plan for all sawmills of N, but now including assets from wood bartering with E. In this scenario, we find an optimal solution for the whole organization N, including the collaboration with E. Thus, the solution may serve as a lower bound on the cost that should be paid by a sawmill in presence of collaboration. We interpret a solution to this scenario describes how good each sawmill of N is in terms of competition with respect to the other sawmills in N and in presence of collaboration with E.

Scenario 5: Individual optimization with collaboration. Similarly to scenario 3, we perform an optimization for each sawmill, but now including assets from wood bartering with E. Again, in the overall solution to this scenario, a same volume may be used by two or more sawmills. The cost resulting from each solution provides an underestimation of the optimal cost. We interpret a solution to this scenario describes how well positioned a sawmill is in terms of geography and in presence of collaboration with E.

4.2 Results

Table 2 provides an overview on the results for each scenario and a percentage comparison with respect to the invoiced amounts and to scenario 1. It can be seen that the mere optimization of the actual flows (scenario 1) reduces the costs with respect to the invoiced by about 8.9%, equivalent to SEK 1.9 million in a month. In the optimal plan, the average transportation distance is reduced to 77 km (against the 87 km experienced in reality). Note these differences are partly due to the invoiced costs include some additional items (such as final driving supplements, supplements for small stack, half-loads, etc.) and that transport costs are not calculated by a general formula but is unique for a number of different carriers. The optimization of scenario 1 uses a general formula for the cost of transport. Another difference between them is that the optimization can choose other train solutions as an alternative to the one used in reality, provided that all sawmills get the volumes they require.

Table 2: Overview of the results.

Scenario	Cost (SEK)	% against invoiced	% against sc. 1
Invoiced	19,595,618	100.0%	111.0%
Sc. 1	17,646,328	90.1%	100.0%
Sc. 2	16,945,059	86.5%	96.0%
Sc. 3	14,394,897	73.5%	81.6%
Sc. 4	16,541,531	84.4%	93.7%
Sc. 5	14,094,777	71.9%	79.9%

The overall impact for N from the collaboration with E can be estimated by comparing scenario 4 with scenario 2. The difference in cost is about SEK 403,528, equivalent to about 2.4% of savings. When compared to the actual invoiced or the scenario 1, the savings are even more prominent, 15.6% and 6.3% respectively.

Note scenarios 3 and 5 achieve the lowest costs. As mentioned previously, these serve as lower bound only and are not implementable, since the solutions to the individual sawmill optimization problems may use a same volume twice or more.

Table 3 disaggregates the results by sawmills and assortment group. The cost is given in kSEK and we followed a similar procedure as in practice to assign the cost to each sawmill. That is, each sawmill pays for their corresponding truck transports on delivery. For the transports done by train, the costs are assigned as follows. First, we calculate truck costs of running into the (train) loading terminal. This gives an average cost for each assortment and terminal. To calculate the cost at an unloading terminal, we add the actual train cost which include loading and unloading costs. This gives an average cost for each combination of assortment and (train) unloading terminal. The average cost is then multiplied by the volume delivered by trains to each sawmill.

The percentages in Table 3 correspond to how much each sawmill represents over the total cost of the corresponding scenario. For example, the actual amount invoiced to sawmill N_1 was kSEK 2353, equivalent to 12.0% of the total cost invoiced to all sawmills. Or, in scenario 3, the cost of supplying N_1 assuming that all volumes without collaboration are available for it is equal to kSEK 1667, which represents 11.6% of the sum of the costs individually optimized for each sawmill without including the volumes of collaboration with E.

Table 3: Results for each sawmill in each scenario (costs in kSEK and percentages are with respect to the total).

Sawmill	Specie	Invoiced		Sc.1		Sc.2		Sc.3		Sc.4		Sc.5	
N_1	Spruce	1941	17.3%	1727	16.6%	1762	17.4%	1449	16.5%	1648	16.9%	1369	16.1%
	Pine	411	4.9%	316	4.4%	292	4.3%	218	3.9%	237	3.5%	203	3.6%
	Total	2353	12.0%	2043	11.6%	2054	12.1%	1667	11.6%	1885	11.4%	1572	11.2%
N_2	Spruce	2539	22.7%	2268	21.8%	2244	22.1%	2161	24.6%	2244	23.0%	2161	25.4%
	Pine	380	4.5%	293	4.1%	288	4.2%	274	4.9%	288	4.2%	274	4.9%
	Total	2920	14.9%	2561	14.5%	2532	14.9%	2435	16.9%	2532	15.3%	2435	17.3%
N_3	Spruce	2088	18.6%	1622	15.6%	1537	15.2%	1472	16.7%	1472	15.1%	1435	16.8%
	Pine	224	2.7%	137	1.9%	129	1.9%	109	2.0%	129	1.9%	109	2.0%
	Total	2311	11.8%	1759	10.0%	1666	9.8%	1581	11.0%	1601	9.7%	1544	11.0%
N_4	Spruce	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	Pine	851	10.1%	729	10.1%	699	10.3%	678	12.1%	699	10.3%	678	12.2%
	Total	851	4.3%	729	4.1%	699	4.1%	678	4.7%	699	4.2%	678	4.8%
N_5	Spruce	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	Pine	1554	18.5%	1285	17.8%	1236	18.1%	1049	18.8%	1211	17.8%	1047	18.8%
	Total	1554	7.9%	1285	7.3%	1236	7.3%	1049	7.3%	1211	7.3%	1047	7.4%
N_6	Spruce	2173	19.4%	2004	19.2%	2007	19.8%	1706	19.4%	1745	17.9%	1550	18.2%
	Pine	1797	21.4%	1890	26.2%	1934	28.4%	1276	22.8%	1943	28.6%	1274	22.9%
	Total	3970	20.3%	3893	22.1%	3941	23.3%	2982	20.7%	3689	22.3%	2824	20.0%
N_7	Spruce	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	Pine	509	6.1%	413	5.7%	303	4.5%	256	4.6%	352	5.2%	255	4.6%
	Total	509	2.6%	413	2.3%	303	1.8%	256	1.8%	352	2.1%	255	1.8%
N_8	Spruce	622	5.6%	555	5.3%	527	5.2%	526	6.0%	527	5.4%	526	6.2%
	Pine	215	2.6%	169	2.3%	163	2.4%	159	2.8%	163	2.4%	159	2.9%
	Total	837	4.3%	724	4.1%	690	4.1%	685	4.8%	690	4.2%	685	4.9%
N_9	Spruce	1061	9.5%	758	7.3%	723	7.1%	656	7.4%	755	7.7%	656	7.7%
	Pine	1721	20.5%	1404	19.4%	1270	18.6%	1124	20.1%	1269	18.7%	1124	20.2%
	Total	2782	14.2%	2162	12.3%	1992	11.8%	1780	12.4%	2024	12.2%	1780	12.6%
N_{10}	Spruce	772	6.9%	1491	14.3%	1335	13.2%	833	9.5%	1363	14.0%	827	9.7%
	Pine	491	5.9%	363	5.0%	352	5.2%	334	6.0%	352	5.2%	334	6.0%
	Total	1271	6.5%	1854	10.5%	1688	10.0%	1167	8.1%	1715	10.4%	1160	8.2%
N_{11}	Spruce	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	Pine	88	1.0%	57	0.8%	43	0.6%	40	0.7%	43	0.6%	40	0.7%
	Total	88	0.4%	57	0.3%	43	0.3%	40	0.3%	43	0.3%	40	0.3%
N_{12}	Spruce	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	Pine	150	1.8%	164	2.3%	101	1.5%	73	1.3%	101	1.5%	73	1.3%
	Total	150	0.8%	164	0.9%	101	0.6%	73	0.5%	101	0.6%	73	0.5%

Some noteworthy observations can be done. For example, sawmill N_{10} has considerably higher share of the costs in the five scenarios compared to the invoiced. While the invoiced to N_{10} was 6.5% of the total invoiced, its share in the scenarios is on average 9.4% and ranges from 8.1% to 10.5%. The sawmills that benefit the most from the collaboration with E (based on differences in scenarios 2 and 4 of the total cost) are N_6 (-1.0%), N_1 (-0.7%) and N_3 (-0.1%). On the other hand, other sawmills are left worse in the collaboration, namely N_9 (0.4%), N_{10} (0.4%) and N_7 (0.4%). These results reveal important opposite effects in the outcome of the sawmills. In absolute terms, the differences amount to considerable figures of more than SEK 250,000 in a single month. For other sawmills, such as N_{11} and N_{12} the collaboration is neither harmful nor beneficial. Another noticeable aspect is that some important differences occur in the shares of the sawmills with respect to the different assortments. In fact, there are several sawmills without participation in the use of spruce, which leaves them with 0% cost in this assortment and increases the relative share of the other companies that use it.

5 Concluding remarks

This article studied a problem of collaboration in which an organization of sawmills as a whole benefits from wood bartering with an external company. However, some of the sawmills are left worse in the collaborative solution, because of the volumes they would use in the non-collaborative solution are exchanged with the external company in the collaborative solution. We have used a decision support system to analyze different scenarios for this situation. Our results reveal important differences in the individual outcomes of the sawmills, some of them perceiving a cost reduction of 1% while others a cost increase of up to 0.4%. On a monthly basis, the differences can be as big as SEK 250,000. The organization of sawmills seen as a whole, however, may achieve large benefits from collaboration, equivalent to 2.4% when comparing to the optimized non-collaborative scenario and to 15.6% when comparing to the actual cost invoiced. These results naturally motivate further research to resolve the question on how the total logistics cost should be re-allocated among the sawmills. The different scenarios we have analyzed provide some basis to address such question, as they attempt to capture the importance of the sawmills in terms of competition with respect to each other and in terms of location with respect to the supply areas. Moreover, some scenarios provided upper and lower bounds on the cost of the collaborative solution. An alternative would be to compute an allocation by weighting the solutions to these different scenarios. Another alternative is to use allocation methods from cooperative game theory, which have proved to be useful in several problems on collaborative transportation as reviewed in [1]. These are normally more intensive in the use of data, as they would require the cost outcomes for all possible subsets of sawmills.

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