A REVIEW OF SKIDDING DISTANCES METHOD UNDER VARIABLE RETENTION HARVESTING CONSIDERATIONS

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ABSTRACT

Skidding distances in forest operations have rarely been questioned and the traditional method proposed by Matthews (1942) continues to be generally applied. We propose a modification to this method which integrates variable retention harvesting considerations, specifically volume heterogeneity and obstacles, to determine skidding distances and costs. These spatial and structural elements associated with partial cutting can be very complex, depending on the objectives of retention. In this study skidding distances, volume distribution and harvesting costs were analyzed. First, skidding distances were estimated and compared using three methods: a) tracking skid trails on aerial photos after harvest, b) a GIS raster procedure and c) the traditional method. Results were comparable, but the raster procedure was most efficient for integrating the distribution of variable volume to be harvested. We then included the volume distribution in harvest blocks (values obtained from permanent sample plots) using two assignment methods: a) photo interpretation and b) Thiessen interpolation, to obtain volume weighted by area of influence. Our results show no significant difference between the assignment methods. Third, the raster procedure and Thiessen volume assignment were combined to adjust skidding distances to take into account the shape and volume distribution in harvest blocks. We conclude that, because this combined analysis is highly sensitive to changes in volume distribution and harvest rates, it is useful for estimating skidding and harvesting costs and permits explicit incorporation of spatial considerations (shape, size and volume) of variable retention in forest planning.

Keywords: Skidding distance, harvest cost, variable retention cutting, spatial simulation.

INTRODUCTION

Clear cutting represents a major driver on the managed landscape and careful logging to preserve advance growth (CPRS) is the dominant method in Quebec. However, it is not adapted to all forest stands (MNR, 2003). Partial cutting (PC) refers to a gradient of cuts such as commercial thinning, selection cutting, shelter wood cutting and partial retention cut. Partial cutting seeks different objectives, ex.: removing the diseased stems (MNR, 2003), maintaining key habitat elements for several species (Drapeau et al., 2003, Courtois, 2003), maintaining floristic elements (Fenton, 2005) and, in some cases shortening rotation length (MRN, 2003).

These silvicultural treatments include not only the partial removal of woods, but also the preservation of structural elements in the landscape: the case of variable retention cutting (CRV).

Variable retention cutting is the maintenance for at least one complete rotation of structural elements specific to the stand harvested as forest patches, live trees, snags, woody debris or the thickness of forest floor or understory species - stage (Pentassuglia, 2003). Partial cutting produces long-term benefits and are accepted by the public (Hassler and Grushecky, 2000). Indeed, considering the current forestry context, partial cutting and variable retention become very interesting alternatives to the CPRS. From the ecological point of view, several studies have demonstrated that biodiversity in harvested areas has a positive relationship with the number of structural elements used (Sougavinski and Doyon, 2002). Thus, the PC and CRV could potentially help reduce the effect of stock shortage of mature timber. But, PC is not a common practice in the boreal forest because it is more expensive to implement than CPRS. Adapted machinery is needed, operators must be specially trained, the planning process is complex and more access roads are required (Pentassuglia et Meek, 2004) and lower harvest volume per hectare (Meek et Simard, 2000). However, Holmes et al. (2010) showed that the volume of timber extracted per unit of effort (productivity) may be higher in riparian zones (partial section) than in clearcuts. This means that partial cutting treatments could be more feasible when it is properly planned.

The models used to estimate harvesting costs are generally based on total harvest cutting while skidding distance has rarely been questioned and thus, the traditional method proposed by Matthews (1942) continues to be applied. However, when a harvest incorporates elements of retention, the variable distribution volume in a harvest block and the costs of skidding, estimated harvest costs may incorporate large bias. Most of the known productivity models that estimate harvest costs use statistical models that generate local functions for different equipments. The commonly used variables are skidding distance, the amount of trees to be cut and the volume per stem (Tufts, 1997). These productivity models consider that the trees to be cut are distributed homogeneously within the harvest block. However, corrections must be made when considering structural obstacles during harvest operations and volume heterogeneity. These obstacles may include variable patches of residual trees or individual trees left over after harvesting. These factors may effect the skidding distance and productivity according to proportion and distribution of retention to be maintained and consequently the wood procurement costs.

The overall objective of this project is to propose a model that integrates variable retention harvesting considerations, specifically volume heterogeneity and obstacles, to determine skidding distances and costs. These spatial and structural elements associated with partial cutting can be very complex, depending on the objectives of retention.

The specific objectives were to:

- Select an effective method to estimate skidding distance.
- Determine the effects of variable retention harvested volume and volume heterogeneity on the skidding distance.
- Determine the combined effects of skidding distance and variable retention harvesting on skidding cost.
- Propose a model that integrates variable retention harvesting, volume heterogeneity and obstacles on skidding distance.

DATA AND METHODS

This study was carried out in the north-western Quebec boreal forest in the Abitibi clay belt region. We collected information from a study network where silvicultural treatments (careful logging to preserve advance growth (CPRS)), harvesting with protection of small merchantable stems (CPPTM) and variable retention cutting (CRV)) and an unharvested (control) was applied (Bescond et al., 2011). At each site silvicultural treatments were executed on blocks over 29 ha in size. The sites were harvested using a single-grip harvester and forwarder. In the study territory of 1362 ha, five sites (Puiseaux, Collines de Gaudet, Collines de Maskuchi, Fénelon and Dufay) were analysed (figure 1, table 1). This territory is dominated by black spruce (Picea mariana [Mill.] BSP) – feather moss (e.g., Pleurozium schreberi [Brid.] Mitt.) forests, and is particularly prone to paludification between fires due to its poorly drained clay dominated soil. Plots were established at randomly selected points in the stands before harvest.

SKIDDING DISTANCE

The road spacing calculation presented by Matthews (1942) computes the least-cost road and landing spacing by a trade-off between skidding and road construction costs (Nadeau et al., 2002). Various methods have been elaborated, as summarized by Chung et al., (2008), to design efficient forest road networks. In all cases the average skidding distance is an important input in the total cost. In addition, skidding distance is well correlated with machine productivity and cost.

Estimating average skidding distance depends on the different elements: shape of the harvest block, landing configuration or multiple landings along the forest roads. Different solutions have been proposed to estimate skidding distance following the elements cited earlier (See Greulich (2002) for examples).

We evaluated three different approaches to estimate average skidding distance a) the traditional method (equation 1), b) tracking skid trails on aerial photos after harvest (equation 2) and c) a GIS raster procedure (equation 3) (figure 2, table 2). These approaches are compatible with forest harvesting operations in Quebec's boreal forest because they are characterized by the presence of parallel skid trails and aligned perpendicular to the forest road. These skidding trails, that cover less than 25 % of cut area, facilitate the movement of machinery and preserve advance growth (Anonyme, 2006).

Other researchers, including Greulich, also developed formulas incorporating other parameters such as variable volume distribution and obstacles (Contreras and Chung, 2007). Similarly, many models include the location of roads, either by heuristic procedures or the use of available technologies in recent years to optimize, such as ArcGIS ™.

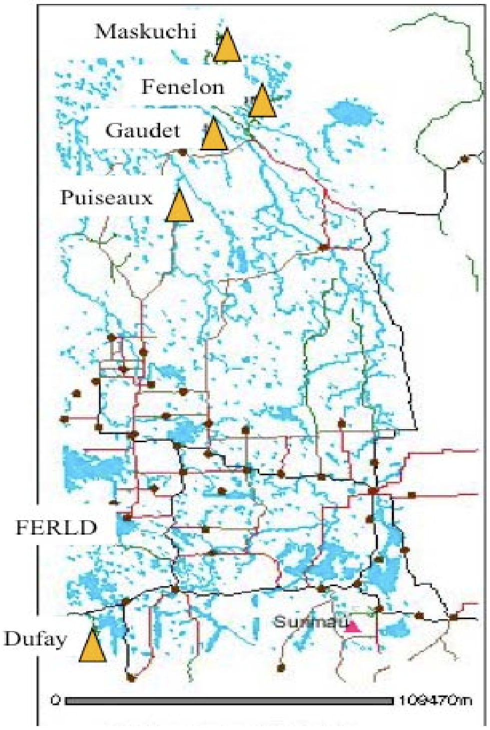

Figure 0: Localisation of study area in the Abitibi clay belt region.

Table 1: Study area description by site, silvicultural treatment, ecological region, area and numbers of available plots.

Site	Ecological region	Treatment	Area (ha)	Plots
Dufay	5a	CPRS	35,03	13
		CPPTM	84,98	13
		Control	29,02	13
Fénelon	6a	CPRS	97,46	14
		CPRV	126,03	18
		control	79,38	18
Gaudet	6a	CPRS	43,11	17
		CPRV	69,23	17
		control	38,15	13
Maskuchi	6a	CPRS	172,78	58
		CPPTM	226,98	104
		control	130,58	34
Puiseaux	6a	CPRS	85,92	19
		CPRV	83,46	17
		control	93,25	18

*Plots : permanents plots.

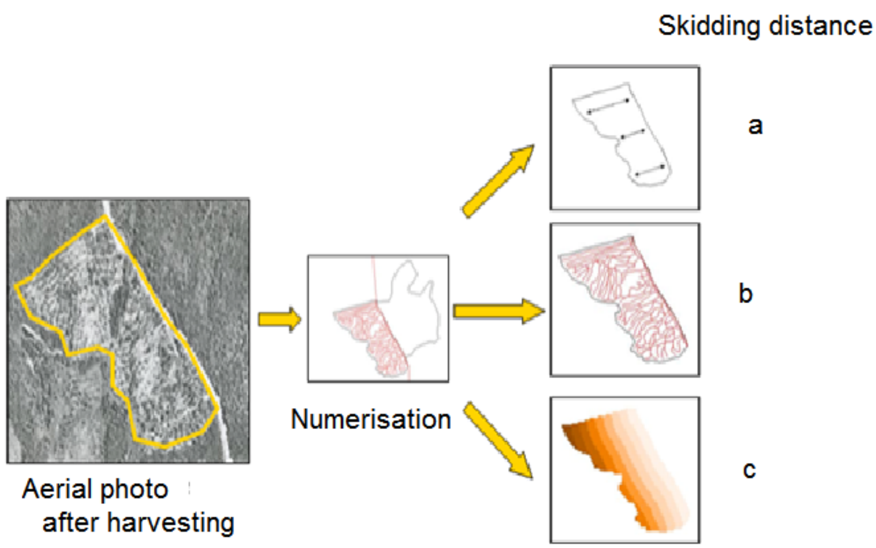

Figure 2: Illustration of three approaches to estimate average skidding distance a) the traditional method, b) tracking skid trails on aerial photos after harvest and c) a GIS raster procedure.

VOLUME ASSIGNMENT

In the absence of forest management (harvest follow by plantation) the natural boreal forest presents a variable distribution of volumes. In fact, the natural boreal forest is rather irregular and uneven, as a result of natural disturbances such as epidemics and forest fires that affect the landscape (Vaillancourt et al., 2008). We then manage the volume distribution in harvest blocks (values obtained from permanent sample plots) using the a) volume average and two assignment methods b) photo interpretation and c) Thiessen interpolation, to obtain volume weighted by area of influence (figure 3). Thiessen interpolation enables the determination of the small harvest units - representing either fixed amounts or characteristics of habitats of interest - (Barrett, 1997), and to describe patterns of volume distribution in forests (Kristensen, 2006) automatically with the help of GIS.

The average volume per hectare obtained from photo-interpretation and those obtained by the Thiessen interpolation, were weighted by the assigned area (Equation 4), and then compared to the average volume from permanent plots - a) traditional method- for each block of harvest (Equation 5).

Table 2: Performed equation to estimate weighted skidding distance

Equation 1	Equation 2	Equation 3	Equation 4	Equation 5	Equation 6
$\overline{D}_A = \frac{D_{\max}}{2}$	$\overline{D}_B = \frac{\sum_{s=1}^{n} D_S}{n}$	$\overline{D}_C = \frac{\sum_{j=1}^{n} D_{i,j}}{n}$	$\overline{V}_{Th-Ph} = \frac{\sum_{j=1}^{m}(V_j \times S_j)}{\sum_{j=1}^{m} S_j}$	$\overline{V}_{Tr} = \frac{\sum_{i=1}^{n} V_i}{n}$	$\overline{D}^c = \frac{\sum_{j=1}^{n}(\frac{V_j}{C_k} \times d_j)}{n}$
Where : $\overline{D}_A$: Average skidding distance (m). *Dmax* : Maximum skidding distance (m).	Where : $\overline{D}_B$: Average skidding distance based on trails visible on aerial photos after harvest (considered as reference) (m). D_s : Distance of skid trail « *s* » (m). *s* : Skid trail id. *n* : Total of skid trail by harvest block.	Where: $\overline{D}_C$:Average Skidding distance (m) $D_{i,j}$: Distance from pixel *i,j* to forest road (m) *i, j*: Position pixel *n* : Total of pixels by harvest block	Where : $\overline{V}_{Th-Ph}$: weighted average volume per ha assigned by photo interpretation or Thiessen interpolation in a harvest block (m³/ha). V_j : estimated volume per ha in the subsection« j » within a harvest block (m^3/ha). S_j : Area of subsection « j » within a harvest block (ha). j : Subsection Id.	Where : $\overline{V}_{Tr}$: Average volume per ha in a harvest block (m³/ha). V_i : estimated volume per ha for the plot « i » in a harvest block (m^3/ha). n : total number of plots in a harvest block.	Where: $\overline{D}^c$: weighted skidding distance in a harvest block (m). V_j : Estimated volume per ha within a harvest block at the « j » position (m^3). C_k : volume per turn (m^3) of skidding machine « k » (Wheeled skidder, forwarder, etc). d_j: Distance at the « j » position within a harvest block from the road (m). *j* : pixel id within the block. *n* : total number of pixels.

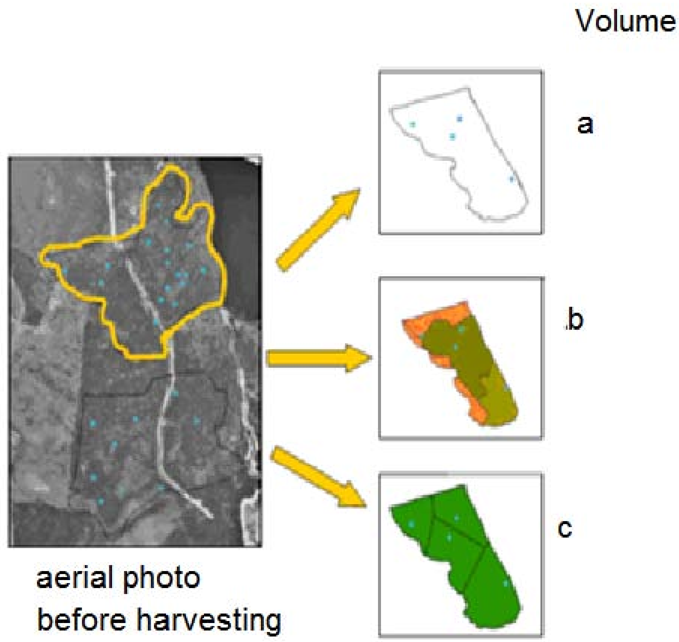

Figure 3: Illustration of average volume per hectare a) traditional method and two assignment methods to obtain volume weighted by area of influence b) photo interpretation and c) Thiessen interpolation.

WEIGHTED SKIDDING DISTANCES

The non-homogeneity distribution of volume in the harvest blocks has been expressed by the two assignment methods. We chose Thiessen interpolation to conduct this analysis because it facilitates computing. The equation 6 take into account skidding distance (obstacles, retention) and weighted average volume within the harvest block.

The ratio (Vj / Ck) in equation 6 represents the number of necessary cycles to haul the wood content on a pixel. This number is set to 1 when the volume to be extracted is smaller than the load capacity. It was assumed that the machine will go to the block position and will travel this distance, even if the load is lower than its capacity. We set 1.5 m^3/turn as load capacity in the analysis. This value was determined by comparing the effects of variation on the skidding distance estimation and taking into account a minimum load capacity. Vj is the value of the volume of the pixel "j" which is determined by multiplying the average volume per hectare in the block or a section of the block times the size of a pixel, in our case 0.01 (pixel size 10 m). A higher pixel size implies taking into account the movements of the machine within a pixel and this element was not considered in this analysis. In addition, the pixel size used (10 m) reflects the separation between skid trails, which is about 20 m in Quebec. Figure 4 illustrates an example of the procedure applied to compute the weighted skidding distance.

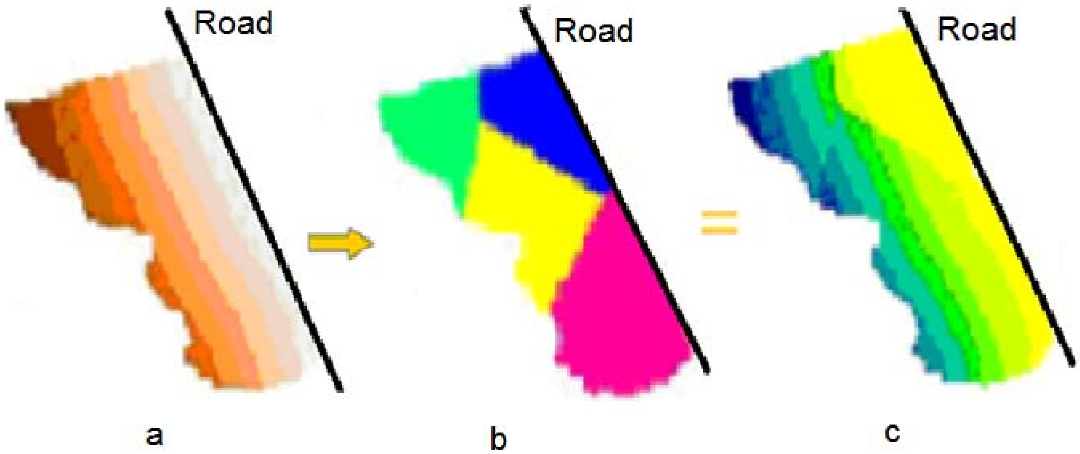

Figure 4: Illustration of the procedure to compute weighted skidding distance a) raster distance, b) weighted estimate volume per hectare with Thiessen interpolation and c) weighted skidding distance.

RESULTS

The results indicate that there were no significant differences between the three methods of estimating skidding distance a) the traditional method, b) tracking skid trails on aerial photos after harvest and c) a GIS raster procedure (*p*= 0,76) (Table 3).The mean value of skidding distance of the traditional method was 115,1 (± 67,7) m. Mean values of tracking skid trails on aerial photos and a GIS raster procedure was 108,4 ± 64,3 m and 109,1 ± 73,7 m respectively. There were not significant differences between block size, number of obstacles (*p*=0,12) and shape index (*p*=0,35) between treatments.

Table 3: Analyse of variance of three average skidding distance methods.

Source	DF	Sum of Square	Mean square	F value	*p*
Regression	2	2599	1299	0,2754	0,76
Residual	282	1330306	4717		

Analysis of variance of volume heterogeneity between sites, blocks and treatments were performed (figure 5). This analysis showed that 8.2% of the variance in volume is explained by the variability between sites, 23.9% of the variance in volume is explained by the variability between blocks and 67.7% of the variance in volumes is explained by the variation within blocks. Consequently, the volumes did not follow a uniform spatial distribution within the blocks of the studied area. Regardless, the average volumes in the three assignment methods showed no significant differences (*p*=0.68).

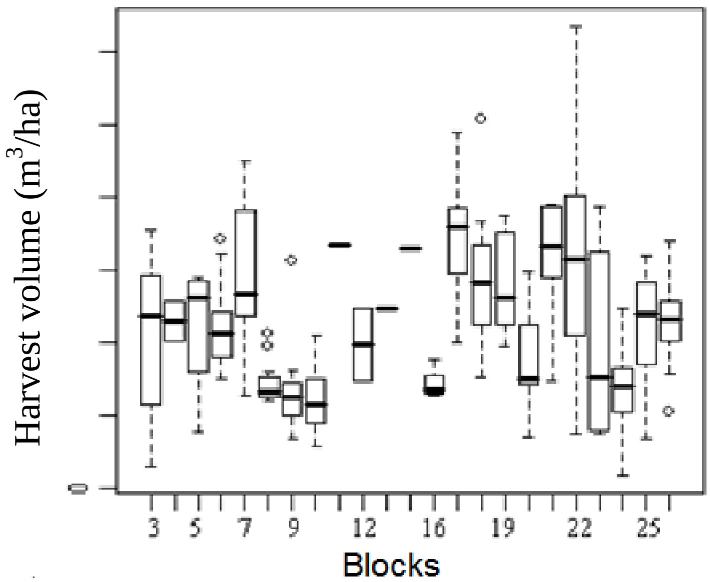

Figure 5: Boxplot of volume m^3/ha in sites: Dufay (blocks 1- 6), Fenelon (blocks 6-7), Gaudet (blocks 8-10), Maskuchi(blocks 11-24) and Puiseaux (blocks 25-26).

Our analyses of the weighted skidding distances in the studied site were performed. The volume per sample plot showed values that ranged from 0 to 302.1 m^3/ha. The average value corresponded to 86.2 ± 50.6 m^3/ha. Equation 6 that proposed the combined analysis was used with a load capacity of 1.5 m^3/turn. Two methods equation 3 and equation 6 have not showed significant differences (*p*=0, 47). The average values of the skidding distances were 109.4 ± 73.8 m and 101.6 ± 67.5 m respectively. The skidding distance values between methods did not show any significant difference, this may be explained by the low volume harvested at each position in the block. Because harvest volume was lower than the load capacity of the machine, the machine must travel at least one time at each pixel position.

Table 4: Average harvest cost ($/m³) by site, treatment and method.

Site	Treatment	processing	Skidding Equation 1	Skidding Equation 2	Skidding Equation 3	Skidding Equation 6
Dufay	CPRS	NA	3,97	3,57	3,69	NA
Dufay	CPPTM	9,25	5,01	4,89	5,12	5,12
Fenelon	CPRS	10,41	3,46	3,43	3,33	3,37
Fenelon	CPRV	6,651	4,99	4,99	5,00	4,99
Gaudet	CPRS	10,49	3,61	3,59	3,67	3,68
Gaudet	CPRV	14,84	4,30	4,36	4,17	4,18
Maskuchi	CPRS	13,43	3,69	3,62	3,53	NA
Maskuchi	CPPTM	7,83	4,62	4,35	4,33	4,32
Puiseaux	CPRS	11,54	3,36	2,96	2,98	2,91
Puiseaux	CPRV	9,64	4,23	3,90	3,89	3,90
Mean	CPRS	11,47	3,62	3,43	3,44	3,32
Mean	CPRV	10,38	4,51	4,42	4,36	4,36
Mean	CPPTM	8,54	4,82	4,62	4,72	4,72

Harvesting costs take into account skidding and processing costs. These estimated costs for the studied site showed that the cost of processing were higher than the skidding costs, processing costs were more sensitive to volume and were not affected by distance (Table 4).

In our analysis equation 1 had a higher mean value compared to the other methods. The principal reason for this difference is the manual way to get the traditional skidding distance. The accuracy depends on shape and size of blocks and preference of the analyst. Equation 3 seems the most appropriate measure to estimate the skidding distance (boreal forest) due to the effectiveness of GIS tools. In addition, it can be determined using various configurations of harvest blocks.

This study is useful when parallel skid trails are considered and it does not consider the use of individual landing zone configurations. The slope was not considered in this analysis because the studied areas consist of flat landscapes.

CONCLUSION

Our results show that the average skidding distance (equation 3) method was effective and that there was no significant difference with the equation 1 and 2. This method is an alternative to the traditional method (equation 1) inspired from Matthews 1942. Moreover, the equation 3 is simple, easy to use and available in GIS tools. We also showed that 67.7% of the variance in volume was explained by the variability within blocks. Consequently, volumes do not follow a uniform spatial distribution within the harvest blocks. To incorporate this heterogeneity within the harvest block, we proposed the Thiessen interpolation method and we noted that although statistically comparable with photo interpretation. The Thiessen method of interpolation is easily integrated with GIS tools. This method requires the identification of sample plots in each block of harvest.

Then a combination of methods using the skidding distance and volume assignments with Thiessen interpolation was proposed (equation 6). The results of this weighted skidding distance analysis showed that the skidding distance was sensitive to changes in distribution and harvest rates. Thus, the analysis of the weighted skidding distance was included in the estimated harvesting costs. The skidding costs ($/m3) in this study range, were about 10% for CPRS to 15% for CPPTM, if retention elements were considered.

Others results that were not outlined in this paper in regards to simulation models were also performed. The simulation model takes into account different distribution and volume heterogeneity within a harvest block and permits to combine different objectives of retention and obstacles. The results show that the skidding distance may vary considerably (volume, orientation, retention). The change in skidding distance and cost depend on the position and volume heterogeneity and spatial configuration of retention.

Finally, our proposal to estimate the weighted skidding distance permits the incorporation of spatial retention elements like shape, size and volume. Thus, in partial cutting, the new estimate of the skidding distance would achieve the objectives of structure and composition of a forest ecosystem, while taking into account the economic consequences of this practice in the Abitibi clay belt.

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