Optimizing a novel method for manual tree falling

by C. Kevin Lyons¹ and Florian Noll²

ABSTRACT

This paper reports the results from work done to optimize a novel manual tree falling method that uses uncut strips of wood on the backcut side of the tree to restrain the tree while the faller is at the base, and then uses a remotely operated hydraulic flange spreader to initiate falling. This paper found the optimal target length of the uncut strips was 7.5 cm, one uncut strip was just as effective as two, and that one uncut strip was much simpler for the faller to cut.

Key words: tree falling, flange spreader, holding wood design

RÉSUMÉ

Cet article porte sur les résultats de travaux réalisés pour optimiser une nouvelle méthode d'abattage manuel des arbres qui comporte la réalisation d'entailles partielles sur le côté de l'arbre opposé au côté de la coupe pour le retenir alors que l'abatteur est à l'œuvre à la base, et qui est suivie de l'utilisation d'un écarteur hydraulique pour amorcer la chute. L'article indique que la longueur cible optimale des entailles partielles est de 7,5 cm et qu'une entaille incomplète est aussi efficace que deux tout en étant beaucoup plus simple à réaliser pour l'abatteur.

Mots clés : abattage d'arbre, écarteur, principe de retenu

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Introduction

Manual tree falling is considered to be one of the most dangerous professions in the forest industry, especially in the Pacific Northwest (Paulozzi 1987; WorkSafeBC 2004 2009). Unseen debris falling out of the canopy is one of the most common causes of fatalities and serious injuries when manually falling trees (Holman *et al.* 1987, Myers and Fosbroke 1994, NIOSH 1997, Helmkamp and Derk 1999, Bentley *et al.* 2005), and this often occurs when a tree begins to displace during falling (Peters 1991). Thus, removing the faller from the base of the tree when it begins to displace can greatly improve safety. Previous research has shown that a new system consisting of two uncut strips, called tension strips (Fig. 1), can be used in conjunction with a remotely actuated hydraulic flange spreader to remove the faller from the base

of the tree when displacement is initiated (Noll and Lyons 2010). In previous research, it was found that the tension strips were more reliable if they were designed to fail in shear rather than axial tension. Horizontal cuts were bored into the tree below the tension strips in order to create a shear failure, and these cuts were termed the weakening cuts. It was also found in the previous research that the faller preferred to vary the vertical distance between the backcut and the weakening cuts to accommodate tree strength and imbalance. However, minor tree imbalance is a combination of lean, sweep, and crown asymmetry and this can be difficult to judge. It is not uncommon for a faller to call a minor imbalance in the direction of fall only to have the tree sit back and require wedging. The vertical distance between the backcut and the weakening cuts should be sufficient to ensure that trees with a modest imbalance in the direction of fall do not begin to move until the faller is in the clear; however, there still needs to be sufficient reserve strength in the spreader to initiate falling if the imbalance was actually opposite to the direction of fall.

The objectives of this paper are 1) to determine the optimum distance between the backcut and the weakening cut that maximizes the rate of success, and 2) to determine whether using one tension strip, as opposed to two, reduces the rate of success. Three datasets will be considered in the following analysis. The first dataset comes from a sample of 62 trees where the distance between the plane of the backcut and the weakening cut was selected randomly from 5 cm, 7.5 cm, and 10 cm; this dataset will be called *Dataset1*. The second dataset comes from a sample of 67 trees where only one tension strip was used while the other dimensions were fixed

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Fig. 1. Plan view holding wood design (for the one tension strip design remove p6 to p9)

at the optimum value found from previous research; this dataset will be called *Dataset2*. The third dataset is the intersection of *Dataset1* and *Dataset2* including all the trees that had a target distance between the backcut and the weakening cut of 7.5 cm (89 trees); this dataset permits comparison of trees with one tension strip to those with two and will be called *Dataset3*.

Methods

The field trials for all datasets were conducted at the Malcolm Knapp Research Forest (MKRF) during the summer of 2009 and the spring of 2010. All trees used in the field trial were 70- to 75-year-old second growth from natural regeneration after fire. Trees that were smaller than 30 cm DBH were not used in this research, due to insufficient room behind the holding wood to bore the backcut and to form the tension strips. Trees were sampled in the order that the faller normally worked the stand. The research conducted for this paper used the same hydraulic flange spreader as used by Noll and Lyons (2010), which had a maximum separation force of 44.5 kN (10 000 lb). The method used to design the cuts follows those developed by Noll and Lyons (2010). In the following, *UC* is the horizontal depth of the undercut, *BC* is the depth of the backcut, and *HW* is the width of the holding wood. Two different tension strip patterns were used in this study (Fig. 1). The external corners of all the features were marked in the field (p_1 to p_7 for the two tension strip system and p_1 to p_4 for the one tension strip system). The depth of the line p_8 to p_{11} (two tension strip system) and the line p_{10} to p_{11} (one tension strip system), were marked on the

Fig. 2. Holding wood design side view

side of the tree to show the target dimensions for the faller to cut. The target distance between the weakening cuts and the plane of the backcut is called d_1^T (Fig. 2), where d_1^T is a class variable with three levels. Target dimensions for the falling cuts used in the field tests conducted for this paper can be found in Table 1.

The following process was used to make the cuts for the two tension strip system identified in Fig. 1) The faller cut a Humboldt undercut with a horizontal depth approximately equal to one-third the diameter of the stump. 2) The faller inserted the saw between p_1 and p_7 and bored horizontally through the tree, he then brought the blade towards the undercut to form the holding wood. 3) With the saw still in the backcut the tip was pushed towards p_5 , the objective of this cut was to mark the plane of the backcut at p_5 . The saw was then removed from the backcut and inserted at p_5 , keeping the saw perpendicular to the holdingwood the cut was brought towards p_6 and then back to p_4 completing the tension strips. If necessary the faller would trim the tension strips into p_7 and p_3 to form the correct dimensions. 4) Once the tension strips had been formed the faller bored into the tree directly below each tension strip (Fig. 2) to form the weakening cuts. Once all the cuts were completed the faller inserted the flange spreader and retreated to a safe position. A similar process was used to make the cuts for the one tension strip system, except the faller did not have to push the tip through to p_5 and only one tension strip was cut (p_6 to p_9 eliminated in Fig. 1).

Table 1. Target dimensions

	Dimension	Distance (cm)	Dimension	Distance (cm)
Dataset1 (Two tension strips)	UC	$(\frac{1}{3})\text{Diameterstump}$	p_4 to p_{10}	4
	HW	3	p_{10} to p_{11}	4
	BC	$(\frac{2}{3})\text{Diameterstump}$	p_4 to p_6	15
	p_7 to p_8	4	d_1^T	5, 7.5, 10
	p_8 to p_9	4		
Dataset2 (One tension strip)	UC	$(\frac{1}{3})\text{Diameterstump}$	p_{10} to p_{11}	6.5
	HW	3	p_5 to p_4	7.5
	BC	$(\frac{2}{3})\text{Diameterstump}$	d_1^T	7.5
	p_4 to p_{10}	6.5		

Table 2. Data Summary for Dataset1

d_1^T	n	Mean diameter (cm)	Western hemlock	Douglas-fir	Western red cedar	$S = 1$	$S = 0^a$	$S = 0^b$
5	20	59.1	15	4	1	16	3	1
7.5	22	59.6	19	3	0	20	2	0
10	20	61.9	15	1	4	14	2	4

^aTree fell before faller in the clear

^bFlange spreader unable to initiate falling

Table 3. Data Summary for Dataset2

Species	n	Mean diameter (cm)	$S = 1$	$S = 0^a$	$S = 0^b$
western red cedar	34	82.8	26	2	6
Douglas-fir	3	69.0	1	0	2
western hemlock	30	53.4	25	2	3

^aTree fell before faller in the clear

^bFlange spreader unable to initiate falling

Table 4. Data Summary for Dataset3

TS(1)	Species	n	Mean diameter (cm)	$S = 1$	$S = 0^a$	$S = 0^b$
34	western red cedar	34	82.8	26	2	6
3	Douglas-fir	6	72.0	3	1	2
30	western hemlock	49	54.9	43	3	3

^aTree fell before faller in the clear

^bFlange spreader unable to initiate falling

Two explanatory variables were recorded before a tree was felled, tree imbalance and species. An imbalance of a tree is defined as the center of gravity of the tree not being directly over the center of the stump. It was assumed that imbalance would strongly affect the success of the novel manual tree falling system; however, imbalance is difficult to measure since it is the combined effect of lean, sweep, and an asymmetric crown. Fallers are experienced in estimating the direction of imbalance and so in this study the faller was asked to estimate the direction and magnitude of imbalance, where a major imbalance indicates the faller is confident in the direction of imbalance, while minor imbalance indicates the imbalance is small and could be in a direction other than that specified by the faller. Tree imbalance (*Imbalance*) is a class variable with three levels. *Imbalance*(1) is defined as a major imbalance in the direction of fall and *Imbalance*(2) is defined as a major imbalance opposite to the direction of fall. *Imbalance*(0) denotes a minor imbalance in any direction or a major imbalance sideways from the direction of fall. Tree species (*Spcode*) was recorded as a class variable with two levels, where *Spcode*(1) indicates western redcedar (*Thuja plicata* Donn ex D. Don) and *Spcode*(2) indicates either Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) or western hemlock

(*Tsuga heterophylla* [Raf.] Sarg.). Douglas-fir and western hemlock were combined into *Spcode*(2) because of the low numbers of Douglas-fir sampled, and their similar mechanical properties (Green *et al.* 1999).

The faller was given the target dimensions described above; however, the researcher did not interfere during the cutting process after marking the

dimensions. The actual dimensions of the cuts were a function of the faller's ability to accurately cut to the prescribed points. Thus, the total tree height in meters (*Height*), the average diameter measured outside bark at stump height (*Diameterstump*), the total cross section area of the tension strips as a product of depth and width (*TCA*), and the actual distance between the plane formed by the backcut and the weakening cuts (d_1^{PF}) were measured after the tree was on the ground as post-falling measurements. Note in *Dataset1* for the post-falling measurements that d_1^{PF} is the minimum of the two distances actually cut for the two tension strips, and that d_1^{PF} is a continuous variable for all the datasets considered in this paper. The falling method can have two possible outcomes failure ($S = 0$) and success ($S = 1$), where $S = 1$ indicates the tree did not move until the faller was in the clear and the hydraulic flange spreader was able to initiate falling. A summary of the post-falling data for each dataset is given in Tables 2, 3 and 4. Note, since S is a binary variable logistic regression will be employed when S is used as the response variable.

Results

Results for Dataset1

Recall that *Dataset1* uses two tension strips and that the dimensions for d_1^T were randomly selected from 5 cm, 7.5 cm, and 10cm. The success rate for the d_1^T target values of 5 cm, 7.5 cm, and 10 cm are respectively 0.8, 0.91, and 0.7, where success rate is defined as the number of successes divided by the number of observations for the target value. When using the target dimensions the success rate is highest when d_1^T is 7.5 cm.

In the following logistic regression analysis the actual post-falling dimensions of d_1^{PF} will be considered a continuous variable, and as can be seen from the d_1^T success rates, d_1^{PF} will likely have a non-linear relationship with success and so a second order relationship will be assumed. In order to determine if d_1^{PF} and $(d_1^{PF})^2$ are significant in explaining the variation in S consider the following two models.

$$[1] \quad S_i = \beta_0 + \epsilon_i$$

$$[2] \quad S_i = \beta_0 + \beta_1 d_1^{PF} + \beta_2 (d_1^{PF})^2 + \epsilon_i$$

Here β_0 is the intercept, ϵ_i is the error term, $i = 1, \dots, n$ observations, β_1 to β_2 are the coefficients for d_1^{PF} and $(d_1^{PF})^2$.

Eq. 1 is nested within eq. 2; therefore, they can be tested using the Likelihood Ratio Test (LRT). Setting eq. 2 as the full model and eq. 1 as the reduced model the test statistic is $-2\lambda = 60.925 - 55.115 = 5.81$ using maximum likelihood (ML), thus, d_1^{PF} and $(d_1^{PF})^2$ are significant in explaining the variation in S ($\chi^2, df = 2, p = 0.0547$). Including the coefficients

found when fitting eq. 2 to *Dataset1* results in

$$[3] \quad S = 4.6328 + 1.7160d_1^{PF} - 0.1102(d_1^{PF})^2$$

Take the first derivative of eq. 3 with respect to d_1^{PF} , set the result to zero, and solve for d_1^{PF} . The value for d_1^{PF} that maximizes success is 7.8 cm, which is similar to the target dimension result of 7.5 cm. Thus, this paper will use 7.5cm as the preferred target dimension for d_1^T .

Results for Dataset2

Recall that *Dataset2* uses only one tension strip with the target value for d_1^T fixed at 7.5cm. To examine whether *Spcode*, *Diameterstump*, *Height* and *Imbalance* are significantly correlated with success, consider the following three models.

$$[4] \quad S_i = \beta_0 + \epsilon_i$$

$$[5] \quad S_i = \beta_0 + \beta_1 \text{Imbalance}(1) + \beta_2 \text{Imbalance}(2) + \epsilon_i$$

$$[6] \quad S_i = \beta_0 + \beta_1 \text{Imbalance}(1) + \beta_2 \text{Imbalance}(2) + \beta_3 \text{Spcode}(2) + \beta_4 \text{Diameterstump}(2) + \beta_5 \text{Height}(2) + \epsilon_i$$

Here β_0 is the intercept, ϵ_i is the error term, $i = 1, \dots, n$ observations, β_1 to β_5 are the coefficients for *Imbalance*, *Spcode*, *Diameterstump*, and *Height*, where *Spcode*(2) and *Imbalance*(0) have been assigned to the reference level.

Setting eq. 6 as the full model and eq. 5 as the reduced model the LRT test statistic is $-2\lambda = 50.452 - 51.257 = 0.805$ using ML; therefore, the variables *Diameterstump*, *Height*, and *Spcode* in eq. 6 are not significant ($\chi^2, df = 3, p = 0.8482$). This result indicates success is insensitive to these variables over the range considered in this dataset. Using LRT and setting eq. 5 as the full model and eq. 4 as the reduced model the test statistic is $-2\lambda = 71.258 - 51.257 = 19.001$ using ML; therefore, the variable *Imbalance* is significant for this data set ($\chi^2, df = 2, p = 0.00007$). The results for *Dataset2* are similar to what Noll and Lyons (2010) concluded for a two-strip design, which also showed that diameter, height and species were not significantly correlated with success.

Recall that *Imbalance*(1) is a major imbalance in the direction of fall, *Imbalance*(2) is a major imbalance opposite to the intended direction of fall, and *Imbalance*(0) is a minor imbalance in any direction or a major imbalance sideways. Considering the parsimonious model eq. 5 the odds ratio estimate for *Imbalance*(1) compared to *Imbalance*(0) was 0.192; 95% Confidence Interval, 0.037–1.002, indicating the chance of successfully falling a tree is 81% lower when it is associated with *Imbalance*(1). When comparing *Imbalance*(2) to *Imbalance*(0) the odds ratio was 0.029; 95% Confidence Interval, 0.005–0.170, indicating the chance of successfully falling a tree is 97% lower when it is associated with *Imbalance*(2). These results highlight the optimization problem that results from using a relatively small hydraulic flange spreader. If the tension strips are too small they are not strong enough to support a tree with a major imbalance in the direction of fall; however, if the tensions strips are too large then the hydraulic flange spreader is not strong enough to break the tension strips if there is a major imbalance opposite to the direction of fall. In order to increase the success rate for trees with major

imbalance it will be necessary to increase the separation force supplied by the falling tool; however, this must be done without greatly increasing the weight of the tool.

Results for Dataset3

Note that *Dataset3* combines the observations from *Dataset1* with d_1^T equal to 7.5 cm and all observations from *Dataset2*, and that *Dataset1* used two tension strips and that *Dataset2* used one tension strip. This permits a comparison between the two and one tension strip designs. The variable *TS* will be included as a class variable with two levels, where *TS*(2) represents observations with two tension strips and *TS*(1) represents observations with one tension strip. In order to determine if *TS* is significant in explaining the variation in *S*, consider the following four models.

$$[7] \quad S_i = \beta_0 + \epsilon_i$$

$$[8] \quad S_i = \beta_0 + \beta_1 \text{Imbalance}(1) + \beta_2 \text{Imbalance}(2) + \epsilon_i$$

$$[9] \quad S_i = \beta_0 + \beta_1 \text{Imbalance}(1) + \beta_2 \text{Imbalance}(2) + \beta_3 \text{TS}(1) + \epsilon_i$$

$$[10] \quad S_i = \beta_0 + \beta_1 \text{Imbalance}(1) + \beta_2 \text{Imbalance}(2) + \beta_3 \text{Spcode}(2) + \beta_4 \text{Diameterstump}(2) + \beta_5 \text{Height} + \beta_6 \text{TS}(1) + \epsilon_i$$

Here β_0 is the intercept, ϵ_i is the error term, $i = 1, \dots, n$ observations, β_1 to β_6 are the coefficients for *Imbalance*, *Spcode*, *Diameterstump*, *Height* and *TS*. Recall *Spcode* is a class variable with two levels, *Imbalance* is a class variable with three levels and *TS* is a class variable with two levels; *Spcode*(2), *Imbalance*(0) and *TS* (2) have been assigned to the reference level.

Setting eq. 10 as the full model and eq. 9 as the reduced model the LRT test statistic is $-2\lambda = 68.248 - 65.397 = 2.851$ using ML; therefore, the variables *Diameterstump*, *Height* and *Spcode* in (10) are not significant ($\chi^2, df = 3, p = 0.4151$). Setting eq. 9 as the full model and eq. 8 as the reduced model the LRT test statistic is $-2\lambda = 71.294 - 68.248 = 3.046$ using ML; therefore, the variable *TS* in eq. 9 is not significant ($\chi^2, df = 1, p\text{-value} = 0.081$) in explaining the variation in *S*. Unfortunately, the effect of the number of tension strips is confounded with location since *Dataset1* and *Dataset2* were taken from two different locations. Changing location could result in changes in tree form (that are not captured by height and diameter), wood strength, and weather. Thus, since *TS* is not significant in explaining the variation in *S* this could mean either 1) neither the number of tension strips nor the location had a significant effect on *S*, or 2) the effect of the number of tension strips cancelled out the effect of location. Note when considering eq. 8 as the full model and eq. 7 as the reduced model that *Imbalance* is again significant ($\chi^2, df = 2, p = 0.00004$) over the range considered in this dataset.

Conclusions

This paper reports the results from two different field trials using manual tree falling techniques that were similar to those reported by Noll and Lyons (2010). In the first field trial 62 trees were tested using two tension strips, while varying d_1^T , and the results of this paper indicate that the optimum target value for d_1^T is 7.5 cm. In the second field trial 67 trees were

tested using a single tension strip when holding the target value for d_1^T fixed at 7.5 cm. When considering the results from the second field trial they appear to be very similar to those found by Noll and Lyons (2010). Specifically, the one tension strip system was insensitive to factors such as tree species and size within the range considered in the tests, and had a success rate of 78%. The observations from the first field trial that used a 7.5 cm value for d_1^T were combined with the observations from the second field trial, in order to obtain a comparison between the two tension strip system and the one tension strip system. When considering this combined dataset, and including the class variable *TS* to indicate whether one or two tension strips were used, it was found that *TS* was not significant in explaining the variation in *S*. Since *TS* was not significant it may be possible to infer that using two tension strips does not significantly increase the rate of success, and since the faller found cutting one tension strip was much simpler than two, one tension strip should be the preferred design. The caveat with this observation is that *TS* is confounded with location since the two trials were conducted in different locations and only one level of *TS* was used at each location; thus, the effect of location could be cancelling the effect of the number of tension strips.

This research has been constrained by the desire to minimize the weight of the separation tool; therefore, the separation force has been limited to 44.5 kN. The relatively small separation force limits the maximum size of the tension strips and for trees that are imbalanced in the direction of fall this can result in failure where the tree displaces before the flange spreader is inserted. Additionally the relatively small separation force limits the ability of the flange spreader to overcome an imbalance opposite to the direction of fall. Thus, a tool with a larger separation force would permit the use of larger tension strips while still having a sufficient reserve to initiate falling of trees with significant imbalance opposite to the direction of fall. Future research will concentrate on developing such a tool.

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