

Log Damage and Value Loss Following Motor-manual Tree Harvesting in the Hyrcanian Forest, Northern Iran

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Abstract

Damage is often seen as an important consideration when conducting partial harvests in hardwood stands. Damage to harvested logs, especially hardwood saw and veneer logs can be an even more important concern relative to value loss associated with log degradates. The objectives of this study is to determine damage type, to quantity of the log damage volume and value loss throughout the tree felling process. The log damage and value loss were examined by felling function, species, and damage type, in Kheyroud Forest in the Hyrcanian Forest of Iran. To estimate wood value loss following small-scale tree felling, a total 206 beech and hornbeam trees were measured, and four types of damage recorded: split damage, gouge damage, slab damage and scrape damage. Volume and value losses of damaged logs were significantly sensitive to tree species and tree diameter. The total value of logs damage was calculated as 46.87 m³ or 0.6 m³/ha (5.2%) for all trees. Slightly over half (51.6%) of the volume loss was from woody tissue damage caused by splintering or breakage. Value loss associated with splits was 32.5%, and value loss associated with high stump was 9.9%. Slabs damage caused a small amount of average volume loss per damaged log. Splits damage caused the greatest value loss to logs (183.3 USD per ha). Breakage damage caused losses of 165.3 USD per ha for the damaged logs while high stump was result 92.6 USD per ha in value loss.

Keywords: Motor-manual tree felling, Wood value loss, Log damage, *Fagus orientalis*, *Carpinus betulus*

1. Introduction

Having information about the quantity and quality of wood products in forest harvesting is a powerful tool to determine the optimal management of a forest. Estimating the amount of wood from logging operations in forest management is one of the major tasks in wood products market management. By improving quality of logs arriving at sawmill, a greater value can be achieved from individual sawlogs through increasing the recovery of timber from the log. Damage is often seen as an important consideration when conducting partial harvests in hardwood stands, because excessive damage to residual trees will reduce the potential value of the residual stand. Damage to harvested logs, especially hardwood saw and veneer logs, can be an even more important concern relative to value loss associated with log degrade (Wang et al., 2004). Damage to hardwood saw logs can be caused by the felling, skidding, bucking, decking, loading and unloading stages of the timber harvesting process. Damage takes place as physical wounds that detract value from the harvested log. Manual operating systems cause more damage than mechanized harvesting systems to harvested logs, and

most of this damage is from felling by motor manual (Greene and McNeel, 1987). The increase in use of mechanized harvesting systems has led to problems of log damage, including butt pull, log splitting during handling and cross cutting, and crushing of the log. However, it has been reported that some mechanized harvesting operations have greatly reduced the incidence of log damage due to mechanical handling.

Hardwood sawlog damage occurs at all processing points in the harvesting and processing system prior to presentation at the saw bench. Damage occurs on butt logs during felling and on subsequent logs cut further up the stem. Damage includes torn wood fibres and the splitting of stems and logs during felling (capping, slabbing, splitting, shake, shatter and fracture), snagging (shatter, fracture), cross cutting (slabbing, spiking) and transport (shatter, spiking, quartering), and includes internal damage to wood structure during falling and processing (Connell, 2003). During falling enormous stresses can be produced as the tree weight and natural stresses (stresses caused by the 'lean' of a tree, disproportionate crown size, wind effect) are transferred

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to the ‘‘hinge’’ wood during cutting. The main factors in the harvested coupe that can affect the amount and severity of log damage are the stand characteristics – which affect the ease and efficiency of harvesting. These include relative density of harvestable sawlogs, tree size, tree lean, terrain condition (steepness of slope, rocky and steep terrain), ground Debris, and weather factors (snow, frost, wind).

Gerasimov and Seliverstov (2010) studied the industrial round-wood losses associated with harvesting systems and found that mechanical damage (torn and loosened grain, cuts in stemwood, and gouges made by grapples), processing defects (branches, log end splits and cracks) and contamination with dirt were the most frequent types of damage. Unver and Acar (2009) studied log damage and quantity losses during ground base skidding and developed damage prediction model. Marshall et al. (2006) developed a simulation model to estimate the value loss caused by measurement errors and found that between 3% and 23% of the potential value were losing. Nuutinen et al. (2010) studied the log damage caused by harvester head.

Some log damage can be controlled and substantial gains in potential value can be achieved through a log quality control system (Wang et al., 2004). Murphy and Twaddle (1985) reported that nearly 40% of the standing value of a tree could be lost through degradation during the harvesting process (Vanderberg, 2002). McNeel and Copithorne (1996) found that extent of breakage varied between tree species. Han and Renzie (2005) found that both feller-buncher and chainsaw felling methods resulted in lower stumps as the average stump diameter increased. These authors found that mechanical felling resulted in lower stumps, by an average of 5.5 cm, relative to chainsaw felling, but stump height was significantly affected by species, slope, and average stump diameter.

Damage to the butt log has the potential to incur the greatest loss in both volume and value. McMorland and Guimier (1984), in British Columbia, undertook a detailed analysis of butt log damage associated with various felling systems and rated the degree of damage to the type of felling system. These authors provided the analysis of stresses in softwood and hardwood species caused during machine felling. Murphy and Buse (1984) measured that approximately 30% of the value lost during the felling process is due to wood loss in high stumps. Wang et al. (2004) observed that volume and value losses of damaged logs were not sensitive to tree species and log size. Gerasimov and Seliverstov (2010) indicated that motor-manual cut-to-length and fully mechanized cut-to-length systems provided the minimum losses and the total annual losses in industrial round wood value were estimated as 1.0 \$ per industrial round wood (m^3).

Wang et al. (2004) found that motor-manual harvesting systems caused more damage to logs than mechanized harvesting systems. These authors also

observed that felling resulted in significantly more log damage when compared to skidding, decking, and loading operations. Haynes and Visser (2004) recorded that 15% were under cut and 74% were over length, and also an average value loss of 20.7% was calculated for all five crews during bucking operations. McNeel and Copithorne (1996) indicated that species was a factor in defining the extent of breakage expected during harvest. They found that more brittle species, in this case western red cedar (*Thuja plicata*), exhibited significantly more damage than less brittle species in the same harvest (Vanderberg 2002). Holmes et al. (2002) measured the wood waste for reduced impact logging (RIL) and conventional (CL) operations in eastern Amazon. They also stated that wood waste volume and cost were 6.05 m^3/ha and USD 0.40/ m^3 for typical CL operations and 1.92 m^3/ha and USD 0.09/ m^3 for typical RIL operations. Kizha and Han (2015) studied forest residues recovered from whole-tree timber harvesting operations and resulted that forest residues delivered compared to the estimated amounts of forest residues generated were 70 percent for the shovel logged unit and 60 percent for the cable yarded unit.

Since most of the harvested trees in northern forests have large diameter and can use for veneer, furniture and ply wood Industry, Surface conditions have a key point in the grading of logs. Manual falling of trees is a dangerous operation and a prevalence of injuries and death to manual operators has been a major impetus towards machine harvesting. In Hyrcanian forest, all of the harvesting operations are still solely carried out by manual fallers because of the combination of the timber size, mountainous area, and low investment in forestry sectors which allows for minimal control over directional felling. A few studies on the wood value loss in various stages of operation and various system of harvesting have been conducted in forests of northern Iran. Sarikhani (1972) was estimated the 53% of total harvesting volume has been left by chainsaw felling and processing contained stump-pull, or slabbing or both. Sarikhani (1972) also found that about 15% of the volume of harvested trees were wasted by incorrect methods and equipments that used by workers. Soleimanzade (1987) studied the stump height to reduce waste and value loss during cutting in beech and hornbeam forest trees and concluded that by cutting the tree at the lowest possible compared to common method, volume of wood loss was decreased 2.33% but working time was increased about 8%. Emadi (1997) determined the loss of wood damage by the different functions of the timber harvesting process and stated that log damage during felling, skidding, and decking operations were 14.8%, 7.43%, and 0.21%, respectively. The aims of this study are as follows: to determine damage type, to quantity of the log damage volume and value loss throughout the tree felling process.

2. Materials and Methods

2.1. Study Area

The research was carried out in Compartments 219 and 223 of Namkhaneh district, in Kheyroud Educational and Research Forest Station in the Hyrcanian forest region in the north of Iran. The compartments have an altitude range of 830-1100 m asl, and the forest lies on an southern aspect. Average rainfall ranges from 1420 to 1530 mm/year, and is heaviest in summer and autumn. The forest stand was uneven aged with average growing stock of 403 and 201 m³/ha. This area is dominated by natural forests containing native mixed deciduous tree species including *Fagus orientalis* Lipsky, *Carpinus betulus* L., and *Alnus subcordata*. The silvicultural regime is selection based, with harvesting as a combination of group selection and single tree selection.

2.2. Method

Field data were collected during March of 2011. The combination of timber type and topography limits mechanization to the transport function. Felling, limbing, topping, and on-site processing trees are motor-manual (Jourgholami, 2012). In compartment no. 219, totally 153 trees (3 trees per hectare) have been marked and volume of these trees were 720 m³ (13 m³/ha). In compartment no. 223, a total of 161 trees (6 trees/ha) were marked and volume of these trees was 600 m³ (27 m³/ha). The average slope was an important factor in choosing the harvest sites. Site information includes the site name, tree marking number, site slope in percent, site aspect in degrees, tree diameter in cm, and tree volume in m³.

In order to determining measurable damage sustained and commercially important hardwood logs value loss, 206 trees in beech and hornbeam trees were measured during motor-manual tree felling operation. For each log, measurements were made of large end

diameter, small end diameter, length, species, damage type, damage location slope, damage dimension and log grade, and comments about factors that caused damages (following Vanderberg, 2002). Large end diameter and small end diameter were measured in inches within 5 cm diameter classes. Length of each saw log was measured in cm. Damage type was recorded as the type of log damage sustained, if any. These authors recorded four types of damage:

1. Splintering or breakage damage – damage that occurred from any of the harvesting functions that resulted in a portion of the log being broken and crushed (Figure 1a).
2. Stump height – High stumps are considered to be the result of poor felling practices, and requires stump height to be lower than 20 cm for all harvest sites (Figure 1b).
3. Slab damage – damage that occurred from any of the harvesting functions that resulted in a portion of the log being split from the main stem and discarded (Figure 1c).
4. Split damage – damage that occurred from chainsaw felling function that resulted in a portion of the log being split in two yet still attached to the main stem (Figure 1d).

In this study the volume of wood damage was calculated by using Huber's formula ($V=g_m*L$), where, V is volume of logs in m³, g_m is basal area in the average of logs in square metre and L is length of logs in metre. In this research, the rot of logs and fractures due to this factor was not considered.

In estimating value loss associated to log damage, sale price of timber at depot (reported in Table 1) was applied to volume loss across species and wood products. Wood products were grouped according to dimension and superficial condition.



Figure 1. Damage type was recorded as the type of damage; splintering or breakage damage (a), stump height (b), slab damage (c) and split damage (d)

Table 1. Hardwood log prices by species and product types in the depot Kheyroud Forest in 2011 (USD/m³)

Species	Wood Product type			
	Log	Pulpwood	Sawn lumber	Fuelwood
Beech	180	70	170	20
Hornbeam	100	60	90	20

3. Results

DBH of felled tree ranged from 20 to 130 cm and averaged 68 cm while volume per felled tree was between 0.2 and 29.7 m³ with an average of 6.6 m³ and the average of slop near the stump of marked trees was 24%. Totally 206 trees were measured that 74 trees were damage during felling by chainsaw. In the other hand, 36% of trees were damaged by four grades of wood loss during chainsaw felling. From all damaged trees, 55 trees were in beech trees and 151 trees were from hornbeam trees. Beech and hornbeam had average value losses of 42% and 34% per tree respectively (Table 2). Log damage volume varied from 0.05 to 3.85 m³ per tree with an average of 0.53 m³ per tree.

Total volume for both beech and hornbeam were 256.08 and 646.06 m³ respectively. Beech and hornbeam had total value losses of 27.16 m³ (0.35 m³/ha) and of 19.7 m³ (0.25 m³/ha) respectively. About 11% of the volumes of beech trees were damaged during felling operation while the amount of damage for Hornbeam trees was about 3%. In the other hands, beech and hornbeam had total value losses of 58% and 42% respectively (Table 3).

Damage volume loss by damage type suggests the majority of woody tissue damage is caused by splintering or breakage with 51.6% (Table 3 and Figure 2). High stump height (9.87%) and slab damage (4.42%) caused a small amount of average volume loss per damaged log for both beech and hornbeam. Value loss associated with splintering or breakage was 24.39 m³ (0.31 m³/ha), value loss associated with split was 15.21 m³ (0.2 m³/ha), value loss associated with high stump height was 4.63 m³ (0.06 m³/ha), and value loss associated with slabs was 2.07 m³ (0.03 m³/ha).

Damage volume loss by damage type and species showed different trend. In hornbeam trees, volume loss per log showed the most of the woody tissue volume loss occurring to splintering or breakage damage which had a value of 78.17% (Figure 3). High stump height and split damage show the least amount of average volume loss per log with values of 7.01% and 5.84%. In contrast, damage volume loss by beech trees suggests the majority of woody tissue damage is caused by split with 51.76%.

Table 2. Percentage of total volume lost per tee and damaged log by site and species

Felling site	Total cutting		Damage and loss		Without damage	
	Number	Volume (m ³)	Number	volume (m ³)	Number	volume (m ³)
No. 219	134	545.8	46	23.38	88	522.48
No. 223	72	356.3	28	23.48	44	332.8
Total	206	902.1	74	46.87	132	855.28

Table 3. Damage and loss of wood volume by tree species and type of damage caused by tree felling

Species	Total volume of cutting (m ³ /ha)	Without damage (m ³ /ha)	Stump height (m ³ /ha)	Breakage damage (m ³ /ha)	Split damage (m ³ /ha)	Slab damage (m ³ /ha)	Total damage volume (m ³ /ha)	Damage ratio (%)
Beech	256.08 (3.28)	228.92 (2.93)	3.25 (0.04)	8.78 (0.11)	14.06 (0.18)	0.51 (0.01)	27.16 (0.35)	11
Hornbeam	646.06 (8.28)	926.36 (11.88)	1.38 (.02)	15.4 (0.2)	1.15 (0.01)	1.56 (0.02)	19.7 (0.25)	3
Total	902.14 (11.57)	855.28 (10.97)	4.63 (0.06)	24.39 (0.31)	15.21 (0.2)	2.07 (0.03)	46.87 (0.6)	5.2

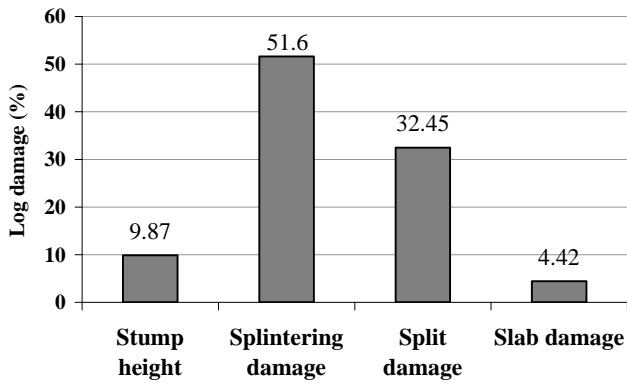


Figure 2. Percentage of log damage by four types of damage in felled tree

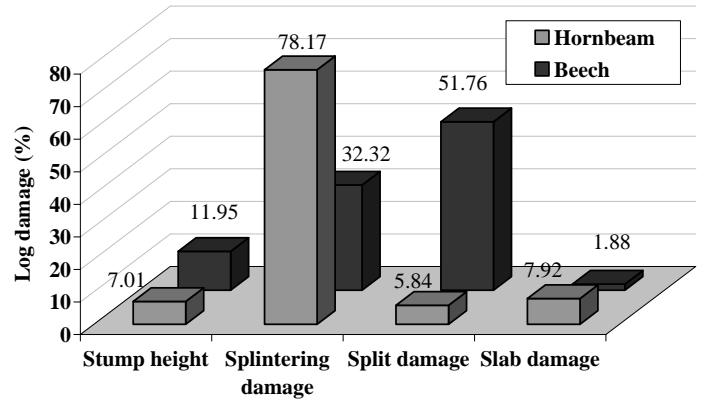


Figure 3. Percentage of log damage by four types of damage and hornbeam and beech

Between the variable factors that measured and wood damage volume, the only relationship between the diameter and the wood damage has been significant. The model of relationship between the diameter of felled tree and the wood loss was employed as an exponential function (Equation 1). In other hand, the total damage volume was best described by DBH. Statistical significance was checked by an F-test of the overall fit and t-tests for individual parameters (Table 4 and Figure 4).

$$Y = 0.0518e^{0.0274x} \quad (1)$$

where,

$$Y = \text{log damage (m}^3\text{)}$$

$$X = \text{tree diameter (cm)}$$

Table 4. ANOVA model of the relationship between log volume damages and felled tree diameter

Source	Sum of square	df	Mean square	F-value	R ² (%)	P-value
Regression	21.8	1	21.8	43.2	37.5	0.000
Residual	36.4	72	0.51			
Total	58.2	73				

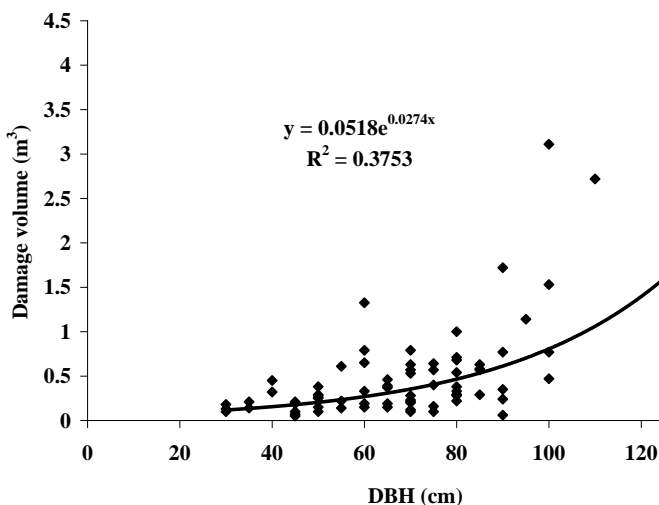


Figure 4. A scatter plot showing the relationship between log volume damages and felled tree diameter

An analysis of variance of damage volume versus log diameter (as depicted in is presented in Figure 4) is presented as Table 4. The coefficient of determination indicates that 37.5% of the total variability can be explained by the model. The F statistic confirms that the model was significant at probability level of 0.05.

A regression analysis with the stepwise method between independent variables (slope at stump area, tree diameter, and tree species) and log damage volume as dependent variable was employed to predict the log damage on the data collected. Stepwise regression analysis has revealed that log damage volume depends on tree diameter and tree species affect (Figure 5) and thus a log damage volume regression model was developed using tree diameter and tree species as independent variables (Equation 2). Statistical significance was checked by an F-test of the overall fit and t-tests for individual parameters (Table 5).

$$Y = -0.0774 + 0.0201X_1 - 0.4572X_2 \quad (2)$$

where,

$$Y = \text{log damage (m}^3\text{)}$$

$$X_1 = \text{tree diameter (cm)}$$

$$X_2 = \text{tree species.}$$

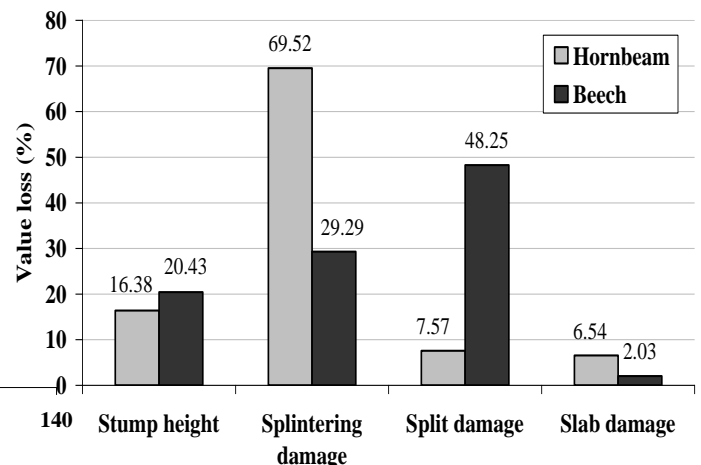


Figure 5. Percentage of value loss of log damage by four types of damage and hornbeam and beech tree

Table 5. ANOVA model of log damage volume regression developed using tree diameter and tree species

Source	Sum of square	df	Mean square	F-value	R ² (%)	P-value
Regression	14.92	2	7.46	32.2	47.5	0.000
Residual	16.44	71	0.23			
Total	31.37	73				

One-way ANOVA was used to test log damage differences on the tree species, tree diameter and stump area slope. The results are summarized in Table 6. Generally, the volume losses of damaged logs were significantly sensitive to tree species (df = 73; F = 8.1; P = 0.01) and tree diameter (df = 73; F = 9.37; P = 0.00), whereas the volume losses of damaged logs did not change significantly with stump area slope (df = 73; F = 0.95; P = 0.49). There were significant differences in damage volume between species (df = 73; P = 0.01).

Regarding appropriate principles to felling tree and skill of felling crew have been result that small amount of wood in the stump was remained as high stump height. Although splintering or breakage damage during felling operation was the highest percentage but should be noted that logs were experiencing this type of damage barely were recovered to the pulpwood or sawn-lumber and optimistically could process to

fuelwood. The other damage types, although removing logs from common logs grading but these could produce sawn-lumber and pulpwood that had added values considering the value losses. Log value loss was determined by their species and wood products. Wood products were based on dimension and superficial condition. In order to determine the exact wood value loss, it was necessary to know that: 1) prior to the logs were damaged, the logs process to which product groups (such as logs, pulpwood, sawn-lumber and fuel wood); 2) after delimiting and bucking operation, which products derived from damaged logs. By considering value loss in wood product prices, total value loss was estimated for each damage type and species.

A whole of damaged wood, due to break the large branches of cut trees, 18.9 m³ (40.4%) of woods were converted to fuelwood if without loss, had become a pulpwood. On the other hand, 6.15 m³ of any kinds of logs were converted to the conversion products such as sawn-lumber and pulpwood. Also, 12.3 m³ (26.3%) of any types of logs were converted directly fuelwood by damage during felling operation. Finally, wood volume loss was multiplied in price of logs, sawn-lumber, pulpwood and fuelwood according to type of products, volume loss and price loss, and then wood value loss was calculated (Table 7).

Table 6. Summary of the effect of species, tree diameter and stump area slope on log damage volume in one-way ANOVA

Factor	Source	Sum of Squares	df	Mean Square	F-value	P-value
Species	Between Groups	3.17	1	3.17	8.1	0.01*
	Within Groups	28.2	72	0.39		
	Total	31.37	73			
Tree diameter	Between Groups	22.73	16	1.42	9.37	0.00*
	Within Groups	8.64	57	0.15		
	Total	31.37	73			
Stump area slope	Between Groups	3.71	9	0.41	0.95	0.49**
	Within Groups	27.66	64	0.43		
	Total	31.37	73			

* Significant at the 0.01 probability level.

** Not significant.

Table 7. Value loss of wood volume by tree species and type of damage caused by tree felling in USD (USD per ha)

Species	Stump height	Breakage damage	Split damage	Slab damage	Total value loss	Value loss percent ratio
Beech	5841 (74.49)	8372 (107.3)	13791 (176.8)	581 (7.4)	28583 (366.4)	80.7
Hornbeam	1380 (17.7)	4524 (58)	503 (6.4)	435 (5.6)	6843 (87.7)	19.3
Total	7221 (92.6)	12896 (165.3)	14294 (183.3)	1016 (13)	35426 (454.2)	-

Damage value loss wasn't significantly different among species ($df = 73$; $F = 0.49$; $P = 0.87$) and tree diameter ($df = 73$; $F = 2.004$; $P = 0.52$). The value loss associated with degrade was 35,426 USD (454.2 USD per ha). Correspondingly, value loss was significantly different among the damage types. Split damage accounted for a total value loss of 14,294 USD (183.3 USD per ha), and was significantly different from all other damage types (Table 7). Splintering or breakage damage had a total value loss of 12,896 USD (165.3 USD per ha), and was significantly different from high stump height damage and slab damage, which had average value losses of 7,221 USD (92.6 USD per ha) and 1,016 USD (13 USD per ha) respectively.

The value loss suffered by the various species followed a slightly different pattern than the total volume loss. Beech showed a total value loss of 28,583 USD (36.4 USD per ha), and hornbeam had 6,843 USD (87.7 USD per ha) worth of damage caused to it. Damage to beech resulted in 58% loss of the volume and 80.7% of log's value loss, while hornbeam showed average value losses of 42% loss of the volume and 19.3% of log's value loss (Fig. 5). In beech logs, the greatest value loss of 13,791 USD, or 176.8 USD per ha, was presented by split damage. Splintering and breakage damage accounted for a total value loss of 8,372 USD, and slab damage had a total value loss of 5,841 USD. For hornbeam logs, the greatest value loss of 4,524 USD was presented by splintering and breakage damage. High stump height and split damages showed total value losses of 1,380 USD and 503 USD respectively. The least amount of value loss occurred by slab damage, with a total value loss of only 435 USD.

4. Discussion

About 5.2% of all observed logs were damaged to some extent in the field study, which could result in losses of up to 46.87 m³ in volume. The majority of the value loss was caused during the felling operation when using a motor-manual harvesting system. A number of related studies returned similar findings (Haynes and Visser, 2004; Wang et al., 2004; Han and Renzie, 2005; Gerasimov and Seliverstov, 2010; Kizha and Han, 2015). The log damage volume was measured in this study was lower than the volume loss that was counted by Emadi (1997) study. High stump height show the least amount of average volume loss per log with values of 0.06%. However, Soleimanzade (1987) stated that log damage due to high stump height was considerable. The proper training of worker in felling operation in recent year was resulted the reduction of wood loss due to stump height in study area. Also, Han and Renzie (2005) found that chainsaw felling can cause stump-pulls, slabs, and unevenness at the bottom of the tree being felled, requiring a further reduction of wood that could potentially be used for solid wood products.

High volume loss in splintering and breakage damage type, On the one hand, due to larger diameter and crowns of hardwood trees and the thick canopy of

deciduous trees were broken and crushed after felling. Also, non-directional felling methods (such as using wedge) and also lack the proper season to tree felling lead to the loss of wood. Although one should not ignore the rough conditions of the study area. The relief of Kheyrud forest was characterized by carbonate rocks (limestone and dolomite) and their numerous karst forms: crests, carks in limestone, under-ground flows and sink hole structure. This karst hole was one of the limiting factors for performing tree felling and logs skidding in Kheyrud forest. In addition to sink holes, terrain slope was another limiting terrain factors for performing timber skidding in the study area. The fulcrum points (rocks, stumps and gullies) which will cause the stem to bend or flex on contacting the ground will maximize shatter and fracture.

All of the reasons of wood loss and damage were recorded during field inventory of felling trees operations. The most frequent cause of wood loss that observed in this study was related to broken branch of thick trees in beech and hornbeam species that this was about 30 m³ (46% log volume loss). The existence of multiple karst hole structure in harvested compartment in Namkhaneh district has led to felling trees associated with some problems and 20% of log damage volume was related to this structure and their roughness that the cutting and felling operation encountered with difficulty. The other reasons for wood loss in order of importance based on the amount of loss caused were: tree felling on uneven and roughness areas, tree felling on the road, tree felling on the other felled trees and timbers, improper cutting technique and high gradient and slope steepness of area. Wang et al. (2004) also state that an important area that needs attention is a harvest site's forest road network. It would be beneficial to determine how damage relates to skid trail density, road capacity, multiple landings and their locations, and length of skid. Along with these factors, terrain slope could be analyzed more closely, especially its correlation with the occurrence of switchbacks that may damage logs.

Due to beech wood products are the higher price of hornbeam logs, damage to beech resulted in 58% loss of the volume and 80.7% of log's value loss, while hornbeam showed average value losses of 42% loss of the volume and 19.3% of log's value loss. Beech presented a significant difference in volume and value loss compared to the hornbeam logs which was in agreement with the results of other researchers (Wang et al., 2004; Unver and Acar, 2009). Results that results from this study are consistent with those of Wang et al. (2004) that found white ash presented difference in volume and value loss compared to the other species. McNeel and Copithorne (1996) indicated that species was a factor in defining the extent of breakage expected during harvest. They found that more brittle species, in this case western red cedar (*Thuja plicata*), suffered more damage than less brittle species in the same harvest. Species such as beech (*Fagus orientalis*) were

regarded as more prone to freeness and splitting and younger regrowth of these species were particularly prone. Wang et al. (2004) also stated that another reason for differences among species could be the time of harvest. Damage volume loss by damage type suggests the majority of woody tissue damage is caused by splintering or breakage with 51.6%. In contrast, Wang et al. (2004) found that damage volume by splits is significantly higher than the other damage types.

5. Conclusion

Tree felling in any direction away from the natural lean applies pressure to the stem and often causes binding of the saw. Actions required to keep the kerf open and force the direction of fall create considerable stresses with the stem and contribute most of the forces causing capping and slabbing. For this reason there is sound ground for scarf cutting all trees to be felled. Directional falling is facilitated by the scarf cut and less forcing is required during the final cutting phase. Avoiding fulcrum points (rocks, stumps and gullies) which will cause the stem to bend or flex on contacting the ground will minimize shatter and fracture. Falling uphill on steeper slopes will minimize impacts and damage and assists to present the butt ends of the logs ready for snigging.

The skill of the chainsaw operator has an important role in the damage to the sawlogs during falling and the other mechanical parts of processing. Experienced operators can foresee likely damage problems for individual trees and minimize the damage. Manual falling of trees is a dangerous and risky operation and the training of working crew was an important role in order to reduce log damage and value loss. In this study, log damage was examined related to two species during chainsaw felling operation. Then further research is needed to determine the effects that other harvesting functions and tree species may have on log damage and value loss.

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