New methods for manually falling trees using hydraulically powered flange spreaders

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Abstract

Manual tree falling is widely regarded as the most dangerous part of forestry work. This thesis reports the results from a project that used a remotely operated hydraulic flange spreader and a novel holding wood pattern, consisting of uncut strips (tension strips) to remove the faller from the base of the tree when it starts to displace, since this is when many accidents occur. The novel holding wood pattern uses uncut strips of wood on the backcut side of the tree to hold the tree in static equilibrium while the flange spreader is inserted. Field testing was conducted in three different trials and overall resulted in a 80% success rate. Success of the system was analyzed using logistic regression and multi linear regression. Success of the method used in the first trial was insensitive to tree species, diameter, and height; however, it was strongly affected by tree imbalance. In the second trial the distance between the backcut and the weakening cut was optimized to maximize success. In the third trial only one tension strip was used, as opposed to two in the previous trial, and it was found that this design was simpler for the faller to cut and performed similarly to the two strip design.

The strength of the tension strips had to be designed so the flange spreader could initiate falling even when there was a small imbalance opposite to the direction of fall, while also preventing the tree from displacing if a tree had an imbalance in the falling direction. These competing constraints resulted in a design that sometimes failed because the tension strips could not hold the tree against a lean or wind, and sometimes failed because the flange spreader was not strong enough to initiate falling. The goal of future research is to design a tool with 89kN of separation force, weighing 4.5kg. This new tool will permit the use of stronger tension strips which will reduce the likelihood of trees falling before the faller away, while also providing a reserve force to initiate falling of trees with an imbalance opposite to the falling direction.

Table of contents

List of tables

List of figures

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Co-authorship statement

As the author of this thesis, I was assisted by Kevin Lyons in the identification and design of the study and the conduct of the research used for Chapter 2 and 3. As the author of this thesis I am also responsible for field work and data analysis. I was aided also by Kevin Lyons in preparing the manuscript for Chapter 2 and 3 by providing me with early feedback.

1. Introduction

1.1. Overview

Forestry is one of the largest resource industries in British Columbia (BC) with a workforce of about 22,000 (Province of British Columbia, 2007) and it is widely regarded as one of the most dangerous. When comparing the number of time loss accidents and serious and fatal injuries between industries, the chances of getting injured are higher in forestry than in any other industrial profession (Rummer, 1995). Within forestry the most dangerous job designation is manual tree falling (BCForestSafetyCouncil, 2010; Bentley et al, 2005; Helmkamp and Derk, 1999; Myers and Fosbroke, 1994; NIOSH, 1976; Peters, 1991); between 1998 and 2002 WorkSafeBC accepted 26 faller-related fatal claims and over 1,400 faller injury claims (WorkSafeBC, 2010_a). Over the years continuous efforts have been made to make manual tree falling safer, possible solutions included increasing the level of mechanization, developing better safety protocols, increasing the amount of supervision, and the introduction of standardized training.

Standardized training is the main tool currently proposed to eliminate the high number of accidents in manual tree falling. The faller certification program was implemented by the BC Forest Safety council in 2003 and became mandatory for all commercial manual tree fallers as of July of 2006. The program goal is to avoid accidents through comprehensive training, and by having new fallers working under the supervision of experienced fallers for the first 180 days on the job (BCForestSafetyCouncil, 2010). Currently about 3700 certified manual tree fallers are registered in BC, though many of these were grandfathered into the program prior to 2006 (BCForestSafetyCouncil, 2010) and never received the current standardized training. In the year certification became mandatory (2006) there were no manual tree faller fatalities in BC, and in

2007 there was only one; however, in 2008 there were 8 fatalities. It is obvious that better training alone does not eliminate fatalities completely, because there are job specific hazards that are beyond the control of the faller and cannot be eliminated with even the best training. The most common cause of accidents in manual tree falling is the faller getting hit by falling debris, which is most likely to happen when tree begins to displace and the faller is still at the base, or when the tree brushes up against neighboring trees (Peters, 1991).

Current methods for manual tree falling are described in WorkSafeBC (1998, 2010$_b$, 2010$_c$) and OSHA (2010$_a$) and have evolved little over the last eighty years. After determining the intended falling direction the faller will then cut a wedge shaped piece out of the trunk of the tree. This piece is called the undercut and it points the tree into the desired falling direction. From the opposite side of the undercut another horizontal cut is brought towards the undercut and this cut is termed the backcut. The backcut is stopped before reaching the undercut and the uncut piece of wood between the backcut and the undercut is called the holding wood. The holding wood acts as a hinge and is used to guide the tree in the desired direction. When using traditional methods to manually fall trees the faller usually inserts a plastic wedge in the backcut when there is sufficient space given the position of the saw. The faller then proceeds to complete the backcut, occasionally tapping the wedge with an axe to keep it tight. This will prevent the tree from settling back on the chainsaw bar and moves the tree in the desired direction. The problem with this method of falling trees is that the faller is at the base of the tree when it begins to displace, and this is when debris is likely to dislodge from the canopy and strike the faller. Moving the faller farther away from the base of the tree before it begins to displace and eliminating driving wedges removes the faller from many of these hazards.

1.2. Existing technology and proposed solutions

Existing technologies for manual tree falling without the use of falling wedges are bottle jacks and other hydraulic devices such as hydraulic wedges which work without relying on the impact generated by driving wedges with an axe (Waldwirtschaft Schweiz, 2010). In order to actuate these devices the faller is still at the base of the tree when it begins to displace. Bottle jacks also require a large opening (called windowblock) below the backcut in order to be engaged, resulting in higher stumps. Another important disadvantage is the weight of large bottle jacks, which prohibits their widespread use by fallers.

It was found that flange spreaders commonly used to pry apart pipe flanges, can be inserted in the backcut and can provide enough lifting capacity to move a tree in the desired direction given the other attributes of the tree such as species, imbalance and diameter. The opening mechanism of a flange spreader consists of jaws attached to the front of the spreader (Figure 1.1) and a single jaw attached to a hydraulic cylinder inside the unit. Commercially available flange spreaders used in this research supply a three inch lift with 44.5kN of lifting force. The total weight of one spreader, a 3m hose and a hydraulic pump is about 20kg, which still is too heavy to be carried as part of a fallers kit but shows room for weight savings.

The second part of this new falling system is an improved design for the falling cuts that can hold the tree in static equilibrium until the flange spreader is inserted and actuated. Keeping trees in static equilibrium by using uncut wood strips is commonly used in manual tree falling of heavily imbalanced trees to avoid vertical splits of the tree trunk also known as “barberchairing” (WorkSafeBC, 1998; WorkSafeBC, 2010_b and 2010_c; OSHA, 2010). In this case the trees are usually felled by cutting the strap (uncut strip of wood on the backcut side) or by using a pusher tree to fall the imbalanced tree. In order to keep the tree from moving when the faller is at the base this project used uncut strips of wood on the backcut side of the tree, with the intent that these strips would be broken out of the stump when the spreader is actuated. This is achieved by weakening cuts below the plane of the backcut which transform the failure of the tension strips into a shear failure. Therefore, the strips are positioned so the flange spreader can sit perpendicular to the holdingwood and beside the tension strips.

Figure 1.1, Flange spreader in partially extended position

1.3. Objectives

1.3.1. A novel method for manually falling trees

Objective: The objectives of Chapter 2 were to test a new holding wood design to determine if it can hold a tree in static equilibrium while the faller is at the base of the tree, and if falling can be initiated remotely by a hydraulic flange spreader.

Chapter 2 used a two tension strip design in conjunction with the 44.5kN flange spreader on 47 trees, that were sampled in the order the faller worked his falling face. The faller was allowed to modify the dimensions of the tension strips and the weakening cut distance based on his experience. All dimensions were measured after falling and used as covariates in the analysis. Logistic regression was used to determine the explanatory variables that significantly affect success, and multiple linear regression was used to detect possible interactions between explanatory variables.

1.3.2. Optimizing a novel method for manual tree falling using flange spreaders

Objective: The objectives of Chapter 3 were to determine the optimum distance between the weakening cuts and the backcut, and to determine if a one tension strip design performed similarly to a two tension strip design.

Chapter 3 used the results from two datasets from two different cutblocks. The first dataset consisted of 62 trees and utilizes a two tension strip design that was based on the design used in the previous chapter. The trees were again sampled in the order the faller works his falling face. For this dataset all the variables were fixed, except for one variable that was found to be significant in the previous analysis, was randomly changed in pre-defined increments.

Logistic regression was used again and with the help of success ratios and derivatives the value of the distance between the backcut and the weakening cuts associated with the maximization of success was determined.

The second dataset consisted of 67 trees and used an optimized design based on one tension strip in conjunction with the previously tested optimum distance between the backcut and the weakening cuts. This optimized design was analyzed using logistic regression and the change in the rate of success between different variables estimated using the odds ratio. From the observations with the optimum dimension for the tested variable in the first dataset and the complete second dataset a third dataset was formed in order to test for influence of the change in falling cut design on success of the system. Logistic regression was used in order to test for significant influence of the falling cut pattern on success of the system.

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2. **A novel method for manually falling trees**[1]

2.1. Introduction

The BC Forest Safety Council began mandatory certification of manual tree fallers in British Columbia with the goal of standardizing training and reducing fatal accidents (WorkSafeBC, 2004). After mandatory certification, the number of serious accidents dropped to 0 and 1 fatality in the years 2006 and 2007 respectively; however, in 2008 there were 8 fatalities (BC Forest Safety Council, 2009). There are many hazards that are difficult for a manual tree faller to predict (Peters, 1991), with the most common cause of fatalities and serious injuries being unseen debris falling out of the canopy (Bentley et al, 2005; Helmkamp et al, 1999; Myers et al, 1994; NIOSH, 1976).

The recommended dimensions of the falling cuts for the traditional Humboldt undercut are drawn from WorkSafeBC (1998) and OSHA (2009_a). When falling trees a wedge of material is taken out of the side of the tree that is in the intended falling direction. This wedge is termed the undercut, and it is recommended that the horizontal width of the undercut be 25% to 33% of the diameter of the tree. From the side of the tree opposite the undercut, a horizontal cut is brought in towards the undercut in a plane that is 2cm to 5cm higher than the undercut. This horizontal cut is termed the backcut. The backcut is stopped before reaching the horizontal position of the inside of the undercut. The wood between the backcut and the undercut is termed the holding wood, and the width of the holding wood must be sufficient to maintain directional control of the tree. The traditional role of the holding wood is to control the direction of the tree while it is falling.

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[1] A version of this chapter has been accepted for publication by *The Forestry Chronicle*. Noll, F. and Lyons, C.K., 2010. A novel method for manually falling trees

When using traditional methods to manually fall trees the faller usually inserts a plastic wedge in the backcut when there is sufficient space given the position of the saw. The faller then proceeds to complete the backcut, occasionally tapping the wedge with an axe to keep it tight. This will prevent the tree from settling back on the chainsaw bar and moves the tree in the desired direction. The problem with this method of falling trees is that the faller is at the base of the tree when it begins to displace, and this is when debris is likely to dislodge from the canopy and strike the faller. The objectives of this paper are 1) to present a new procedure for manually falling trees that uses a novel holding wood design and remotely operated hydraulic flange spreader to remove the faller from the base of the tree when it begins to displace, 2) to determine if common variables such as tree species affect the success of falling a tree with this procedure, and 3) to determine which variables affected the faller and made him vary from the target dimensions of the novel holding wood pattern. Logistic regression will be used in the analysis of success, since success is a binary response variable, and multiple linear regression will be used to test correlation between the measured dimensions of the falling cuts and covariates such as tree species and size.

2.2. Methods

2.2.1. Novel holding wood description

This project has developed a novel holding wood pattern that holds the tree in static equilibrium while the falling cuts are being made, and while a hydraulic flange spreader is inserted into the backcut. The method is derived from the falling standard as stated by WorkSafeBC (2009) and OSHA (2009_b) for falling trees with significant imbalance. The novel holding wood pattern uses the traditional holding wood that acts as a hinge with the addition of two uncut strips of wood (tension strips) that are left at the outside of the backcut opposite to the undercut (Figure 2.1). The objective of the tension strips is to hold the tree in static equilibrium while the faller is working at the base of the tree and when the flange spreader is being inserted, while permitting the faller to remotely operate the flange spreader to break the tension strips and initiate falling.

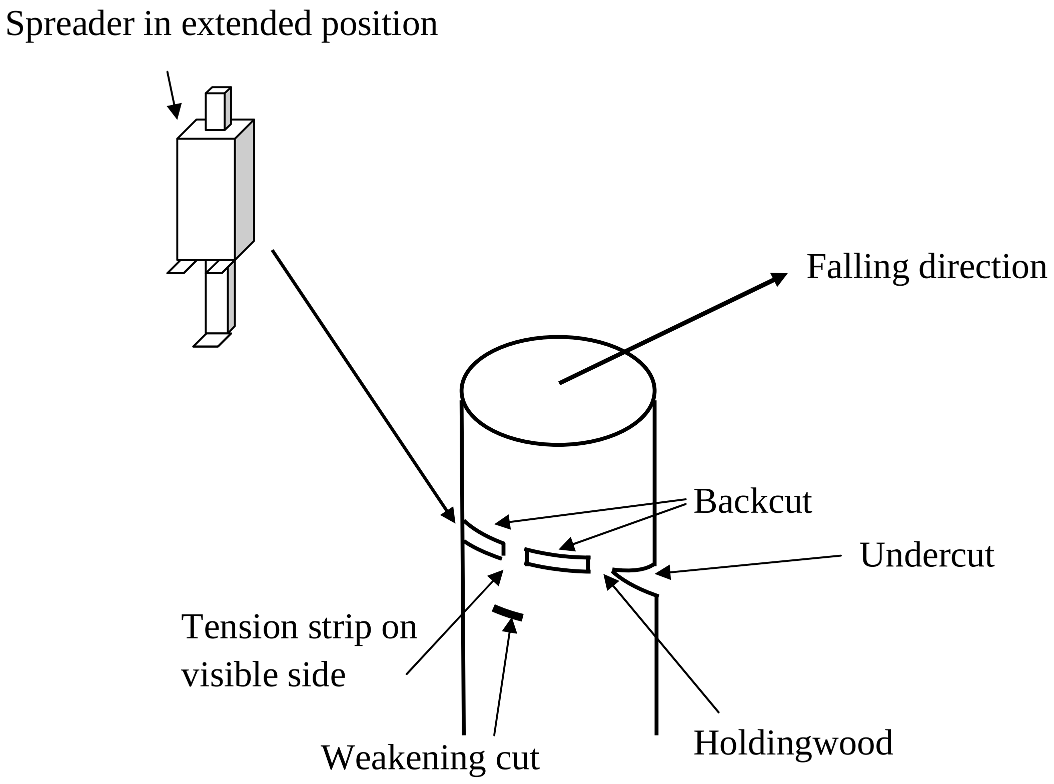

Figure 2.1, Novel holding wood design

It is desirable to have strong tension strips that prevent the tree from moving while the faller is at the base; however, if they are too strong the flange spreader is unable to break them to initiate falling. The strength of the tension strips with respect to the strength of the flange spreader is a significant design concern since the flange spreader used in this study was limited to 10,000lb (44.5kN) of separation force, in order to minimize the weight of the equipment the faller has to carry. Wood is relatively strong in tension parallel to the grain as opposed to shear parallel to grain, and if the tension strips are designed to fail under tension their cross sectional area has to be quite small. Very small tension strips are difficult for the faller to cut and if a small error is made it can remove a significant portion of the cross section. Thus, a horizontal cut is bored into the tree directly below a tension strip at a distance below the plane of the backcut (Figure 2.1), and the tensions strips are designed to fail under mode 2 shear, where a plug of wood is pulled out of the stump. The following process was used to makes the cuts identified in Figure 2.2.

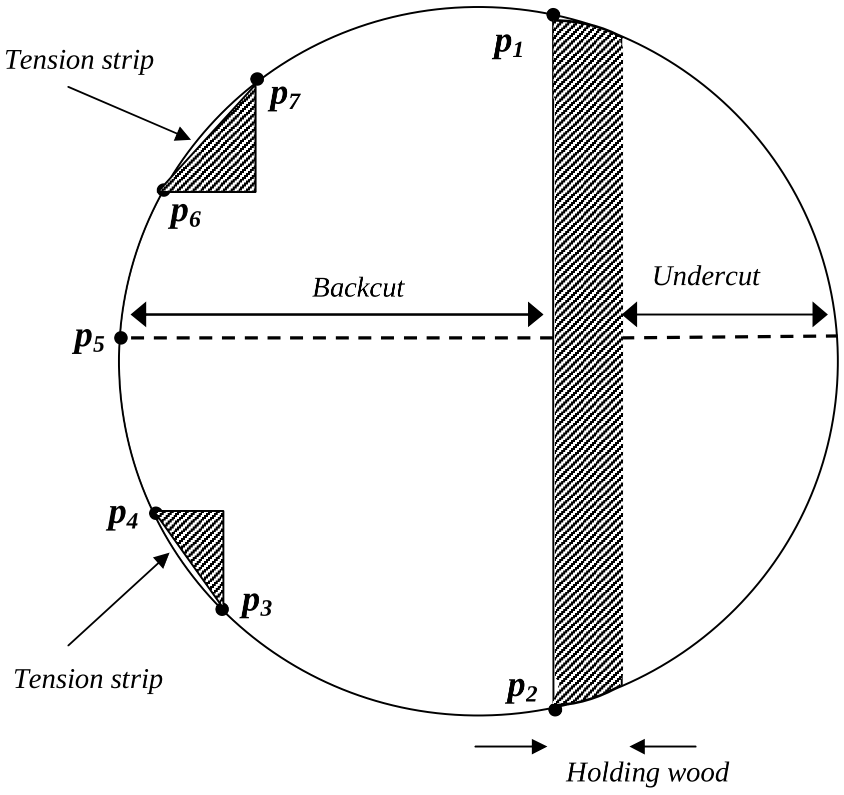

Figure 2.2, Plan view of novel holding wood design

1. For a selected tree the faller cut away the bark on the backside of the tree so the spreader was in contact with the wood instead of the bark (from *p4* to *p6* as seen in Figure 2.2) and for the holdingwood and the tension strips to be clearly seen when cutting from *p2* to *p4* and from *p6* to *p1*.
2. The faller cut a Humboldt undercut with a horizontal depth approximately equal to $^1/_3$ the diameter on the stump (*Diameterstump)*.
3. 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.
4. 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.
5. Once the tension strips had been formed the faller bored into the tree directly below each tension strip (Figure 2.1) to form the weakening cuts. Once all the cuts were completed the faller inserted the flange spreader and retreated to a safe position.

2.2.2. Data collection methods

Two variables were measured 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. *Imbalance* in this paper is a class variable with three levels. The faller was asked to estimate *Imbalance* where *Imbalance*(0) indicates imbalance sideways from the direction of the fall, *Imbalance*(1) indicates imbalance in the falling direction, and *Imbalance*(2) indicates imbalance opposite to the direction of fall. Tree species was also recorded as a class variable (two levels); *Spcode*(1) was assigned to western redcedar *(Thuja plicata)*, and *Spcode*(2) was assigned to Douglas-fir (*Pseudotsuga menziesii)* and western hemlock (*Tsuga heterophylla)* due to their similar mechanical properties (Green et al. 1999) and the small number of Douglas-fir sampled.

The total tree height in meters (*Height*) and the measurements of the cuts seen in Figure 2.2 were taken after the tree was on the ground as post-falling measurements. *UC* is the horizontal depth of the undercut, *BC* is the depth of the backcut, *HW* is the width of the holdingwood, *Diameterstump* is the average diameter measured outside bark at stump height, *TCA* is the sum of the crossectional areas of the two tension strips, and d_1^{PF} is the minimum distance between the plane formed by *BC* and the weakening cuts. For the logistic analysis failure was classified as *S*=0 and success as *S*=1, refer to Figure 2.3 for the definition of success and failure. A summary of the sample data is given in Table 2.1. Douglas-fir and western hemlock are separated in Table 2.1; however, due to the low number of Douglas-fir sampled and their relative similarity in strength properties to western hemlock they are combined into *Spcode*(2) for analysis.

The field trial was conducted at the Malcolm Knapp Research Forest (MKRF) during the spring of 2009. All trees used in the field trial were 70- 75 year old second growth from natural regeneration after fire. Trees smaller than 30cm dbh were not attempted 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. Preliminary testing was conducted to establish approximate dimensions for the novel holding wood pattern prior to the commencement of research. The target dimensions developed with the aid of a certified faller were $UC \approx 30\%\ of\ Diameterstump, HW \approx 3cm, TCA \approx 30cm^2$ and $d_1^{PF} \approx 10cm$. The faller was given the target dimensions; however, the researcher did not interfere during the cutting process and so the actual dimensions of the cuts were a function of the faller's ability to estimate the dimensions and to accurately cut the dimensions.

Table 2.1, Data summary

Species	*n*	Mean Height (m)	Mean Diameterstump (cm)	Mean d_1^{PF} (cm)	Mean UC Ratio*	Mean BC Ratio*	Mean HW Ratio*	Mean TCA (cm^2)
Cw	37	29.2	68.7	8.3	0.35	0.55	0.04	31.9
Fd	2	35.5	79.8	4.8	0.44	0.54	0.03	15.6
Hw	8	29.3	49.8	5.7	0.30	0.59	0.03	26.3

* ratio of *UC, BC, HW* with respect to *Diamterstump*

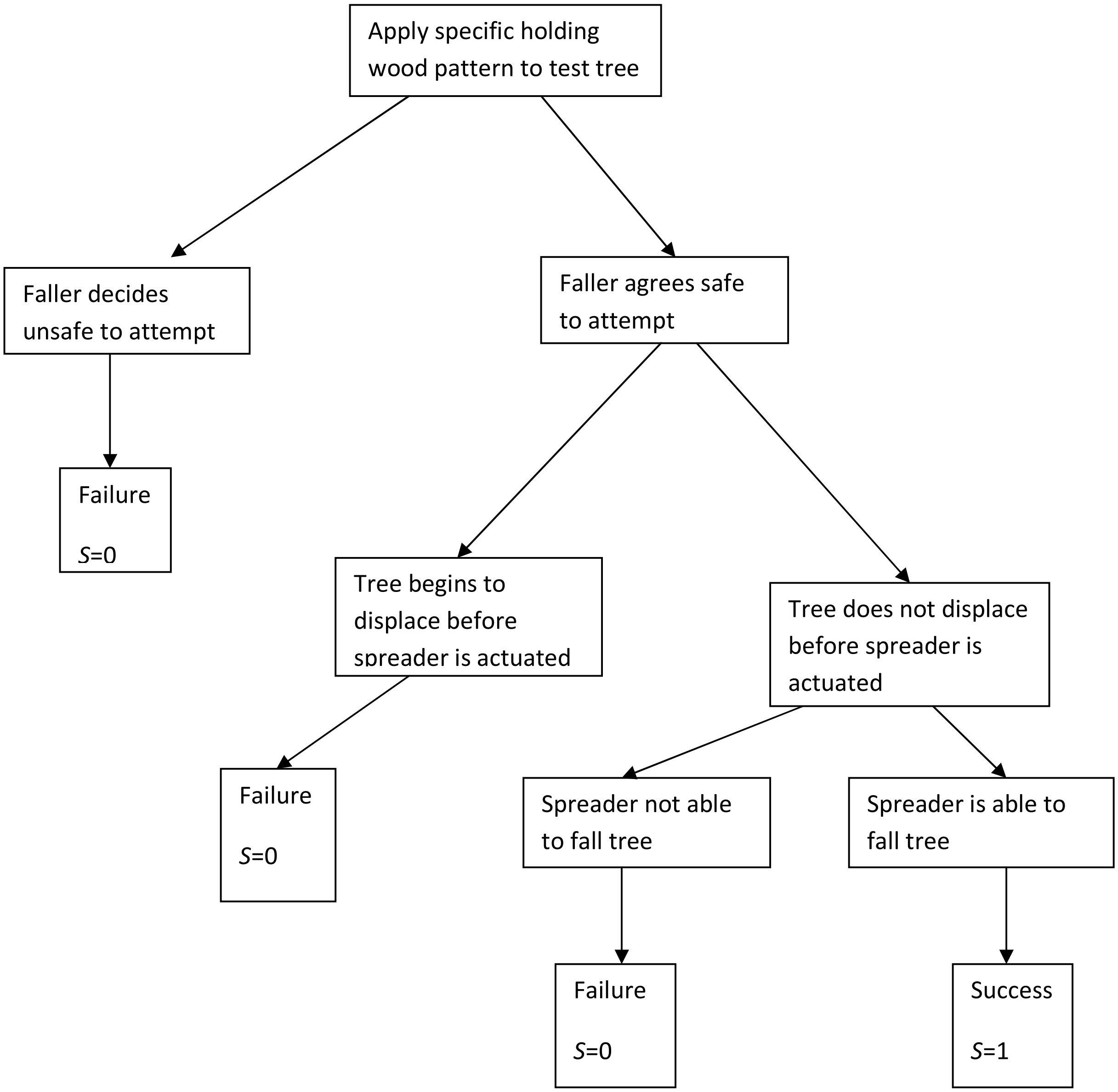

Figure 2.3, Decision tree of success and failures

2.2.3. Analysis methods

Logistic Regression was used for analysis of *S* since it is a binary variable, where as Multiple Linear Regression (MLR) was used to determine if the dimensions of the cuts used to form the holding wood are correlated with attributes such as *Spcode*, *Diameterstump*, *Height* and *Imbalance* in the tree that the faller may have recognized. Problems were encountered when using Logistic Regression to analyze the data in this study; therefore, the theory is summarized here to help explain this.

Allison (2000) notes in logistic regression the probability that $Y_i = 1$ is estimated using the logit model for probability.

$$p_i = \frac{1}{1+e^{-\boldsymbol{\beta x}_i}} \tag{2.1}$$

Here p_i is the probability that $Y_i = 1$, $\boldsymbol{\beta}$ is a row vector of unknown constants, $\boldsymbol{x}_i$ is a column vector of known values for the explanatory variables of the *i*th observation , and *i* ranges from 1 to *n*, where *n* is the number of observations.

Since the observations are assumed to be independent the Likelihood function (L) is the product of the individual probabilities.

$$L = \prod_{i=1}^{n} \Pr\,(y_i) \tag{2.2}$$

$$\Pr(y_i) = p_i^{y_i}(1-p_i)^{1-y_i} \tag{2.3}$$

Note y_i is 1 for a success and zero for failure. Substitute (2.3) into (2.2), take the log of both sides, and substitute (2.1) into this, then the log of the Likelihood function is

$$\log L = \sum_{i=1}^{n} \boldsymbol{\beta x}_i y_i - \sum_{i=1}^{n} \log(1+e^{\boldsymbol{\beta x}_i}) \tag{2.4}$$

Logistic Regression determines the values for $\boldsymbol{\beta}$ by maximizing log*L*.

To compare the fit between a full model and a reduced model, where the reduced model is nested within the full model, take the difference of (2.4) for the full and reduced model.

$$LR = -2(logL_R - logL_F) \tag{2.5}$$

Here the subscripts *R* and *F* correspond respectively to the reduced and full models.

When using logistic regression to consider success of the falling method developed in this study, the class variable for imbalance of the tree (*Imbalance*) cannot be included due to quasi complete separation of sample points. Allison (2000) notes that quasi complete separation of sample points occurs in logistic regression when a linear combination of explanatory variables almost perfectly predicts the dependent variable. Quasi complete separation of sample points commonly occurs when one level of a dummy variable is associated with only one case of the response variable. In the dataset considered in this paper *Imbalance*(0) is only associated with *S*=1). Since there were only a small number of failures the cause of each failure based on the researchers qualitative observations is summarized in Table 2.2.

Table 2.2, Description of failures

Tree #	Species	Direction of imbalance	Cause of failure
4	Cw	In falling direction	The tension strips failed and the tree began to displace before the weakening cuts were completed and the flange spreader could be inserted, due to imbalance in the falling direction and wind.
6	Cw	In falling direction	The tension strips failed and the tree began to displace after the weakening cuts were completed but before the flange spreader was inserted, due to imbalance in the falling direction and wind.
7	Hw	In falling direction	The tension strips failed and the tree began to displace before the weakening cuts were completed and the flange spreader could be inserted due to imbalance in the falling direction and wind.
11	Hw	Opposite to falling direction	The flange spreader was not able to break the tension strips and initiate falling due to imbalance opposite to the falling direction.
13	Cw	In falling direction	The tension strips failed and the tree began to displace before the weakening cuts were completed and the flange spreader could be inserted due to imbalance in the falling direction and wind.
17	Cw	Opposite to falling direction	All cuts were made and the spreader was inserted and pumped up to the maximum pressure. Due to improper placement the flange spreader ripped out on one side of the backcut and was not able to initiate falling.
19	Cw	Opposite to falling direction	All cuts were made and the flange spreader was inserted and pumped up to the maximum pressure. The tree did not displace due to imbalance opposite to the falling direction.
21	Fd	In falling direction	All cuts were completed and the spreader was inserted and pumped up to the maximum pressure. The flange spreader was not able to break the tension strips and initiate falling.
24	Cw	In falling direction	The tension strips failed and the tree began to displace after the weakening cuts were completed but before the flange spreader was inserted, due to imbalance in the falling direction and wind.

2.3. Results

To examine whether *Spcode*, *Diameterstump* and *Height* are significantly correlated with success, consider the following two models.

$$S_i = \beta_0 + \varepsilon_i \tag{2.6}$$

$$S_i = \beta_0 + \beta_1 Spcode(1) + \beta_2 Diameterstump + \beta_3 Height + \varepsilon_i \tag{2.7}$$

Here β_0 is the intercept, ε_i is the error term, $i = 1, \dots, n$ observations, β_1 to β_3 are the coefficients for *Spcode*(1), *Diameterstump*, and *Height*. Recall *Spcode is a* class variable and here *Spcode*(2) has been assigned to the reference level.

Equation (2.6) is nested within (2.7) and can be tested using the Likelihood Ratio Test (LRT). Setting (2.7) as the full model and (2.6) as the reduced model the LRT test statistic is $-2\lambda = 45.907 - 42.544 = 3.363$ using maximum likelihood (ML); therefore, the variables in (2.7) are not significant ($\chi^2, df = 3, p - value = 0.3389$). Since the explanatory variables *Diameterstump, Height*, and *Spcode* are not significant this indicates success is insensitive to these variables over the range considered in this data set.

Recall *Imbalance* could not be included in the logistic regression analysis due to quasi separation of data points. The affect of *Imbalance* on success is summarized in Table 2.2. Of the nine failures three were called by the faller to have an imbalance opposite to the direction of fall, and in these cases the force supplied by the flange spreader was not sufficient to overcome the component of self weight acting opposite to the falling direction and the strength of the tension strips. Five of the failures had an imbalance in the falling direction, and in these cases the strength of the tension strips was not sufficient to support the component of self weight directed in the falling direction, resulting in the trees beginning to displace before the faller was in the clear. One failure was called by the faller to have an imbalance acting in the direction of fall; however, the flange spreader was unable to initiate falling in this case. This indicates that imbalance strongly affects the success of the methods used in this project; however, this also indicates that in eight of the nine failures the faller correctly recognized the imbalance.

To examine whether *TCA* is correlated with the tree attributes that a faller might recognize consider the following model.

$$logTCA = \beta_0 + \beta_1\, Imbalance(1) + \beta_2\, Imbalance(2) + \beta_3\, Spcode(1) + \beta_4\, Diameterstump + \beta_5\, Height + \varepsilon_i \tag{2.8}$$

Here *TCA* has been log transformed (*logTCA*) in order to normalize the residual errors, β_0 is the intercept, ε_i is the error term, $i = 1, \ldots, n$ observations, β_1, *to* β_5, are coefficients for *Imbalance*(1), *Imbalance* (2), *Spcode*(1), *Diameterstump*, and *Height*. Recall, *Imbalance* and *Spcode* are class variables, and here *Imbalance*(0) and *Spcode*(2) have been assigned to the reference level. When setting (2.8) as the full model and considering the intercept only model as the reduced model the explanatory variables are not significant ($partial\ F - test, df1 = 5, df2 = 41, p - value = 0.1085$). This indicates the faller did not consistently deviate from the target *TCA* based on the recorded tree attributes.

To examine whether d_1^{PF} is correlated with the tree attributes that a faller might recognize consider the following two models.

$$d_1^{PF} = \beta_0 + \beta_1 Spcode(1) + \varepsilon_i \tag{2.9}$$

$$d_1^{PF} = \beta_0 + \beta_1\, Spcode(1) + \beta_2 Imbalance(2) + \beta_3 Imbalance(1) + \beta_4\, Diameterstump + \beta_5\, Height + \varepsilon_i \tag{2.10}$$

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

When setting (2.10) as the full model and considering (2.9) as the reduced model the omitted explanatory variables are not significant ($partial\ F - test, df1 = 4, df2 = 41, p - value = 0.4758$). Setting (2.9) as the full model and the intercept only model as the reduced model *Spcode*(1) does explain a significant portion of the variance in d_1^{PF} ($partial\ F - test, df1 = 1, df2 = 45, p - value = 0.0011$). Since the coefficient for β_1 is positive this suggests the faller was increasing d_1^{PF} when encountering western redcedar. When the faller was asked why he varied d_1^{PF} as opposed to *TCA* he felt he had better control over the d_1^{PF} dimension, and given the difficulty in cutting the tension strips he preferred to use a constant *TCA* while varying d_1^{PF} to accommodate the strength variations between species.

2.4. Conclusions

This paper presents a new method for manually falling trees that removes the faller from the base of the tree during the critical time when the tree begins to displace. This new method of manually falling trees uses two uncut strips at the outside of the backcut to hold the tree in static equilibrium while the cuts are being made and a hydraulic flange spreader is being inserted in the backcut. The hydraulic flange spreader is then used to break the uncut strips to initiate falling. Using a flange spreader with 44.5 kN of separation force and target dimensions for the falling cuts developed during preliminary testing, the new method of manually falling trees was applied to 47 trees.

In the data set considered in this paper the success of the new falling method is insensitive to many variables that a faller commonly considers important when falling a tree. These variables include species, height, and diameter. The variable that was found to be important when considering success of the new falling method was imbalance. Of the 47 test trees 9 were failures; 5 of the failures were due to the tension strips failing while the faller was still at the base of the tree, and 4 of the failures were due to the flange spreader not being able to initiate falling. When considering the 5 failures where the tension strips failed, the faller identified the trees as having an imbalance in the falling direction and in the opinion of the faller if he had increased the strength of the tension strips by either increasing *TCA*, or by increasing d_1^{PF}, then these failures could have been prevented. When considering the 4 failures where the flange spreader was unable to initiate falling, the faller identified 3 of the trees as having an imbalance opposite to the falling direction. For the trees where the flange spreader was unable to initiate falling it is not clear whether altering the dimensions of the tension strips would have prevented the failure. In some cases the effect of the imbalance opposite to the falling direction may have been too large for the small flange spreader to overcome irrespective of the dimension of the tension strips.

It was found in the data set considered in this paper that *TCA* was not significantly correlated with imbalance, species, or the diameter at stump height. However, d_1^{PF} was found to be significantly correlated with species, where d_1^{PF} tended to be larger for western redcedar. This indicates the faller was making small adjustments to the target dimensions to account for the weaker strength properties of western redcedar by increasing d_1^{PF} to increase the strength of the tension strips. When asked why the faller chose to increase the strength of the tension strips by increasing d_1^{PF} he indicated it was difficult to cut very small *TCA* and that he preferred to use a standard *TCA* with a variable length d_1^{PF}. This suggests a preferred strategy will be to set *TCA* sufficiently large so it can be cut reliably, and to control the strength of the tension strips through the magnitude of d_1^{PF}. The goal of future research will be to determine optimum d_1^{PF} values for particular classes of trees.

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3. Optimizing a novel method for manual tree falling using flange spreaders[2]

3.1. 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, 2010 $_{a,}$ 2010$_b$). The most common cause of fatalities and serious injuries when manually falling trees is attributed to unseen debris falling out of the canopy (Bentley et al, 2002; Helmkamp et al, 1999; Holman et al, 1987; Myers et al, 1994; NIOSH, 1976), 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 (Figure 3.1), 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 the 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 distance between the plane of the backcut and the weakening cuts to accommodate tree strength and imbalance.

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[2] A version of this chapter will be submitted for publication. Noll, F. and Lyons, C.K., 2010. Optimizing a novel method for manual tree falling trees using flange spreaders

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 5cm, 7.5cm, and 10cm, this dataset will be called *Dataset*1. The second dataset comes from a sample of 67 trees where only one tension strip was used while the other dimensions were held fixed at the optimum value found from previous research; this dataset will be called *Dataset*2. The third dataset is the intersection of *Dataset*1 and *Dataset*2 including all the trees that had a target distance between the backcut and the weakening cut of 7.5cm (89 trees), this dataset permits comparison of trees with one tension strip to those with two and will be called *Dataset*3.

3.2. 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- 75 year old second growth from natural regeneration after fire. Trees that were smaller than 30cm 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 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, *HW* is the width of the holding wood. Two different tension strip patterns were used in this study (Figures 3.1 and 3.2). The corners of all the features were marked in the field (p1 to p9 in Figure 3.1 and p1 to p7 in Figure 3.2) to show the target dimensions for the faller to cut.

The distance between these weakening cuts and the plane of the backcut is called d_1^T (Figure 3.3), 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 3.1.

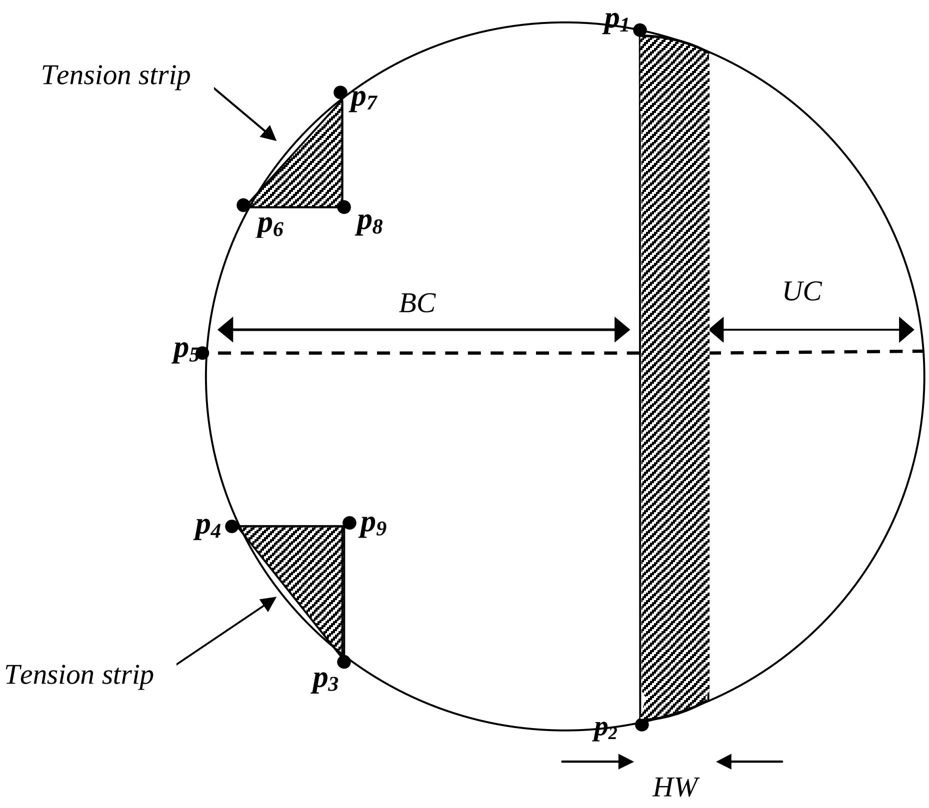

Figure 3.1, Plan view of *Dataset*1 (double tension strip) holding wood design

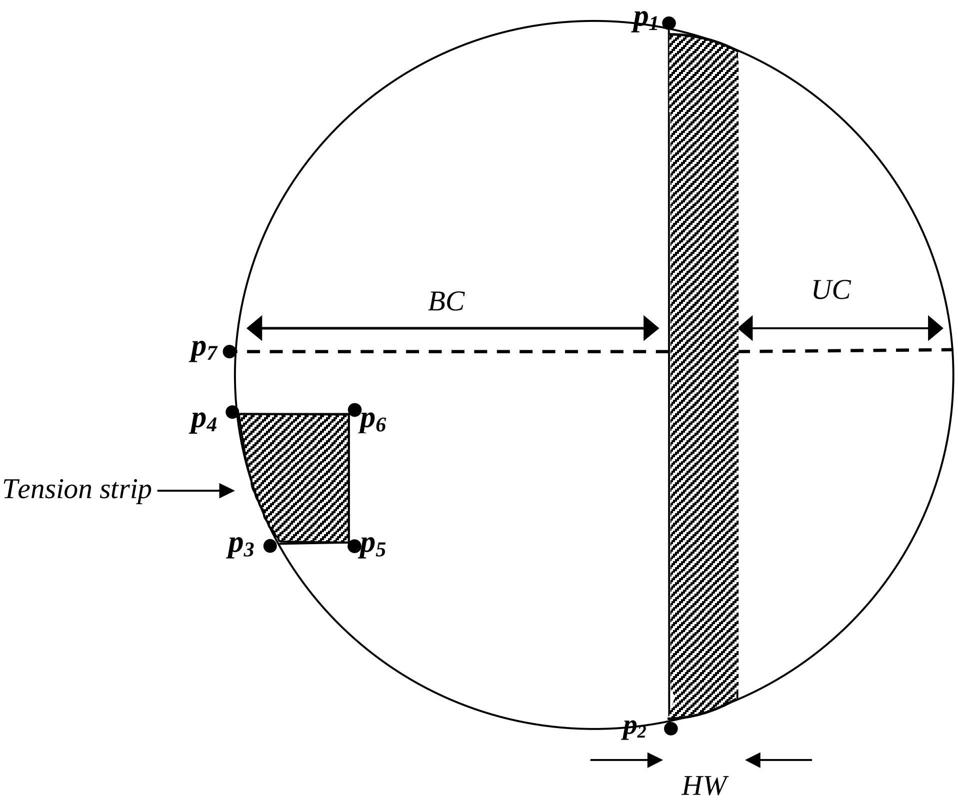

Figure 3.2, Plan view of *Dataset*2 (single tension strip) holding wood design

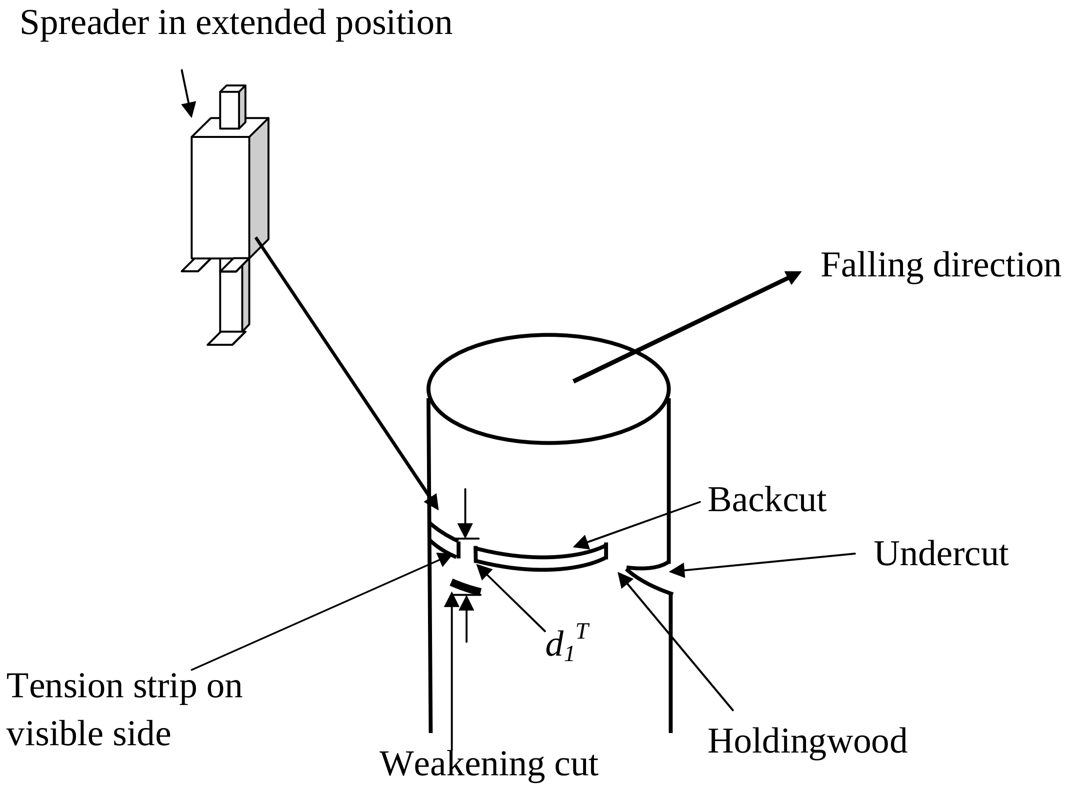

Figure 3.3, Holding wood design sideview

Table 3.1, Target dimensions

	Dimension	Distance (cm)	Dimension	Distance (cm)
*Dataset1**	*UC*	*Diameterstump*/3	p8 to p7	4
	HW	3	p9 to p3	4
	BC	2(*Diameterstump*/3)	p4 to p6	15
	p6 to p8	4	d_1^T	5, 7.5, 10
	p4 to p9	4		

*based on description in Figure 3.1

*Dataset2***	*UC*	*Diameterstump*/3	p5 to p6	6.5
	HW	3	p7 to p4	7.5
	BC	2(*Diameterstump/3*)	d_1^T	7.5
	p4 to p6	6.5		

**based on description in Figure 3.2

Two explanatory variables were measured 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 3 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*) and *Spcode*(2) indicates either Douglas-fir (*Pseudotsuga menziesii*) or western hemlock (*Tsuga heterophylla*). 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, and so the actual dimensions of the cuts were a function of the faller's ability to accurately cut to the prescribed points (p1 to p9 in Figure 3.1 and p1 to p7 in Figure 3.2). Therefore the total tree height in meters (*Height*), the average diameter measured outside bark at stump height (*Diameterstump*), the total crossectional area of the tension strips as a product of depth and width (*TCA*), the actual distance between the plane formed by the backcut and the weakening cuts (d_1^{PF}), and the actual dimensions of the cuts listed in Table 3.2 were measured after the tree was on the ground as post-falling measurements. Note that in *Dataset*1 for the post-falling measurements d_1^{PF} denotes the minimum of the two distances actually cut for the two tension strips, and that d_1^{PF} is a continuous variable. A summary of the post-falling data for each dataset is given in Tables 3.2, 3.3 and 3.4. Since the system can only have two possible outcomes in the analysis *S=0* represents failure and *S=1* success, success and failure are defined in Figure 3.4.

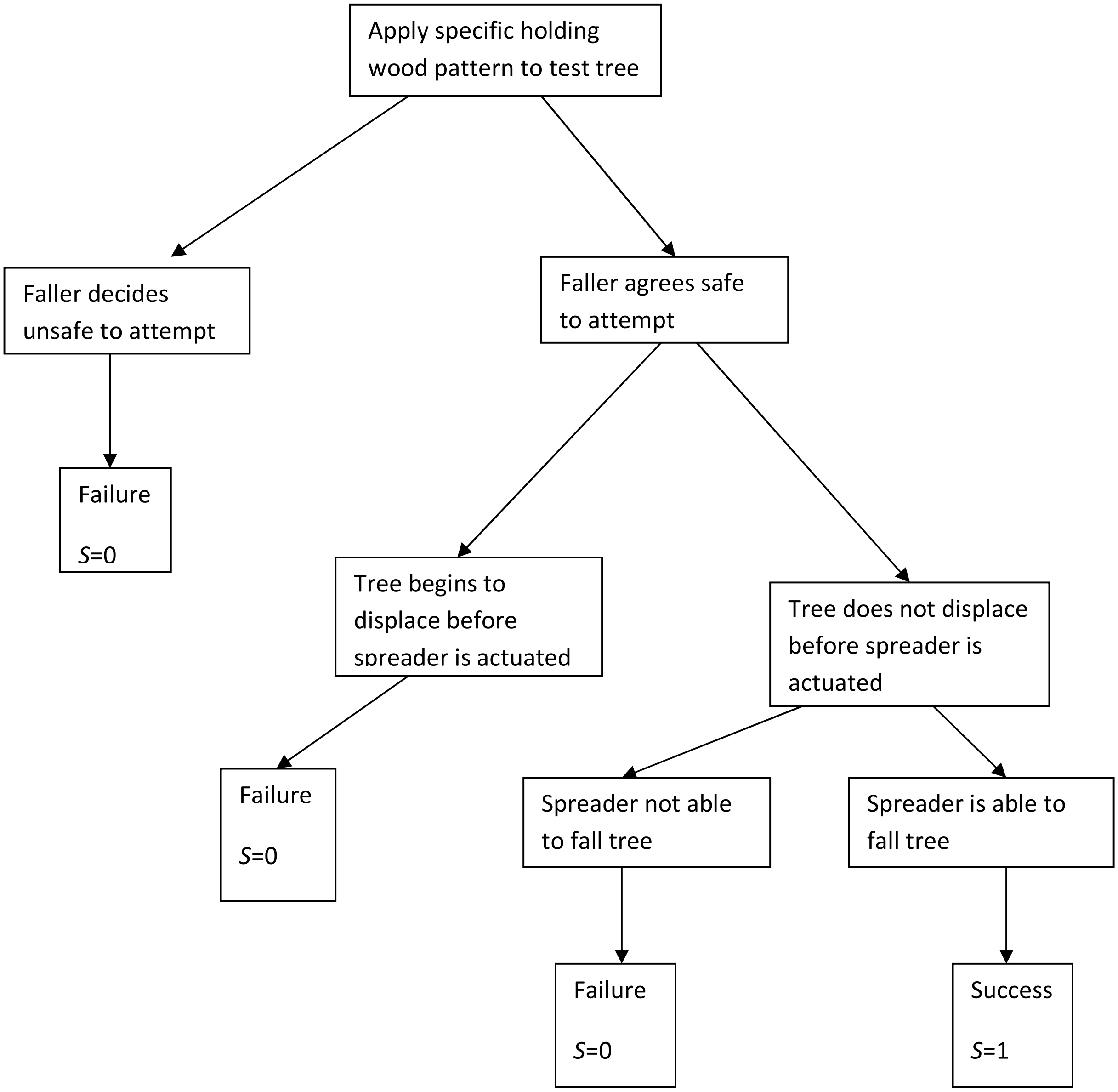

Figure 3.4, Decision tree of success and failures

Table 3.2, Data summary for *Dataset*1

d_1^T	*n*	Hw	Fd	Cw	successes	Mean d_1^{PF}(cm)	Mean *UC* Ratio*	Mean *BC* Ratio*	Mean *HW* Ratio*	Mean *TCA* (cm^2)
5	20	15	4	1	16	5.3	.35	.53	.05	38.7
7.5	22	19	3	0	20	7.9	.34	.55	.05	42.9
10	20	15	1	4	14	9.4	.33	.55	.05	42.1

*Ratio with respect to *Diameterstump*

Table 3.3, Data summary for *Dataset*2

Species	*n*	*S*(1)	Mean *Height* (m)	Mean *Diameterstump* (cm)	Mean d_1^{PF} (cm)	Mean *UC* Ratio*	Mean *BC* Ratio*	Mean *HW* Ratio*	Mean *TCA* (cm^2)
Cw	34	26	30.6	83	7.9	.37	.47	.04	63
Fd	3	1	40.7	69	7.0	.31	.54	.05	44
Hw	30	25	33.7	53	8.0	.32	.52	.05	55

*Ratio with respect to *Diameterstump*

Table 3.4, Data summary for *Dataset*3

TS(1)	Species	*n*	*S*(1)	Mean *Height* (m)	Mean *Diameterstump* (cm)	Mean d_1^{PF} (cm)	Mean *UC* Ratio*	Mean *BC* Ratio*	Mean *HW* Ratio*	Mean *TCA* (cm^2)
34	Cw	34	26	30.6	82.8	7.9	.37	.47	.04	63
3	Fd	6	3	41.1	72.0	7.3	.33	.55	.04	40
30	Hw	49	43	34.0	54.9	8.0	.33	.53	.05	48

*Ratio with respect to *Diameterstump*

3.3. Results

3.3.1. Results for *Dataset*1

Recall that *Dataset*1 uses two tension strips and that the dimensions for d_1^Twere randomly selected from 5, 7.5 and 10cm. The success rate for the d_1^Ttarget values of 5, 7.5, and 10cm are respectively 0.8, 0.91, and 0.7, where success rate is defined as the number of successes (S(1)) dived by the number of observations for the target value. When using the target dimensions the success rate is the highest when d_1^T is 7.5cm.

In the following regression analysis the actual post-falling dimensions of d_1^{PF} will be considered as a continuous variable; however, as can be seen from the success rates it has a second order relationship with success. 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.

$$S_i = \beta_0 + \varepsilon_i \tag{3.11}$$

$$S_i = \beta_0 + \beta_1 d_1^{PF} + \beta_2 (d_1^{PF})^2 + \varepsilon_i \tag{3.12}$$

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

Equation (3.11) is nested within (3.12); therefore they can be tested using the Likelihood Ratio Test (LRT). Setting (3.12) as the full model and (3.11) as the reduced model the test statistic is $-2\lambda = 60.925 - 55.115 = 5.81$, d_1^{PF} and $(d_1^{PF})^2$are significant in explaining the variation in the data $(\chi^2, df = 2, p = 0.0547)$. Including the coefficients found when fitting (3.12) to *Dataset*1 results in

$$\hat{S} = -4.6328 + 1.7160 d_1^{PF} - 0.1102 (d_1^{PF})^2 \tag{3.13}$$

To find the value for d_1^{PF} that maximizes success take the first derivative of (3.13) with respect to d_1^{PF}, set the result to zero, and solve for d_1^{PF}. The post falling value for d_1^{PF} that maximizes success is 7.8cm, which is similar to the target dimension result of 7.5cm. Thus, this paper will use 7.5cm as the preferred target dimension for d_1^T.

3.3.2. Results for *Dataset*2

Recall that *Dataset*2 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.

$$S_i = \beta_0 + \varepsilon_i \tag{3.14}$$

$$S_i = \beta_0 + \beta_1 Imbalance(1) + \beta_2 Imbalance(2) + \varepsilon_i \tag{3.15}$$

$$S_i = \beta_0 + \beta_1 Imbalance(1) + \beta_2 Imbalance(2) + \beta_3 Spcode(1) + \beta_4 Diameterstump + \beta_5 Height + \varepsilon_i \tag{3.16}$$

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.

Equation (3.14) is nested within (3.15) and equation (3.15) is nested within equation (3.16), and they can be tested using the Likelihood Ratio Test (LRT). Setting (3.16) as the full model and (5) as the reduced model the LRT test statistic is $-2\lambda = 50.452 - 51.257 = 0.805$ using maximum likelihood (ML); therefore, the variables *Diameterstump, Height,* and *Spcode* in (3.16) 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 data set. Using the LRT and setting (3.15) as the full model and (3.14) 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 ($\chi^2, df = 2, p =< 0.00007$).

Considering the parsimonious model (3.15) 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) . Recall that *Imbalance*(1) and (2) are major imbalances in the direction of fall and opposite to the intended direction of fall respectively and *Imbalance*(0) is a minor imbalance in any direction or a major imbalance sideways. The results for *Dataset*2 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 and that Imbalance strongly affected success. This indicates the one tension strip design is performing similarly to the two tension strip design.

3.3.3. Results for *Dataset*3

Note that *Dataset*3 combines the observations from *Dataset1* with d_1^T equal to 7.5cm and all observations from *Dataset*2, and that *Dataset1* used two tension strips and that *Dataset*2 used one tension strip. This permits a direct 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.

$$S_i = \beta_0 + \varepsilon_i \tag{3.17}$$

$$S_i = \beta_0 + \beta_1 Imbalance(1) + \beta_2 Imbalance(2) + \varepsilon_i \tag{3.18}$$

$$S_i = \beta_0 + \beta_1 Imbalance(1) + \beta_2 Imbalance(2) + \beta_3 TS(1) + \varepsilon_i \tag{3.19}$$

$$S_i = \beta_0 + \beta_1 Imbalance(1) + \beta_2 Imbalance(2) + \beta_3 Spcode + \beta_4 Diameterstump$$
$$+ \beta_5 Height + \beta_6 TS(1) + \varepsilon_i \tag{3.20}$$

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 (3.20) as the full model and (3.19) as the reduced model the LRT test statistic is $-2\lambda = 68.248 - 65.397 = 2.851$ using maximum likelihood (ML); therefore, the variables *Diameterstump*, *Height* and *Spcode* in (3.20) are not significant ($\chi^2, df = 3, p = 0.4151$).

Setting (3.19) as the full model and (3.18) as the reduced model the LRT test statistic is $-2\lambda = 71.294 - 68.248 = 3.046$ using maximum likelihood (ML); therefore, the variable *TS* in (3.19) is not significant ($\chi^2, df = 1, p - value = 0.081$) in explaining the variation in the data for S. Unfortunately the effect of the number of tension strips is confounded with location since *Dataset*1 and *Dataset*2 were taken from two different locations. 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 canceled out the effect of location. Note that *Imbalance* in (3.18) is again significant ($\chi^2, df = 2, p = 0.00004$) over the range considered in this dataset.

3.4. 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 7.5cm. 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 7.5cm. 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 consider in the tests, and had a success rate of 78%. The observations from the first field trial that used a 7.5cm value for d_1^T were combined with the observations from the field trial with the one tension strip, in order to obtain a direct 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 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 canceling 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 44.5kN. 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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4. Conclusion

This thesis presents a new method for manually falling trees that removes the faller from the base of the tree during the critical time when the tree begins to displace, which is regarded as the one of the most dangerous times in manual tree falling (Bentley et al, 2005; Helmkamp and Derk, 1999; Holman et al, 1987 Myers and Fosbroke, 1994; Noll and Lyons, 2010; NIOSH, 1976; Peters, 1991). This new method of manually falling trees uses uncut strips at the outside of the backcut to hold the tree in static equilibrium while the cuts are being made and a hydraulic flange spreader is being inserted in the backcut. The hydraulic flange spreader is then used to break the uncut strips to initiate falling. Overall the success rate in this thesis was close to 80%, which is promising given the exploratory nature of this research.

It was shown in Chapter 2 that a two strip design is insensitive to variables that a faller considers important when falling a tree and it was shown that the faller tended to increase the distance between the backcut and the weakening cuts when falling Cw. In Chapter 3 the distance between the backcut and the weakening cuts was examined to find the optimum distance given the dimensions of the other cuts, and it was found that 7.5cm produced the highest rate of success. A simplified design using only one tension strip was then tested and it was found that the one tensions strip design performed similarly to the two strip design and was much simpler for the faller to cut. The studies included in this thesis had both strengths and weaknesses. All the field trials used in this thesis were observational rather than experimental, and this resulted in a high number of categorical variables, which combined with a limited number of replications to caused problems in the statistical analysis, especially in *Dataset*1. However, using observational studies was also a strength in that it provided the opportunity to modify the novel holding wood design as more was learned about its properties. It was also found that imbalance of the tree was difficult to measure because it is a combination of lean, sweep, and an asymmetric crown. Accurate measurement of imbalance would require detailed mapping of the stem and crown, which would be costly for the large number of replications used in this thesis. It was recognized that a faller is trained to recognize imbalance and so the class variable *Imbalance* was created. In Chapter 2 *Imbalance* had only three levels, representing imbalance in the direction of fall, perpendicular to the direction of fall, and opposite to the direction of fall. This definition of *Imbalance* proved to be useful in understanding how the novel falling method was working; however, it was necessary to add magnitude to the definition in order to account for small imbalance that the faller may have called in the wrong direction. Using the more detailed definition of *Imbalance* in Chapter 3 permitted a more detailed statistical analysis of its effect.

This research was constrained by the desire to minimize the weight of the separation tool, and this resulted in the separation force being limited to 44.5kN. 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 stronger tension strips, while still having a sufficient reserve to initiate falling of trees with significant imbalance opposite to the direction of fall.

In this research it was found that species, diameter, and height were not significant in explaining the variation in the success rate of the new method for manually falling trees. This is an interesting result since these variables are normally considered to be important factors to consider when manually falling trees. This result is likely related to the choice of separation force and the resulting tension strip strength that could be used. For the range of trees considered in this research the factor of safety for preventing early displacement of the trees, and the reserve separation force for trees with imbalance opposite to the direction of fall, were sufficient to account for variation in loading and wood properties associated with tree size and species. If dramatically larger trees were considered this would dramatically change the loading on the tension strips and it is quite likely that the species, diameter, and height would be significant in explaining the rate of success, provided the separation force and tension strip strength were not altered. However, as previously mentioned the next stage in developing this system is to develop a tool that has a larger separation force, with a reduced weight. With a larger separation force it will be possible to use stronger tension strips, and it is expected stronger tension strips will result in success of the system being independent of species, diameter, and height over a larger range of trees.

The most likely application for the new falling method developed in this research is to use it to overcome specific falling problems rather than to use it to fall every tree in a cutblock. To use this new falling method in British Columbia it is necessary to have it included in the British Columbia Faller Training Standard (WorkSafeBC, 2010_a; 2010_b), and this will require development of the stronger falling tool and testing the system over a wider range of trees. It will be important to determine the reliability of the system given the stronger falling tool; however, it is unlikely there will be a zero chance of failure, where failure is the tree beginning to displace before the falling tool is actuated or the falling tool is unable to initiate falling. Thus, to include the new falling method in the British Columbia Falling Standard it will be necessary to develop procedures for its use given the chance of failure is not zero.

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