Analysis of Chain Saw Selective Felling Operations on Damage Rate of Residual Trees during Winter Time in a Mixed Conifer–Broad-Leaved Forest in China

Lihai Wang
Na Wang
Xiangfei You
Chun Meng

Abstract

Decreasing the damage rate of residual trees during selective cutting operations is quite important for forest landowners to reduce wood production waste and to use forest resources sustainably. In this article we analyze the impacts of chain saw selective felling operations on the damage rate of residual trees during winter in a mixed conifer–broad-leaved forest. A case study was conducted in Dongfanghong Forest Farm located in northeast China. After theoretical analysis, the influencing factors were identified, and a mathematical model that considers the relationships among damage rate of residual trees, harvesting intensity, initial stand density, and single stem volume to be harvested was established. The theoretical model was verified using the data collected from harvesting sites. Results show that the residual trees' damage rate increases linearly with an increase in stand density and in the volume per stem of felled trees. The damage rate of residual trees increases initially then decreases as the selective cutting intensity increases. In theory, the damage rate is at its highest value when the selective cutting intensity reaches 50 percent. The damage rate is significantly reduced by controlling the falling direction of felled trees, which shifts the maximum damage rate such that the highest rate occurs when the selective cutting intensity is 39 percent. The following recommendations for loggers are proposed to reduce damage rate: (1) effectively control the falling direction of trees being felled, (2) conduct cutting operation in nonfrozen seasons, and (3) design the cutting intensity (E) to be either $E < 20$ percent or $E > 60$ percent.

Residual trees refer to all the stems, except for saplings and seedlings, in a harvest site that are intentionally reserved for certain purposes (Ma 1965, Qiu and Zhou 1997, Shi and Xiao 2001). The felled trees can have direct impacts on the residual trees when falling, causing damage to them, which is of particular concern during selective cutting operations. The types of damage mainly include breakage of the main tip, breakage of the lateral branch, trunk splitting, and trunk skin scratching (Shi and Xiao 2001, Wang et al. 2005).

Studies on the effects of forest harvesting on the damage rate of residual trees are very limited in China and abroad. Mo (1981) analyzed the Korean pine forest and spruce–fir mixed coniferous forest in Changbai Mountain of China and concluded that harvesting intensity had a linear positive relationship with mortality rate. With a harvesting intensity of 70 percent, the mortality rate could reach 60 percent. Dong et al. (1995) studied the impacts of selective cutting on the damage rate of residual trees in different stand density and different selective cutting intensity and derived the general rules among damage rate of residual trees,

The authors are, respectively, Professor, Graduate Research Assistant, Graduate Research Assistant, and Associate Professor, Forest Operations and Environment Research Center, Northeast Forestry Univ., Harbin, Heilongjiang Province, China (lihaiwang@yahoo.com, jlwang@sohu.com, xiangfeiyou@yahoo.com, donglin882001@yahoo.com.cn). This paper was received for publication in February 2011. Article no. 11-00025

Forest Prod. J. 61(4):283–289.

harvest intensity, and stand density. They concluded that (1) the damage rate of residual trees increased with the increase of harvesting intensity, but increased relatively slowly with regard to the increase of stand density and (2) the damage rate of residual broad-leaved trees was larger than that of conifers. Qiu and Zhou (1997) analyzed the impacts of selective cutting operations on the damage rate of residual trees using four different harvesting intensities, including mild moderate selective cutting (13.0%), moderate selective cutting (29.1%), intensive selective cutting (45.8%), and extremely intensive selective cutting (67.3%). They found that the damage rate of residual trees was related to the average diameter at breast height (DBH) of cutting trees and the intensity of selective cutting. When both of them increased, the damage rate increased. Dong et al. (2007) used statistical regression methods to analyze the impact of selective cutting on the damage rate of Larch plantation residual trees and indicated that the damage rate of those trees did not have a direct proportional relationship with the selective cutting intensity and stand density. The damage rate of residual trees increased at first and then decreased under different harvesting intensity and stand density.

Crome et al. (1992) showed that the extent of damage on residual trees was 12 m^2 hm^{-2} (the ratio of damage area and cutting area), which was caused by selective cutting in a tropical rain forest (selective cutting intensity was 37 m^3 hm^{-2}), and there was an obvious linear relationship between the total amount of damaged trees and selective cutting intensity. Hannerz and Hanell (1997) conducted research on the damage of residual trees during forest harvesting in Maine and concluded that the operation season has a significant effect on the injured parts and damage width of the residual trees. Johns et al. (1996) showed that the damage rate of residual trees (the ones with DBH above 10 cm) under well-planned harvesting operations could be 16 percent lower than the damage rate in unplanned harvesting operations based on analysis in the east Amazon basin rain forest. The damage to residual trees consisted mainly of smashed canopy and abraded or scratched trunk, and the damage was most severe for the trees alongside the skidding roads. The damage to residual trees can be effectively reduced by clearing out vine before harvesting. The investigation in Malaysia indicated that the damage to residual trees could be reduced by ¼ to ⅓ through improved cutting operations (Pinard and Putz 1996). The literature review shows that there are many factors affecting the damage rate of residual trees during forest harvesting operations, and most studies considered only a single factor.

China is a country with relatively poor forest resources, and the current forest harvesting method is mainly selective cutting (Chen 2003, Li et al. 2008). With the rapid increase of population and the continuous development of China's economy, the demand for wood products is growing gradually. In order to meet the requirements of wood products in the market and to guarantee the healthy and sustainable development of forest resources, it is critically important to reduce the damage rate of residual trees during forest harvesting in order to use the limited forest resources with high efficiency and low consumption.

Our goal in this article is to analyze the impacts of chain saw felling on the damage rate of residual trees during selective cutting in winter based on the current forest resources and forest harvesting methods applied in the Northeast and Inner Mongolia forest zone of China. Specifically, the following objectives are addressed: (1) identification of the key factors affecting residual tree damage rate and the relationships among these factors; (2) development of a theoretical model that considers the relationships among damage rate of residual trees, harvesting intensity, initial stand density, and single stem volume to be harvested; and (3) validation of the model through field survey data. Finally, suggestions for operational implementation of the findings are given.

Methodology

Model establishment

It is necessary to clearly define the residual trees' damage rate before analyzing their influence factors. The following definition was adopted from articles by Gullison and Hardner (1992), Wasterlund (1992), and Groot (1995): the damage rate of residual trees equals the number of damaged residual trees per unit area divided by the total number of trees in the stand before harvesting, that is,

$$R = \frac{r}{T_s} \times 100\% \quad (1)$$

where R is damage rate of residual trees, r is the number of damaged residual trees, and T_s is the total number of trees before cutting.

Without taking into account the impact on the residual trees' damage during skidding, the injury of residual trees is mainly caused by falling trees hitting residual trees during the cutting process. In this case, the damage to residual trees can be quantified by the number of damaged residual trees per unit area. Damages to residual stands can be taken into account when the diameter of a main twig or lateral branch broken is over 5 cm, the diameter of a trunk split is over 8 cm, and the scratch area on the bark is larger than 3 cm^2.

The number of damaged residual trees is directly proportional to the hit area caused by the felled trees and the density of the residual trees, and the hit area is proportional to the number and size of the cutting trees (Bragg et al. 1994).

Based on the above analysis, the following hypotheses are made for the theoretical model to be established: (1) the terrain is relatively flat, (2) trees are evenly distributed in the forest, (3) the trees are felled without changing the falling direction, (4) the operations are conducted in winter, and (5) chain saws are used to perform the selective cutting.

In the unit area, let n be the number of felled trees, q be the volume of felling tree per stem, and d be the initial tree density in the harvested site. Then the number of damaged residual trees per unit area is

$$r = bqn(d - n) \quad (2)$$

where b is the conversion coefficient of volume to injured area for each individual tree to be felled (m^2 m^{-3}). According to the definition of the damage rate of residual trees, the residual trees' damage rate in unit area can be expressed as

$$R = \frac{r}{d} \times 100\% = bqEd(1 - E) \times 100\% \quad (3)$$

where E is the harvesting intensity of the total tree amount, $E = n/d$. Equation 3 is the theoretical model of the residual trees' damage rate. Equation 3 shows that the damage rate of residual trees R is related to the harvesting intensity, initial stand density, and stem volume of each tree scheduled to be cut down. The relationship among them will be analyzed in detail in the following single factor analysis.

The partial derivative of E by R is calculated and supposed to be zero,

$$\frac{\partial R}{\partial E} = (bqd - 2bqdE) \times 100\% = 0 \quad (4)$$

The stagnation point of maximum R is calculated, that is, $E^* = 50$ percent, and the corresponding maximum damage rate is $R_{max} = bqd/4$. That means the damage rate of residual trees is largest when the harvesting intensity of total trees is 50 percent under conditions of random harvesting.

Model modification

Besides the harvesting intensity, initial stand density, and stem volume of each cut tree, there are still other factors that affect the damage rate of residual trees in the chain saw selective cutting. One of the most important factors is operation season, which is considered to be constant a. Then Equation 3 can be modified as

$$R = [a + bqEd(1 - e)] \times 100\% \quad (5)$$

In this study, we consider two types of operation seasons, frozen and nonfrozen. Another study (Dong et al. 2007) shows that the value of a in the frozen season, because of the brittleness of branches, is 1.3 times as much as that in the nonfrozen season.

Single factor analysis on the damage rate of residual trees in selective cutting

According to Equation 5, the number of damaged residual trees presents an increasing trend at first and then decreases with the increase of selective cutting intensity when the stand density (tree density before cutting) and the felling tree volume per stem are fixed under the above assumptions (Fig. 1). The damage rate of the residual trees reaches the peak value when the selective cutting volume percentage (intensity) is 50 percent. Based on Equation 5, the damage rate of residual trees shows a trend of linear increase as the stand density increases when the selective cutting intensity is fixed under the assumed conditions and random harvesting. The single stem volume has a similar impact on the damage rate of residual trees.

Multiple factors analysis of the influence of selective cutting intensity, felling tree volume per stem, and stand density on the damage rate of residual trees

Under ideal conditions, if selective cutting intensity, felling tree volume per stem, and stand density are the only factors considered, a three-dimensional surface chart can be generated to reflect the relationship between the damage rate and the product of the three influencing factors based on Equation 5 and the above theoretical analysis (Fig. 2). The damage rate of residual trees increases rapidly with the increase of selective cutting intensity, felling tree volume per stem, and stand density before cutting in the general selective cutting operation ($E < 50\%$).

Data Collection

The sample site is located in the second subcompartment of the 403 compartment in Dongfanghong Forest Farm, Dailing Forestry Bureau, Heilongjiang Province, China, with an area of 3.34 hm^2. It is one of the demonstration plots for the national scientific and technological projects during the ''10th Five-year Plan.'' The sample site is at 46°53′13″N and 129°4′38″E. The elevation is 650 m, and the mesoslope is 22° in the northwest direction with dark brown forest soil. The sample site is a mixed conifer–broad-leaved forest dominated by *Abies fabric,* followed by other main species, such as *Betula platyphylla, Picea asperata, Pinus sylvestris, Ulmus pumila,* and *Fraxinus mandshurica*. The forest is 56 years old, with an average height of 14.1 m and stand volume of 280.2 m^3 hm^{-2}. An experimental selective cutting was carried out in the winter of 2002. The whole sample site was divided into 37 sites, with a quadrat size of 30 by 30 m. Different selective cutting intensities were designed to conduct the experiment. The China-made 051 high grip chain saw was used for cutting, and the loggers had 4 years of working experience with ordinary training for the felling operation. In order to study the damage of residual trees caused by selective cutting, an investigation was carried out in the spring of 2003 to survey the damage

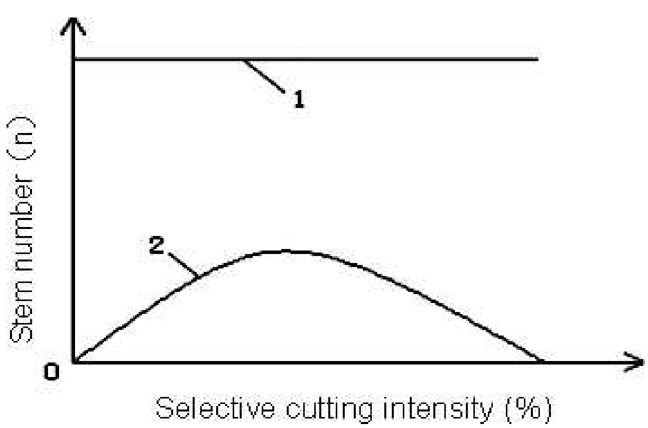

Figure 1.—Relationship of the total number of stems and selective cutting intensity to the number of residual stems suffering damage. 1 = total number of stems; 2 = number of damaged residual trees.

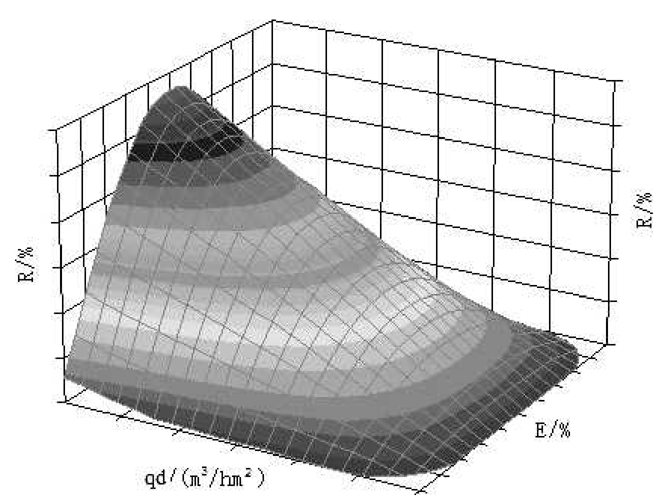

Figure 2.—Relationship of residual trees' damage rate (R) with selective cutting intensity (E) and stand density (qd).

Table 1.—The basic survey data for the second subcompartment of Compartment 403 in Dongfanghong Forestry Farm, Dailing Forestry Bureau.

Sample block no.	Total no. of trees	No. of selective felling stems	No. of damaged stems	Selective cutting intensity (%)	Stand density (stems hm^{-2})	Felling tree volume/stem (m^3 $stem^{-1}$)	Damage rate (%)
A01	87	14	13	16.09	967	0.4689	14.94
A02	74	16	9	21.62	822	0.4297	12.16
A03	105	52	16	49.52	1,167	0.3875	15.24
A04	125	33	18	26.4	1,389	0.3389	14.4
A05	38	21	3	55.26	422	0.3056	7.89
A06	75	20	12	26.67	833	0.4617	16
A07	67	22	9	32.84	744	0.3982	13.43
A08	95	21	14	22.11	1,056	0.4974	14.74
A09	93	27	15	29.03	1,033	0.4412	16.12
A10	89	70	3	78.65	989	0.2184	3.37
A11	42	30	2	71.43	467	0.2667	4.76
A12	49	23	4	46.94	544	0.2807	10.2
A13	67	25	6	37.31	744	0.3173	8.96
A14	59	21	7	35.59	656	0.3026	11.86
A15	43	16	2	37.21	478	0.4392	4.65
A16	44	13	4	29.55	489	0.3389	9.09
A17	51	12	3	23.53	567	0.4696	5.88
A18	41	20	3	48.78	456	0.3355	7.32
A19	74	21	12	28.38	822	0.4758	16.22
A20	72	14	7	19.44	800	0.3442	9.72
A21	49	8	3	16.33	544	0.3398	6.12
A22	83	24	13	28.92	922	0.4746	15.66
A23	44	5	1	11.36	488	0.2194	2.27
A24	102	22	12	21.57	1,133	0.3247	11.76
A25	67	10	2	14.93	744	0.2574	2.98
A26	35	7	2	20	389	0.2785	5.71
A27	70	15	7	21.42	778	0.4086	10
A28	50	6	2	12	556	0.3584	4
A29	74	19	8	25.68	822	0.4485	10.81
A30	72	24	12	33.33	800	0.4179	16.66
A31	33	1	0	3.03	367	0.2134	0
A32	42	11	4	26.19	467	0.3356	9.52
A33	58	12	4	20.68	644	0.2878	6.89
A34	30	9	3	30	333	0.3484	10
A35	38	7	2	18.42	422	0.2154	5.26
A36	42	4	1	9.52	466	0.2128	2.38
A37	57	38	2	66.67	633	0.3611	3.5

condition of the residual trees in the 37 sites. Survey data are shown in Table 1.

Model Validation

Model validation using survey data

In order to validate whether the established model of residual damage rate was in accordance with the actual conditions, the survey data in Table 1 and SPSS software were used to verify the model, and the verification results are shown in Table 2. The F test was applied to check the equation; for the given significance level 0.05, $F_{0.05}(1,37) = 4.13 < 95.001$. So the model is significant. The coefficients are shown in Table 3, and the scatterplot is shown in Figure 3.

As is known through the validation in Table 2, the model of residual trees' damage rate in relation to the cutting intensity, felling tree volume per stem, and stand density is available, and good correlation with the survey data is shown. It can be seen in Figure 3 that the distribution of predictive value is between –2 and 2, indicating that there is no outlier or influential data. The absolute value of t for each variable is larger than $t_{0.025}(37) = 2.026$, and all P values are less than $\alpha = 0.05$. Therefore, the regression coefficients of the model are significant, meaning all three factors have significant influence on the damage rate of residual trees. The three factors, from most important to least important, are selective cutting intensity, stand density, and felling tree volume per stem. They explain 34.7, 33.4, and 31.9 percent of the variance in damage rate, respectively.

Table 2.—Validation of the residual tree damage rate model, which incorporates selective cutting intensity (E), felling tree volume per stem (q), and stand density (qd).

	Model	Revised model	Correlation	F value
Damage rate	$R = [a + bqdE(1 - E)] \times 100\%$	$R = [0.02 + 1.492 \times 10^{-3} \times qdE(1 - E)] \times 100\%$	0.855	95.001

Table 3.—Coefficients of the regression model for residual tree damage rate.

Model 1	Unstandardized coefficients B	Unstandardized coefficients SE	Standardized coefficient, Beta	t	P value
Constant	−11.150	3.254		−3.428	0.002
Cutting intensity (%)	0.179	0.040	0.438	4.439	0.000
Stand density (stems hm^{-2})	0.0115	0.003	0.422	3.845	0.001
Volume/stem (m^3 stem^{-1})	32.79	8.935	0.403	3.670	0.000

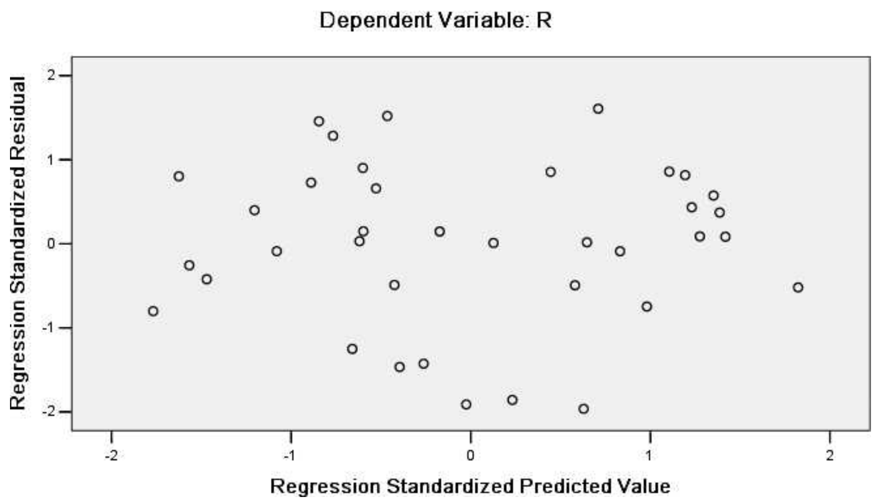

Figure 3.—Scatterplot of the data for residual tree damage rate (R).

The verification model obtained from the survey data could be used to estimate the damage condition of the residual trees caused by these three factors. Meanwhile, the feasibility of residual trees' damage rate model was verified, which could provide model reference for the influence of the three factors on the damage rate of residual trees.

Model validation by single factor and model correction

Model validation by single factor.—To validate the theory of the impact on the damage rate of residual trees caused by selective cutting intensity, the sample data that had similar stand density (the difference among samples is less than 200 stems hm^{-2}) were grouped together and are presented in Table 4. The relationship between the residual trees' damage rate and selective cutting intensity was analyzed through the survey data, and the diagram is displayed in Figure 4. The sample data with close selective cutting intensity (the percentage of the difference among samples is below 5.5%) were grouped as one set of data (Table 5) to validate the theory of the impact on the residual trees' damage rate caused by stand density. The relationship between the residual trees' damage rate and stand density analyzed through the survey data and the scatter diagram of them is shown in Figure 5. Similarly, the impact of felling tree volume per stem on the residual trees' damage rate (Table 6) is shown in Figure 6 under the condition that all the other factors were essentially fixed.

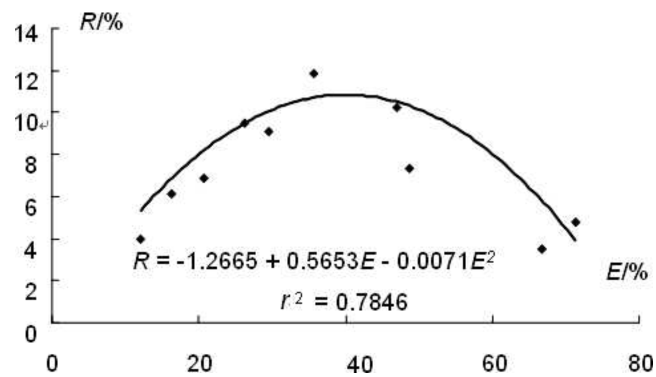

Figure 4.—Relationship between residual tree damage rate (R) and selective cutting intensity (E).

Based on the above validation (Figs. 4 through 6), the residual trees' damage rate shows a trend of increasing at first and then decreasing with the increase of selective cutting intensity, and reaches the maximum value when the selective cutting intensity is about 39 percent. The damage rate of

Table 4.—Block grouping for effects of selective cutting intensity on residual damage rate.

Plot no.	No. of plots	Mean value: Stand density (stems hm^{-2})	Mean value: Volume/stem (m^3 stem^{-1})	Maximum − minimum: Stand density (stems hm^{-2})	Maximum − minimum: Volume/stem (m^3 stem^{-1})
A11/A12/A14/A16/A18/A21/A28/A32/A33/A37	10	546	0.3207	200	0.0944

Table 5.—Block grouping for effects of stand density on residual damage rate.

Plot no.	No. of plots	Mean value: Volume/stem (m^3 $stem^{-1}$)	Mean value: Cutting intensity (%)	Maximum − minimum: Volume/stem (m^3 $stem^{-1}$)	Maximum − minimum: Cutting intensity (%)
A02/A06/A08/A09/A17/A19/A22/A27/A29	9	0.4563	25.26	0.0888	7.61

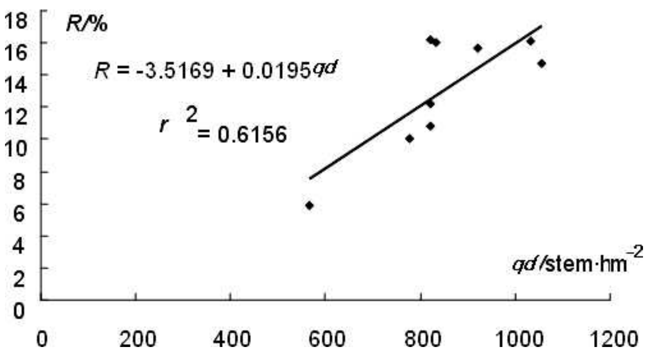

Figure 5.—Relationship between residual tree damage rate (R) and stand density (qd).

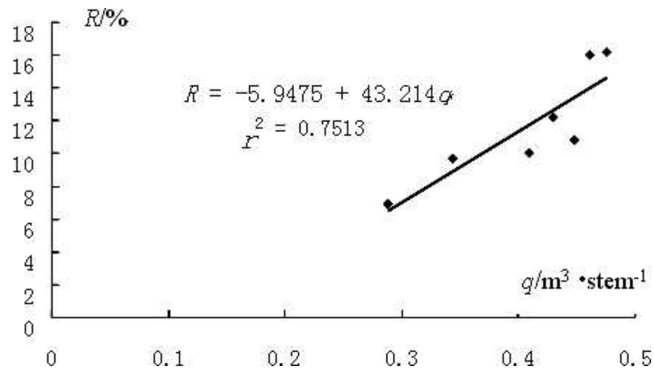

Figure 6.—Relationship between residual tree damage rate (R) and felling stem volume (q).

residual trees increases linearly as the stand density and the felling tree volume per stem increase. The relevance of single factors was much higher, and the result of experimental validation is consistent with the model theory analysis.

Model correction.—We note that the residual trees' damage rate R reaches the maximum value when the selective cutting intensity is 39 percent (Fig. 4), which has certain deviation from the theoretical analysis (with maximum value at $E = 50\%$). The cause for the deviation is that, under ideal conditions, the felling tree falls naturally without the manipulation of loggers. However, in the actual operation, the loggers have to control the falling direction of the felling trees with limited efforts according to process requirements (skidding requirements) and the proposed falling direction of the felling trees; therefore, the maximum residual tree damage rate value appears to be lower than that of uncontrolled operation mode under the same conditions. The operation also demonstrated that it is effective to reduce the damage rate of residual trees by controlling the falling direction. Therefore, it is necessary to revise Equation 5 with the addition of human effective controlling coefficient c to form Equation 6. The human effective controlling coefficient c represents the effectiveness of reducing the residual trees' damage rate and controlling the direction of felling trees based on the information of trees scheduled to be cut, the peripheral residual trees, and terrain. The greater the c value is, the more effective the control is. According to the observation data both in this case study and in the published articles (Dong et al. 1995, 2007; Field and Granhus 1998), the human effective controlling coefficient is set with a range of 1.1 to 1.6.

$$R = [a + bqEd(1 - cE)] \times 100\% \quad (6)$$

The parameter identification results of the revised model are listed in Table 7. The regression coefficient increases significantly when compared with the results in Table 2. Meanwhile, the F test is conducted for Equation 6. For a given significance level of 0.05, $F_{0.05}(2,34) = 3.28 < 66.818$. Therefore, the model is significant, which demonstrates the effectiveness of the introduction of the parameter to the model.

Three-dimensional map of the combined influence of selective cutting intensity, felling tree volume per stem, and stand density on the damage rate of residual trees

The three-dimensional response surface map of the residual trees' damage rate in relation to the product of selective cutting intensity, felling tree volume per stem, and stand density was simulated based on the survey data in Table 1 to reflect the combined effect of the three factors on the damage rate of residual trees. As shown in Figure 7, the trend is almost consistent with that in Figure 2, so the theoretical analysis and the experimental validation coincide with each other.

Suggestion for reducing the damage rate of residual trees

According to the above analysis, three suggestions for reducing the damage rate of residual trees are proposed in combination with the established model and the actual chain saw operations in the northeast area of China:

Table 6.—Block grouping for effects of felling stem volume on residual damage rate.

Plot no.	No. of plots	Mean value: Stand density (stems hm^{-2})	Mean value: Cutting intensity (%)	Maximum − minimum: Stand density (stems hm^{-2})	Maximum − minimum: Cutting intensity (%)
A02/A06/A19/A20/A27/A29/A33	7	794	23.41	155	7.94

Table 7.—The revised validation results for the residual tree damage rate model.

	Model	Validation model	Correlation	F value
Damage rate	$R = [a + bqdE(1 - cE)] \times 100\%$	$R = [0.023 + 1.689 \times 10^{-3} \times qdE(1 - 1.27 \times E)] \times 100\%$	0.893	66.818

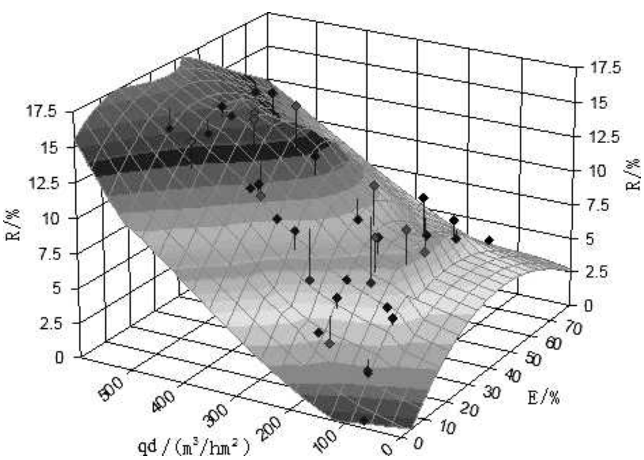

Figure 7.—Relationships among residual tree damage rate (R), selective cutting intensity (E), felling tree volume per stem (q), and stand density (qd).

1. Control the felling direction of trees with a systematic approach according to the conditions of the harvest site, and the requirements of operation process as well, to make full use of space that has no residual trees.
2. Conduct cutting operation in nonfrozen seasons to decrease the value of a.
3. Design the cutting intensity (E, q) rationally to be either lower than 20 percent or higher than 60 percent in order to avoid high damage rates of residual stands.

Discussion and Conclusions

In this article we performed theoretical analysis on the factors affecting the damage rate of residual trees and established a mathematical model with respect to the selective cutting intensity, stand density, and felling tree volume per stem to simulate the damage rate. The model was verified and corrected based on the survey data in Dongfanghong Forest Farm, Dailing Forestry Bureau, Heilongjiang Province, China. The verification results show that there is higher correlation between the simulated data derived from the model and the actual survey data. The model is valid and effective in predicting the damage rate of residual trees.

The research showed that the damage rate of residual trees is affected not only by the parameters of natural conditions in the harvested site (stem volume to be felled, stand density, etc.), but also by the operational parameters (cutting intensity, design on the distribution of felling trees, extent of the felling direction control, etc.). Therefore, reducing the damage rate of residual trees requires systematic engineering by both the harvesting operation designers and the loggers in planning and implementing the operation given existing stand conditions. The damage rate of the residual trees increases at first and then decreases with the increase of selective cutting intensity. In this case study, the damage rate approached its highest value when the selective cutting intensity was about 39 percent. With increasing stand density and felling tree volume per stem, the damage rate of residual trees increases linearly. In selective cutting operations, more attention should be paid to the safety of loggers. Technical training for loggers should be strengthened and efforts should be made in research and development of new types of harvesters featuring high efficiency, low consumption, and safe operations to replace manual felling.

Acknowledgments

This study was sponsored by the National Science and Technology Support Program 2006BA-D03A08-05 and the Special Research Fund for Non-profit Forestry Industry—Development of Efficient and Energy-saving Equipment for Forest Management and Utilization (201104007). We appreciate the assistance provided by the Dongfanghong Forest Farm during our data collection.

Literature Cited

Bragg, W. C., W. D. Ostrofsky, and B. F. Hoffman. 1994. Residual tree damage estimates from partial cutting simulation. *Forest Prod. J.* 44(7/8):19–22.

Chen, H. 2003. Optimal model of comprehensive evaluation for selective cutting in evergreen broad leaves forest areas. *Forest Eng.* 19(3):14–16.

Crome, F. H. J., L. A. Moore, and G. C. Richard. 1992. The effects on vegetation of logging virgin upland rain forest in north Queensland, Australia. *Forest Ecol. Manage.* 49(1/2):1–29.

Dong, X., J. Guo, Y. Wu, and L. Jiang. 1995. Study on felling to stander damage. *Forest Eng.* 11(1):4–7.

Dong, X., X. Yang, Y. Zhang, and G. Yang. 2007. Impacts of cutting modes on damage extents of residual trees in Larch plantations. *Northeast Forestry Univ. J.* 35(9):7–8.

Field, D. and A. Granhus. 1998. Injuries after selection harvesting in multi-stored spruce stand—The influence of operating system and harvest intensity. *Int. J. Forest Eng.* 9(2):33–40.

Groot, A. 1995. Harvesting method affects survival of Black Spruce advance growth. *North. J. Appl. Forestry* 12(1):8–11.

Gullison, R. E. and J. J. Hardner. 1992. The effects of road design and harvest intensity on forest damage caused by selective logging: Empirical results and a simulation model from the Bosque Chimanes, Bolivia. *Forest Ecol. Manag.* 49(1/2):1–29.

Hannerz, M. and B. Hanell. 1997. Effects on flora in Norway spruce forests following clear cutting and shelterwood cutting. *Forest Ecol. Manage.* 90:29–49.

Johns, J. S., P. Barreto, and C. Uhl. 1996. Logging damage during planned and unplanned logging operations in the eastern Amazon. *Forest Ecol. Manage.* 89:57–77.

Li, C., H. Zhang, and S. Li. 2008. Discussion on forest harvesting techniques for the forest from conversion of cropland. *Forest Eng.* 24(9):6–9.

Ma, L. 1965. Preliminary study on reasonable logging. *Northeast Forestry Univ. J.* 4:97–109.

Mo, R. 1981. Promotion on the productivity of forest based on natural laws. *Res. Timber Harvest.* 3:1–5.

Pinard, M. A. and F. E. Putz. 1996. Retaining forest biomass by reducing logging damage. *Biotropica* 28:278–295.

Qiu, R. and X. Zhou. 1997. The influence of different intensity of selective felling on residual trees and seedlings. *Forest Eng.* 13(3):5–7.

Shi, J. and S. Xiao. 2001. Ecological Harvesting System. Northeast Forestry University Press, Harbin, Heilongjiang Province, China. 450 pp.

Wang, L., X. Yang, and C. Meng. 2005. Forestry Operations and the Environment. Northeast Forestry University Press, Harbin, Heilongjiang Province, China. 360 pp.

Wasterlund, I. 1992. Damages and growth effects after selective mechanical cleaning. *Scand. Forestry Res.* 3:259–272.