Optimizing terrain transportation with environmental constraints – Key habitats vs profit

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Abstract:
Biodiversity is assumed to have high value for many people, but the necessary preservation also incurs a cost for the forest owner. Typically, studies of this cost are at the stand level, and hence, not very accurate as the cost may vary even within the stand. In this work, we use a 1m×1m grid, generated from LIDAR data, to estimate the cost for harvesting and forwarding. The method could be utilized to calculate compensation, and to select between key woodland habitats to minimise the cost. In three of four test cases, the main cost was reduced harvested volume, but in one case the key woodland habitat also made the harvesting operations more expensive.

Keywords: forwarding, harvesting, optimisation, transportation

1 Introduction

In Scandinavia, a multi-scaled model for biodiversity conservation in forests is applied (Gjerde et al., 2007; Gustafsson and Perhans, 2010). This model includes management actions ranging from single trees to nature reserves of thousands of hectares. At the stand scale, areas important for forest biodiversity are mapped and forest landowners are committed to secure that a certain amount of measures for conservation of biodiversity is taken. Management options at the stand scale include retention of single living or dead trees, groups of retention tress, or woodland key habitats including whole stands or parts of stands. Since this involves a voluntary commitment of forest owners, the owners have to defray the costs. However, few studies have investigated how the different options of management measures affect these costs.

Biodiversity is a public good, and the value can be thought of as the sum of how every individual value the good. However, these values will vary as time passes, e.g. depending on the size of a species' population (Montgomery et al., 1999). Even though science can be utilized to estimate the value, lack of knowledge (e.g. population size), and the complexity of the real world, will eventually make this a political question.

Preserving biodiversity may lead to costs for the forest owner, e.g. as lost timber sales or more expensive forest operations. Baskent and Keles (2005) give a review of spatial forest planning, i.e. models using stands or landscape units as components. In particular, spatial forest planning has been used for studying the adjacency problem.

Today, key woodland habitats are registered accurately, and e.g. the coordinates of a dead tree may be found. Together with high accuracy digital elevation models (DEM), this can be utilized for making detailed harvesting plans or estimating differentiated harvesting and forwarding cost within a stand.

In this work, we use a grid of 1m ×1m to calculate the cost of harvesting and forwarding. By including key woodland habitats, we get an estimate of the cost of biodiversity for the forest owner. The idea is that this cost, together with estimates of the value of biodiversity, can be used for scientific or political decisions (e.g. sanctuaries or compensations).

There are few publications combining high accuracy DEMs and terrain transportation, and even fewer also including biodiversity.

2 Materials and Methods

In this work we us a digital elevation model generated from high accuracy airborne light detection and ranging (LIDAR) with some 10 measurements per m3. This accuracy is to get a digital elevation model (DEM) of 1m×1m resolution. Using this accuracy, a forest machine is situated at a grid point (vertex) A, and can pick up timber at vertices in a vicinity of A. And vice versa, every vertex with timber has another vertex in the vicinity with the lowest terrain transportation cost.

We use Dijkstra's shortest path algorithm (Dijkstra, 1959) to calculate the cheapest route from every vertex to a forest road, using calculated terrain transportation cost, described in section 2.1, as weights.

Every vertex has a bool parameter that is true if the vertex is within a key woodland habitat. Additionally, there is a parameter giving the percentage that can be harvested at key woodland habitats, and a bool parameter that is true if a forest machine can enter the habitat. If the harvesting percentage is greater than zero, driving in the habitat are allowed.

2.1 Calculation of terrain transportation cost

The terrain transportation cost of driving from a vertex A to a neighbouring vertex B is calculated using the elevation at some vertices in the vicinity of the wheels of a forest machine. This is illustrated in figure 1, where four sectors cover each (or bogie).

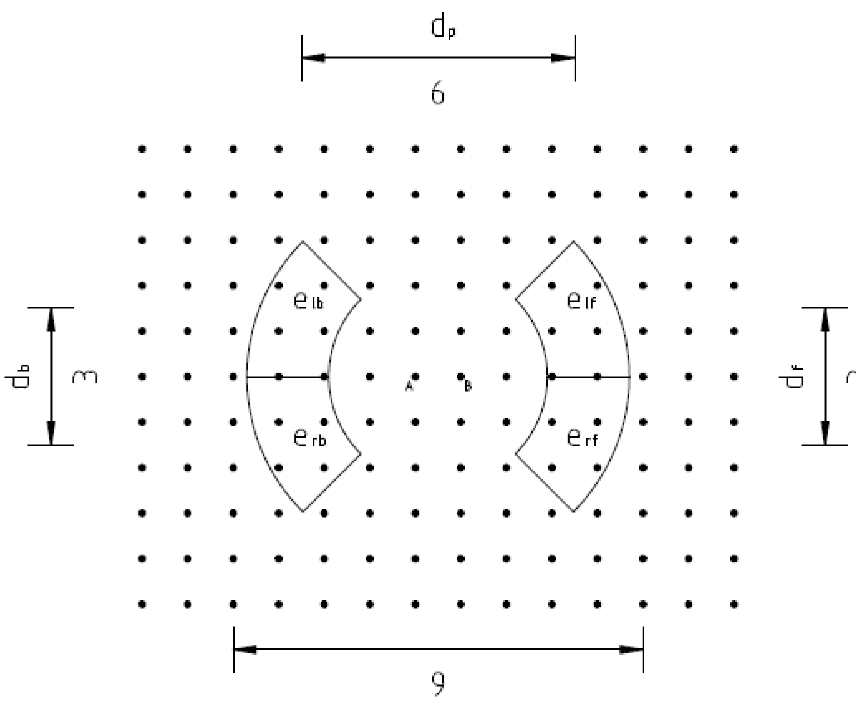


Figure 1: Sectors used for calculating forwarding cost (distances in meters)

The average elevations, as well as the average coordinates, were used to calculate roll and pitch of the machine. *r f* is the roll at the front axle, and *rb* is the roll at the back axle, i.e. the percentage inclination between the wheels on one axle. The roll *r* of the machine when going from A to B is the maximum of *r f* and *rb*, given by equation (1).

$$r = \max(r_f, r_b) = \max\left(\frac{|e_{lf} - e_{rf}|}{d_f}, \frac{|e_{lb} - e_{rb}|}{d_b}\right) \quad (1)$$

The pitch is the percentage inclination in the driving direction, and is calculated using equation (2).

$$p = \frac{\left|\frac{e_{lf}+e_{rf}}{2} - \frac{e_{lb}+e_{rb}}{2}\right|}{d_p} \quad (2)$$

el f , *er f* , *elb* and *erb* are the mean elevation in each sector (figure 1), and *dr*, *db dp* are the mean distance between the coordinates of the points.

Note that *df* and *dr* in figure 1 is 3*m* and *dp* is 6*m*, quite close to the size of most forwarders and harvesters.

The formula used to calculate the cost of terrain transport from A to B is given by (3).

$$C_{vf} = C_d d P_r P_p \quad (3)$$

$$P_r = \begin{cases} 1+2r, & r \leq 0.23 \\ \infty, & r > 0.23 \end{cases} \quad (4)$$

$$P_p = \begin{cases} 1+p, & p \leq 0.35 \\ \infty, & p > 0.35 \end{cases} \quad (5)$$

$$(6)$$

Pr and *Pp* are penalty factors for roll and pitch, respectively. *Cd* is the cost of transporting 1*m*3 timber a distance in flat terrain, and *d* is the distance. We used *Cd* = 60NOK/*m*3 per *km*. If the terrain is flat, *r* and *p* is zero, and hence, *Pr* = 1 and *Pp* = 1. In this case, *Cv f* equals *Cdd*.

Finally, the cost of extracting timber from a vertex is the sum of the cost through the shortest path from the vertex to road.

2.2 Objective function

We use the net profit as objective function, given by equation (7).

$$f = V(\Pi - (C_h + C_{ff} + C_{vf})) \quad (7)$$

V is the available timber volume at the vertex, P is the average price of timber, *Ch* is the cost of felling, bucking and delimbing, *Cf f* is a fixed cost of forwarding and *Cv f* is the variable cost of forwarding that is dependent of the driving distance. *Cv f* is given by equation (3), and we use P = 300NOK/*m*3, *Ch* = 40NOK/*m*3 and *Cf f* = 10NOK/*m*3.

3 Results

The model was tested using four real world cases, described in table 1, all located at Mathiesen Eidsvold Værk (MEV), a forest property in Norway. For each case, we calculated the objective value for five different policies. The ’no impact’ policy was with no driving and no harvest at hotspots, and additional scenarios was with driving allowed at hotspots, and harvesting 0 %, 30 %, 70 % and 100 % of the volumes at hotspots. The scenario with 100 % harvest at hotspots is the same as ignoring key woodland habitats completely.

In table 2, the objective values are listed in column 4. Column 5 is the improvement in objective value compared with the ’no impact’ scenario. Column 6 is the improvement in objective value compared with the scenario without harvest at hotspots, but driving allowed. Column 7, 8 and 9 is the same, but regarding harvested volumes.

Table 1: *Cases*

Case	Total area (ha)	Hotspot area (ha)	Hotspot area in percent (%)	Total volume (m^3)	Volume at hotspots (m^3)
1	111	13.6	12.2	22 127	2 710
2	94	6.5	6.9	18 893	1 305
3	203	18.8	9.3	40 512	3 765
4	345	24.2	7.0	68 972	4 844

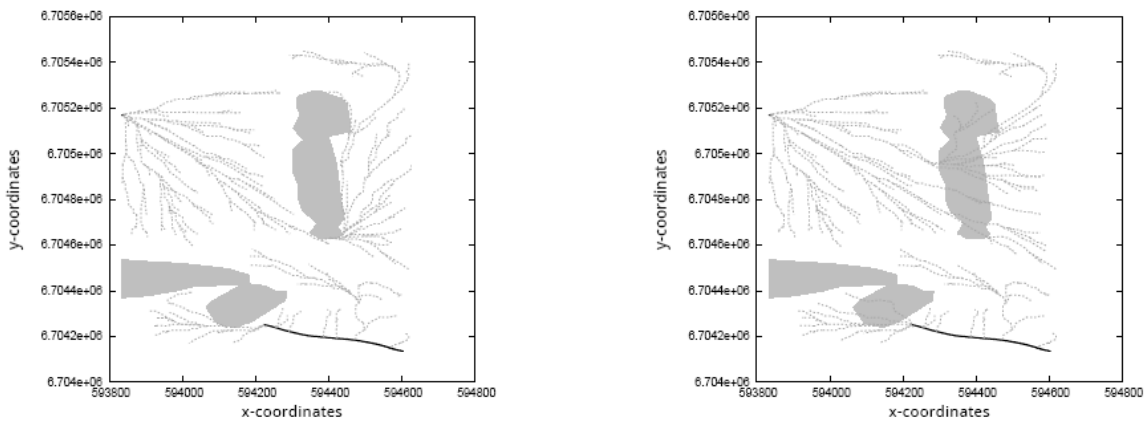
Table 2: *Objective and volume results*

Case	Driving	Harvest (%)	Objective (1000 NOK)	Obj. impr. (%)	Obj. impr. from harvest (%)	Harv. volume (m^3)	Impr. volume (%)	Impr. vol. from harvest (%)
1	No	0	3 438	-	-	17 181	-	-
1	Yes	0	3 600	4.7	-	17 305	0.7	-
1	Yes	30	3 729	8.5	3.6	17 934	4.4	3.6
1	Yes	70	3 902	13.5	8.4	18 772	9.3	8.5
1	Yes	100	4 031	17.3	12.0	19 401	12.9	12.1
2	No	0	3 858	-	-	17 192	-	-
2	Yes	0	3 859	0.0	-	17 197	0.0	-
2	Yes	30	3 928	1.8	1.8	17 497	1.8	1.7
2	Yes	70	4 020	4.2	4.2	17 897	4.1	4.1
2	Yes	100	4 088	6.0	5.9	18 197	5.8	5.8
3	No	0	7 564	-	-	32 006	-	-
3	Yes	0	7 564	0.0	-	32 007	0.0	-
3	Yes	30	7 804	3.2	3.2	33 067	3.3	3.3
3	Yes	70	8 125	7.4	7.4	34 480	7.7	7.7
3	Yes	100	8 365	10.6	10.6	35 540	11.0	11.0
4	No	0	12 475	-	-	58 699	-	-
4	Yes	0	12 485	0.1	-	58 717	0.0	-
4	Yes	30	12 769	2.4	2.3	60 080	2.4	2.3
4	Yes	70	13 147	5.4	5.3	61 899	5.5	5.4
4	Yes	100	13 430	7.7	7.6	63 262	7.8	7.7

4 Discussion

In this work, we use a shortest path algorithm to calculate the cheapest possible terrain transportation cost of each vertex. We assume that timber at a vertex is picked up and transported to roadside through the cheapest path. In practice, a forwarder (and the harvester) would use trails, collecting what is reachable, and the load capacity and different assortments would influence the cost of forwarding. However, our model seems suitable for our aim, to estimate the cost.

One very interesting question addressed in this work is the cost of not being able to drive at key woodland habitats. From table 2, we see that case 2 and 3 are not influenced much by this, but case 4 have a difference in objective value of 10 000 NOK. In case 1, the difference is larger, 162 000 NOK, and the area with decreased extraction cost is 31.4 hectares (table 2). Adding to this, the affected area may be larger, as it reaches the border of the case (figure 2).



(a) Driving in hotspots not allowed, no harvest at hotspots.

(b) Driving in hotspots allowed, no harvest at hotspots.

Figure 2: *Main extraction trails for case 1.*

For this reason, it will be crucial to utilize natural boundaries (e.g. roads and rivers) in the calculations. In Norway, compensation is given to the forest owner, and contrary to our cases, the forest properties are small and, in general, fragmented. Case 1 shows that property borders are not suitable for calculating the compensation.

Of course, whether driving at hotspots should be allowed is a question depending on what type of environmental value we want to preserve, whether we can design a trail through the hotspot with low impact, and the reduced cost by going through the hotspot.

Figure 2 shows the main extraction trails, with a minimum transit volume of 40m3. The solution with driving through hotspots show several trails, and maybe further additions to the model can optimise a minimum impact trail through the hotspot.

The results show that the cost of key woodland habitats varies quite a lot, and, in case of compensation, this could be calculated using our model.

Also, in situations where hotspots are not site specific (e.g. old forest) our model can be used for selecting where to place them with a minimum cost for the forest owner.

5 Acknowledgement

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6 References

E.Z. Baskent and S. Keles. Spatial forest planning: A review. Ecological Modelling, 188:145–173, 2005.

E. W. Dijkstra. A note on two problems in connexion with graphs. Numerische Mathematik, 1:269–271, 1959

I. Gjerde, M. Sætersdal, and H.H. Blom. Complementary hotspot inventory – a method for identification of important areas for biodiversity at the forest stand level. Biological Conservation, 137:549–557, 2007.

L. Gustafsson and K. Perhans. Biodiversity conservation in swedish forests: ways forward for a 30-year-old multi-scaled approach. Ambio, 39:546–554, 2010.

C.A. Montgomery, R.A. Pollak, K. Freemark, and D. White. Pricing biodiversity. Journal of Environmental Economics and Management, 38:1–19, 1999.