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The Felling of Hung Up Trees—A Work Safety and Productivity Issue

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Received: 17 October 2020; Accepted: 18 November 2020; Published: 20 November 2020

Abstract: Research Highlights: The felling of hung up trees is considered by literature in the field as an activity with a high injury risk. The low work productivity in the felling of hung up trees is wrongly cited by workers in order to justify various more or less safe work techniques. Background and objectives: The purpose of this paper was to determine work productivity in the felling of hung up trees when this activity has a well-defined structure with stages and specific activities that would allow workers to assess injury risk correctly. In addition, this paper aims to identify the moment when workers should give up the manual felling of hung up trees with a hand winch and start using specialized logging equipment. Materials and methods: The research was conducted in the Eastern Carpathians in a spruce (*Picea abies* (L.) H. Karst.) tree stand where clear cutting normally takes place. A single team of workers was used consisting of two chainsaw operators—a main one and a secondary one. This team had a high level of qualification and experience in the operations performed. For the felling of hung up trees, the technique based on rotating the tree around a pivot with a hand winch was used. Time was measured in seconds by using the continuous time study method. Results: The results indicated that work productivity decreases with the number of times the traction line needs to be repositioned. It decreases from 3.477 trees·h^{-1} (in trees where no repositioning is necessary) to 1.402 trees·h^{-1} (when the repositioning takes place twice). In trees that needed the repositioning of the traction line, safety rules were broken in the following ways: crossing over the tensioned cable of the traction line, the main chainsaw operator being positioned inside the triangle formed by the hung up trees and the anchorage points of the pulley and the hand winch as well as the operator being positioned very close to the hung up tree stem base while the latter is being tied. That is why, if the repositioning of the traction line is necessary, the question is—would it be better to give up the manual felling of hung up trees and start using specialized equipment? Conclusion: The felling of hung up trees must be regarded and understood, first and foremost, through the perspective of reducing injury risk and protecting workers. Thus, the work productivity of 3.477 trees·h^{-1} can be considered acceptable for trees that need no extra repositioning of the traction line or when the time consumed does not go over 17 min·tree^{-1}.

Keywords: time study; chainsaw operations; work accident; logging; timber harvesting

1. Introduction

When felling a tree, it sometimes happens that it fails to reach the ground. The tree may be hung up in the crowns of the neighboring trees or it may lean against them. This is referred to as a hung up tree. Trees are hung up as a result of choosing the wrong felling direction, of the tree stand being too thick, of a poor felling technique, as well as because of wind or snow [1,2]. Even the most skillful feller will occasionally be faced with a hung-up tree [3]. Irrespective of the cause, this is an undesired situation which increases injury risk in workers and damages wood quality and the support tree. It also decreases work productivity in felling operations due to the time that is needed for the felling of hung up trees. If a tree is hung up, the main priority should be its felling. A hung up tree represents a high risk of injury both for the fellers and for the other co-workers. A hung up tree should not be left in that position from one day to the next. This is only acceptable if the felling by using manual means is not possible under safety conditions and if there is no appropriate equipment (with winch and cable). In this situation, the dangerous area around the tree must be clearly delineated [2,4,5]. Regarding the high injury risk, Moș [6] stated that out of the total number of accidents occurring in tree felling, delimbing, and cross-cutting, about 41% are accidents taking place in the felling of hung up trees. Likewise, Iftimie [7] showed that 47% of accidents occurring in the previously mentioned activities are produced in tree felling. Peters [8] showed that accidents caused by hung up trees account for 26% of all accidents occurring in tree felling. At present, in the EU there is a joint report for work accidents in the field of forestry and logging so it is difficult to know exactly how many of these accidents occurred in the felling of hung up trees. In 2017, there were 499,720 employees working in the field of forestry and logging in the EU. Out of these, 47,750 (9.56%) were in Romania. Therefore, Romania places second after Poland that has 52,700 employees in these fields [9]. As far as the annual number of work accidents is concerned, this differs depending on the source cited. Thus, in 2017, Romania registered the following number of accidents: 121 according to Eurostat [9], 92 accidents according to INS [10], and 111 according to ASFOR [11]. According to the previously cited source, 22–35% were fatal workplace accidents. As far as the number of workplace fatalities and the number of workplace accidents resulting in subsequent disability are concerned, silviculture and logging placed second, after the construction industry [12]. Following a study conducted in some European countries regarding fatal accidents, Klun and Medved [13] showed that forestry accounts for a relatively high percentage of fatal accidents, with a frequency similar to that of mining and building industries. In many countries, it is widely acknowledged that logging is one of the most dangerous occupations and the felling of trees with a chainsaw is the most dangerous of all logging activities [8,14–16].

All solutions for the felling of hung up trees take into consideration the volume or diameter of the hung up tree [1,2,4]. European qualification standards for chainsaw operators developed by various professional organizations such as Awarding Body Association International (ABA) (European Chainsaw Certificate: ECC2 Basic Tree Felling; ECC3 Advanced Tree Felling Techniques) [17], European Forestry and Environmental Skills Council (EFESC) (European Chainsaw Standards ECS2: Basic Tree Felling Techniques (Small Trees); ECS3: Advanced Tree Felling and Safe Winch Systems (Medium & Large Trees)) [18], National Proficiency Tests Council (NPTC) (002004-City & Guilds NPTC Level 2 Award in Felling and Processing Trees up to 380 mm; 002101-City & Guilds NPTC Level 3 Award in Felling and Processing Trees Over 380mm) [19], etc., offer the following solutions for the felling of hung up trees: (i) lever cant hook or simple lever for hung up trees with breast height diameter (DBH) ≤38 cm; (ii) hand winch for the hung up trees with DBH > 38 cm.

For species of resinous trees with a pyramid shaped crown (spruce, fir, larch, Douglas fir, etc.) it is recommendable that the technique based on rotating the tree around a pivot should be used so that the tree would fall on the crown of the support tree. When the technique of rotating the hung up tree is used (with the felling bar cant hook or the hand winch) the hinge wood is not to be cut fully. A pivot is left in the hinge wood, in the part towards which the tree turns. The tree rotates around the pivot so that it falls over the crown of the support tree in the newly chosen falling direction [2,5].

The felling of the holding tree, the cross-cutting of the stem of the hung up tree, the felling of another tree over the hung up one (tree driving), working under the hung-up tree and climbing the hung-up tree are totally forbidden as solutions for the felling of hung up trees. In these situations, injury risk for workers is extremely high [1,5,20].

Despite all these, imperfect interpretation and a wide variation in chainsaw operator training and certification are both a serious trans-national (regional) and international issue [21]. These authors consider the felling of hung up trees as one of the highest risk activities along with the aerial use of the chainsaw (sectional felling and dismantling) and windblown damage felling. Forest workers who fell trees with chainsaws are perhaps exposed to the greatest risks in the industry. High-risk operations include the felling of hung-up trees, taking care of windblown trees, and cleaning up after forest fires [22].

As far as operations performed with the chainsaw are concerned, the highest number of studies were conducted with respect to felling, delimbing, and cross-cutting. The main purpose of these studies was to determine injury risk and the impact of working conditions on workers' health, on the one hand, [8,15,23–25], and time consumption and work productivity, on the other hand [26–32]. Unlike tree felling, the felling of hung up trees cannot be planned as the situation occurs accidentally. It is an isolated phenomenon that must be regarded as extra work and part of the felling operation. The felling of hung up trees is a particular case of felling and it has not been studied as much as the latter. Therefore, this paper has a novelty character due to the fact that it presents the structure of the felling of hung up trees developed and tested by the authors. This allows a better understanding of injury risk when used in training workers. In addition, increased time consumption and low work productivity in the felling of hung up trees are wrongly used by workers in order to justify various more or less safe work techniques. Robb and Cocking [21] states that chainsaw accidents occur mainly due to taking shortcuts and not complying with safety guidance in order to speed up the job. Moreover, the frequency with which hung-up trees are implicated in fatal accidents suggests they are very difficult to see or the danger is greatly underestimated [8]. The pressure to be highly productive at all costs, sleep deprivation, physical fatigue, and inadequate safety training are also a cause of many fatalities in the logging industry [14]. Thelin [24] states that in forestry many fatalities were caused by a well-known wrong work procedure: when a felled tree did not go down properly, the feller tried to take it down by felling another tree so that it fell on the first, hoping that the force will press down both trees. However, it is actually not possible to predict the movements of both trees. These situations cannot easily be prevented by technical measures.

Therefore, the purpose of this paper was to determine time consumption and work productivity in the felling of hung up trees when the latter takes place by following a specific stage structure and specific activities that are well defined and allow workers to assess accurately the injury risks that they are exposed to. In addition, the paper aims to identify the moment when workers should give up the manual felling of hung up trees with the hand winch and start using tractors or skidders equipped with a winch.

2. Materials and Methods

2.1. Research Venue

The tree stand with western aspect is located in the Eastern Carpathians, part of the Curvature Carpathians at a latitude of 45°45′23.83″ N and a longitude of 26°23′37.32″ E. The altitude is between 1300 and 1400 m, with a land slope of 18° (Figure 1). The tree stand is part of the Forest District of Comandău, forest management unit 93A.

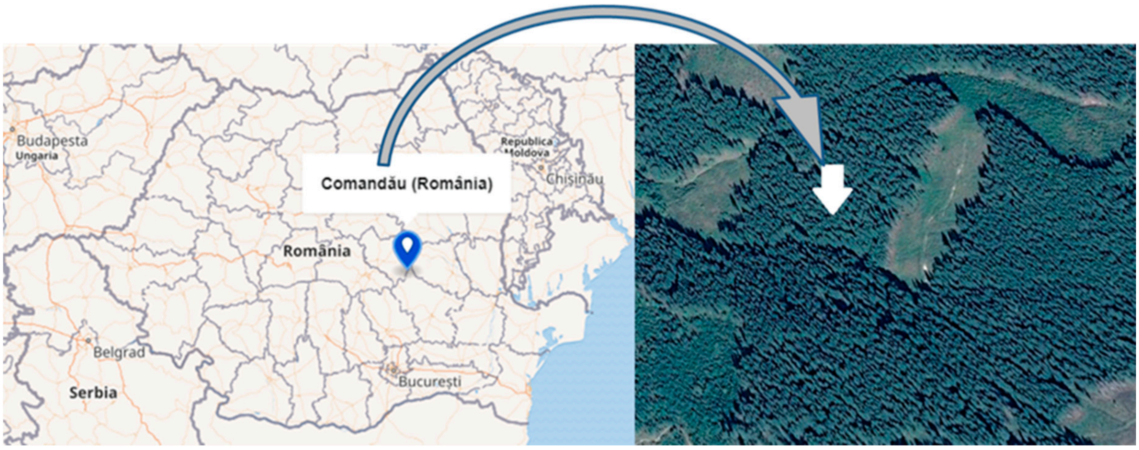

Figure 1. Research venue.

The tree stand where the research was conducted is part of the category of spruce (*Picea abies* (L.) H. Karst) stands, without undergrowth, where clear cutting normally takes place. The characteristics of the tree stand and of the marked trees are presented in Table 1.

Table 1. Characteristics of felled trees and tree stand.

Cutting area surface (ha)	3.25
Total volume (m^3)	1561
Number of trees	983
Stand age (years)	120
Stand consistency	0.8
Pruning (%)	60
Average tree volume ($m^3 \cdot tree^{-1}$)	1.59
Average breast height diameter (cm)	44
Average height (m)	28.0

Operations took place in the first half of June 2020. Air humidity and soil moisture were the main characteristics. They were the result of heavy rains that created the risk of injury through slipping. Visibility in the tree stand dropped below 100 m during foggy periods. There were periods of wind intensification when operations were interrupted because of the high injury risk posed by the potential falling of trees or parts of trees. On 6 February 2020 the wind blew down approximately 75,000 m^3 of wood in this area (when this research was conducted the inventory of felled trees had not been finalized yet), mostly spruce trees aged between 60 and 110 years. The tree stand still has trees whose stability was affected (tilted trees, partially uprooted trees, broken stems, etc.). Wind blows down trees annually in this area. Usually there are just isolated cases but sometimes massive. The year 1995 saw the highest number of windblown trees with approximately 890,000 m^3 of wood being blown down and an area of 10,936.6 ha of forest being affected [33]. Average daily temperature was 10 °C. Working conditions were representative for this area and for the time of the year when the research was conducted. The felling of trees must be interrupted in times of storm, dense fog, icy conditions, heavy snowfall, heavy rain and darkness in order to prevent workplace accidents that may be caused by environmental conditions [34]. Figure 2 presents a bigger picture where working conditions in the tree stand are visible (slope, lack of undergrowth, air humidity, and soil moisture).

Figure 2. Working conditions (alternation of foggy, rainy, and clear sky periods).

2.2. Equipment Used in the Felling of Hung Up Trees

A technique based on the rotation of trees, already mentioned in the Introduction, was used in the felling of hung up trees. Thus, a traction line (TL) containing the following parts (Figure 3) was used: (1) hand winch that develops a traction force (FT) of 1.6 t, equipped with a standard steel cable with the diameter of 11 mm and the length of 20 m and with a grip hook at one end; (2) pulley with the working load limit (WLL) of 4 t; (3) three green flat synthetic slings for anchoring with WLL = 2 t. The entire TL weighs 35 kg.

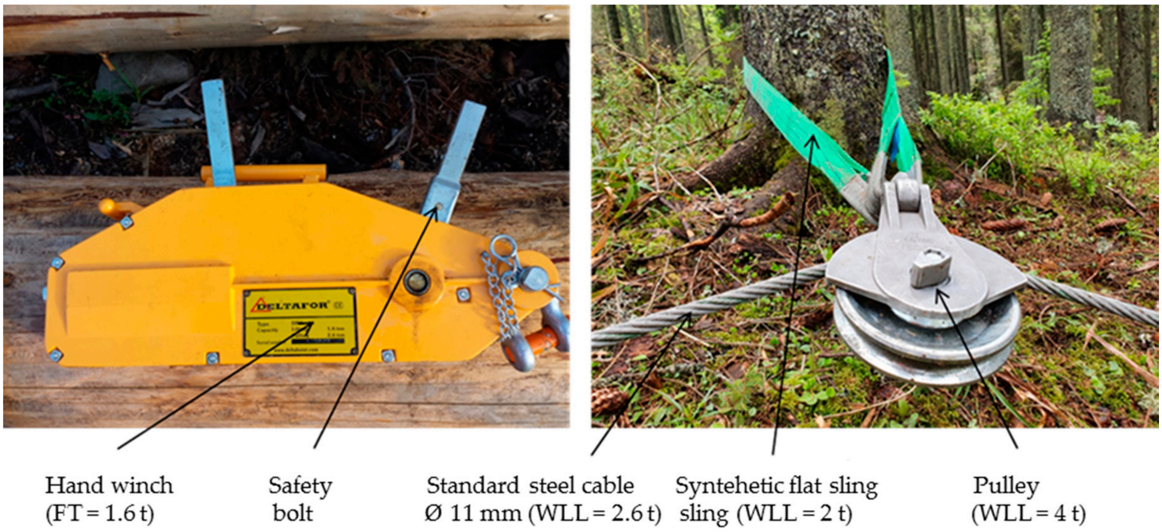

Figure 3. Equipment used in the felling of hung up trees (FT—traction force; WLL—working load limit).

The hand winch—it is used in order to develop the traction force needed for rotating the hung up tree.

The pulley block—it is used in the felling of hung up trees especially in order to position the workers outside the danger zone and also in order to increase the traction force developed by the hand winch. The increase of the traction force varies with the wrap angle between the incoming and departing lines of the pulley block. The multiplication factor has values between 0 at 180° and 2 at 0° [35,36].

The slings—in order to avoid damaging anchor trees, synthetic slings will be used for anchoring the hand winch and the pulley. Synthetic slings are also used in order to tie the hung-up tree.

Sling resistance depends on the way in which they are tied. Basket hitch tying methods in accordance with EN 1492-1:2000 + A1 standards [37], with parallel or $\beta < 45°$ angle variants were used in order to avoid the decrease in WLL of the slings.

The chainsaw—it is used for cutting the hinge wood and the pivot from the stump and stem, for cleaning escape routes and preparing anchorage points (wedge shaped cuts should be made in the stump with the chainsaw in order to avoid the slippage of anchoring slings over the stump). The chainsaw used was Husqvarna 562XP with a weight of 5.9 kg (excluding cutting equipment).

2.3. Field Data Collection

A single team of workers was used consisting of two chainsaw operators—a main one and a secondary one. The main chainsaw operator was responsible for establishing the work technique in the felling of hung up trees. He consulted with the secondary chainsaw operator in order to establish the work technique, assessed risks, chose the felling direction, established the rotation direction of the tree, identified anchorage points and danger zones around these, created the escape route corresponding to the rotation direction of the tree, helped assemble the TL, cut the hinge wood, and helped dismantle and pack the TL. The secondary chainsaw operator was responsible for operating the hand winch and also consulted with the main operator in order to establish the work technique. He prepared the anchorage points and the escape route, helped assemble the TL, operated the hand winch and helped dismantle and pack the TL. This team had a high level of qualification and experience in the operations performed. Both chainsaw operators were trained according to European working standards of ABA International and they both have certificates corresponding to ECC 1, ECC 2 and ECC 3 levels of the same standards [17]. The rotation direction of the tree was chosen by taking into consideration what part of the crown of the support tree is the one that the hung up tree leans on, so that, during the rotation process, the hung up tree does not cross over the stem of the support tree. The following elements were also considered: anchorage possibility of TL, the presence of decay at stump base, knowing the fact that the pivot must be placed in healthy wood, and existing risks (branches/trees or broken parts of trees) so that workers would work outside danger areas.

Working time consumption and its structure were analyzed according to stages and activities. A work stage was considered to be the unitary action that was part of an operation strictly necessary from a technological point of view and mandatory for the normal development of the production process. A series of activities which are not strictly necessary from a technological point of view were added to these stages. Their acceptance was justified by the need to ensure conditions imposed by occupational safety standards, by the peculiar characteristics of activities in forestry and by physiological and ergonomic requirements [31].

The felling of hung up trees was divided into eight distinct work stages as presented in Table 2.

Table 2. Stages in the felling of hung up trees.

Stage	Symbol	Start	End
1. Choice of the felling direction, of the work technique and of the tree rotation direction	ADD	When the main chainsaw operator starts assessing the stability of the hung up tree	When the main chainsaw operator communicates the work strategy to the secondary operator
2. Preparation of anchorage points and creation of escape routes	PPA	When preparation of anchorage points starts	When chainsaw operators finished creating escape routes

Table 2. *Cont.*

Stage	Symbol	Start	End
3. Assembling the TL	MLT	When workers start moving, in the felling area, towards the place where the TL is stored	When the traction line is tensioned in accordance with the rotation direction
4. Cutting the hinge wood	TZF	When the main chainsaw operator starts to cut the hinge wood	When the chainsaw operator finalized the pivot
5. Operating the hand winch	AT	When the secondary chainsaw operator starts to operate the hand winch	When the tree begins to fall
6. Workers' retreat, tree falling and workers' come back	RM	When the tree starts to fall and workers retreat to the escape routes	When the crowns of neighboring trees calm down and workers come back near the stump
7. Cutting the pivot	TP	When the main chainsaw operator starts to cut wood fibers torn from the pivot, the stump and the tree stem	When the main chainsaw operator finished cutting the pivot from the stump and the stem.
8. Dismantling and packing the TL	DAI	When workers start dismantling the TL	When workers moved the TL to the storage place from the felling area

The detailed structure of the working time in the felling of hung up trees according to stages and associated activities is presented in Table 3.

Time was measured in seconds by using the continuous time study method. It was measured with a stopwatch by registering the beginning and the end of each stage. Dendrometric measurements of the hung up trees were made and registered after the felling of these trees with the trees in stable position, on the soil. Tree height, crown length, breast height diameter, and stump diameter were measured with a tape measure. At the same time, the distance from the hung up tree to the support tree was also measured. All measurements were made by the same team of researchers and were registered on field data sheets.

The research methodology emphasizes the factors that might determine variations in time consumption and productivity even in spruce tree stands under relatively uniform work conditions using a single work team. Results obtained do not indicate variations that could be caused by the human factor. It is well known in literature in the field that, under the same working conditions, different work teams have a different work productivity [31]. The operator greatly influences work productivity in most forest works [32,39]. Actually, out of all factors that influence time consumption, the one most difficult to keep constant is the human factor [32,39].

Table 3. Working time structure in the felling of hung up trees (adapted from [38]).

Working Time Structure *				Stages	Activities
WT	PW	MW		4-TZF	- Cutting the hinge wood by leaving a pivot corresponding to the rotation direction; - Cutting a piece of wood from the base of the hung up tree, from the direction opposing the falling direction, in order to grant the guide bar access to the hinge wood—in the case of thick trees.
				5-AT	- Operating the hand winch; - Monitoring the tree movements and the tension of the TL.
		CW		1-ADD	- Analyzing factors that come into play when choosing the felling direction (assessing risks, the stability of the hung up tree and of the support tree, the position of neighboring trees); - Choice of work technique, rotation direction and anchorage points for the hand winch and the pulley; - Identification of danger zones (from the base of the hung up tree, near anchorage points and near the TL).
				2-PPA	- Preparation of anchorage points (cleaning vegetation, obstacles around trees and anchor stumps and also along the TL; making cuts in anchor stumps in order to secure anchor slings); - Creation of new escape routes (both for the main chainsaw operator, in a direction opposing the rotation direction of the hung up tree; an escape route is also created for the worker who operates the winch in order to escape from the range of the lever when the hung up tree falls).
				3-MLT	- Going to the storage place of the TL and taking the latter to the hung up tree and to the anchorage points (on a distance of maximum 30 m); - Assembling and anchoring the TL (installing and anchoring the hand winch and the pulley, tensioning the cable); - Repositioning the TL whenever necessary **; - Tying the hung up tree and tensioning the cable corresponding to the rotation direction.
				6-RM	- Workers' retreat on the escape routes when the tree starts to fall; - Workers wait for the crowns of the neighboring trees to calm down and then come back near the stump.
	SW	PT	RL	8-DAI	- Dismantling and packing the TL; - Taking the TL to its storage place in the felling area (on a distance of maximum 30 m).
		ST	RT	-	- Replacement of the hand winch safety bolt; - Other malfunctions in the TL and anchorage elements.
		AW		7-TP	- Cutting the fibers torn from the pivot area, both from the stump and from the stem.

Notes: * Working time structure: WT—working time; PW—productive working time; SW—supportive working time; MW—main working time; CW—complementary working time; PT—preparation time; ST—service time; AW—ancillary working time; RL—relocation time; RT—repair time. ** The repositioning of the TL should take place if the hung up tree cannot be felled when the TL is first assembled, when the safety bolt shears off or when an unpredictable situation occurs and the work technique must be changed.

2.4. Data Analysis

Statistical analysis involved several steps. A first step consisted in determining sample size. In order to do this, the work team of the company that does work in the felling area were asked the following questions: (1) how many trees do you hang up in one day's work and (2) how many trees do you fell in one day's work. The answer to the first question was about 3 or 4 trees whereas to the second question they answered about 30 trees. Considering that the total number of trees in the felling area was 983, it was estimated that about 10% of these, meaning 98 trees, will be hung up.

Further, the number of necessary measurements was established by using the relation suggested by Giurgiu [40]:

$$n = \frac{u^2 \cdot s_{\%}^2 \cdot N}{N \cdot \Delta_{\%}^2 + u^2 \cdot s_{\%}^2}; \quad (1)$$

where:

- n is the minimum number of felled hung up trees;
- u = 1.96—standard deviation of normal distribution, corresponding to the transgression probability α = 5%;
- s% = 11.21%—variation coefficient of the total working time taken by the felling of hung up trees. It was determined experimentally based on the measures made for the first 10 hung up trees that were felled;
- Δ = ± 10%—limit error;
- N = 98—estimated number of hung up trees in the felling area.

Knowing the parameters that come into play when establishing the number of sample pieces, by applying the above formula, a tree number n = 5 was obtained. As a result that n < 30, the result obtained was considered a temporary value n′, n being recalculated with the same formula where u is replaced by t (t Student distribution) [40]. The value of t is determined according to the number of freedom degrees f = n′ − 1 and according to α. At 4 freedom degrees and α = 5%, it yields that t = 2.776.

By applying the formula again, a number of 9 trees was obtained. A great number of measurements were made (25 hung up trees) in order to normalize the distribution of the values measured and to minimize the Hawthorne effect. The 25 hung up trees were felled as the trees were being hung up by the team that worked in the felling area at that point. Thus, the unbiased character of this research with regard to tree choice was guaranteed. Further on, working time structure in the felling of hung up trees was established, based on the working time consumed for each work stage (Table 4). Work productivity in the felling of hung up trees with the hand winch was determined by using working time as well as the number of trees and their volume.

The inclination angle (α) of the hung up tree (Figure 4) was determined based on the distance (D) between the hung up tree and the support tree and based on the height of the hung up tree (H). The following relation was used:

$$\cos \alpha = \frac{D}{H} \quad (2)$$

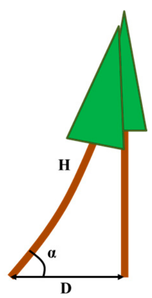

Figure 4. Schematic representation of the calculation method for the inclination angle of the hung up tree (α).

Table 4. The working time corresponding to the stages in the felling of hung up trees and the operational variables measured.

No. of Trees	WT According to Stages								Total WT	DBH	SD	H	LC	V	D	α
	ADD	PPA	MLT	TZF	AT	RM	TP	DAI								
-	s	s	s	s	s	s	s	s	s	cm	cm	m	m	m^3	m	(○)
1 [0]	87	200	387	117	78	48	38	298	1253	29	39	26	6	0.793	5.71	77
2 [0]	98	128	350	125	91	45	39	356	1232	28	38	30	15.5	0.883	4.54	81
3 [0]	56	91	404	134	84	73	27	267	1136	22	29	24.5	11	0.458	5.78	76
4 [0]	63	124	301	121	100	62	50	276	1097	32	38	28	13.5	1.020	3.43	83
5 [2]	78	82	1025	127	780	67	38	371	2568	44	52	29	15	1.820	4.70	81
6 [0]	90	141	362	98	150	45	56	365	1307	33	40	29.5	15	1.145	3.55	83
7 [0]	78	99	345	105	96	67	45	376	1211	29	36	28	10	0.863	4.61	81
8 [1]	110	110	685	170	480	59	54	310	1978	46	37	29.5	14	1.408	3.95	82
9 [0]	68	64	312	95	24	59	34	320	976	32	39	24.5	11	0.874	5.23	78
10 [0]	75	45	289	75	31	54	35	333	937	34	38	25	9.5	0.989	3.59	82
11 [0]	54	129	296	76	15	48	39	354	1011	38	44	25.5	9	1.220	4.68	79
12 [0]	42	135	312	101	47	39	30	365	1071	32	38	26	11	0.936	4.63	80
13 [0]	59	35	298	125	22	50	20	345	954	37	42	28	14.5	1.303	4.75	80
14 [1]	58	87	416	100	388	45	42	367	1503	37	46	29.5	14	0.934	4.35	81
15 [0]	56	40	234	119	32	54	23	260	818	40	48	29.5	14.5	1.578	4.94	80
16 [0]	67	58	244	71	48	62	29	316	895	36	45	29.5	14	1.327	4.02	82
17 [0]	70	133	364	107	18	53	20	352	1117	39	46	32	16	1.670	3.95	83
18 [0]	55	48	288	97	30	45	25	355	943	36	42	28.5	14.5	1.273	4.65	81
19 [0]	73	106	259	108	40	48	22	299	955	28	38	27	8	0.779	3.76	82
20 [0]	68	45	267	131	34	52	25	329	951	38	52	28	12	1.365	3.96	82
21 [0]	57	40	245	90	65	46	28	367	938	28	34	27	9	0.779	4.87	80
22 [0]	67	54	275	78	38	39	29	378	958	31	38	27.5	10	0.958	4.74	80
23 [0]	56	28	244	133	45	43	21	299	869	35	42	28	14	1.187	5.21	79
24 [0]	67	35	329	164	41	48	34	385	1103	35	42	27.5	15	1.169	3.98	82
25 [0]	80	35	339	108	51	48	24	363	1048	38	50	28	12	1.365	3.78	82
Total [0]	1486	1813	6744	2378	1180	1128	693	7358	22,780	-	-	-	-	23.934	-	-
Total [1]	168	197	1101	270	868	104	96	677	3481	-	-	-	-	2.342	-	-
Total [2]	78	82	1025	127	780	67	38	371	2568	-	-	-	-	1.820	-	-

Notes: The operational variables measured: DBH—breast height diameter; SD—stump diameter; H—hung up tree height; LC—hung-up tree crown length; V–tree volume; D—distance between hung-up tree and support tree; α—the inclination angle of the hung up tree. [0]—trees that needed no repositioning of the TL; [1]—trees that needed the TL to be repositioned once; [2]—tree that needed the TL to be repositioned twice.

The next step was to determine statistical indicators (mean, median, minimum and maximum values, standard error, standard deviation, and variation coefficient) of working times corresponding to each work stage and of the variables measured in the felling area. The normal distribution of working time was tested by using the Kolmogorov-Smirnov test (IBM SPSS Statistics version 19 was used) for a transgression probability of 5%. Normal distributions were found. Furthermore, the relationships between working time and independent variables were studied by using ANOVA, and simple linear regression. The regression significance was tested with the Fisher test (*F*) while the significance of the independent variable coefficients was tested using the *t* Student test for a transgression probability of 5%, 1%, and 0.1%.

3. Results and Discussion

In the felling area under research, 25 trees were hung up and the whole felling operation of these trees was subsequently analyzed. Working time was analyzed separately depending on the number of times the TL was repositioned in order to fell the trees safely. Thus, no repositioning of the TL was needed for 22 trees, repositioning was necessary once for 2 trees and, there was just one tree that required repositioning twice. The cumulative working time (WT) consumed in the felling of those 22 trees was 22,780 s. WT structure used in this research in the felling of hung up trees is presented in Table 5.

Table 5. WT structure in the felling of hung up trees.

<table>
<tr><th colspan="11">Trees that Needed no Repositioning of TL</th></tr>
<tr><td rowspan="4">No. of trees</td><td rowspan="3">Average tree volume</td><td colspan="9">WT</td></tr>
<tr><td colspan="4">PW</td><td colspan="5">SW</td></tr>
<tr><td colspan="2">MW</td><td colspan="2">CW</td><td colspan="2">PT
RL</td><td>ST
RT</td><td colspan="2">AW</td></tr>
<tr><td>m^3·tree^{-1}</td><td>s·m^{-3}</td><td>%</td><td>s·m^{-3}</td><td>%</td><td>s·m^{-3}</td><td>%</td><td>-</td><td>s·m^{-3}</td><td>%</td></tr>
<tr><td rowspan="3">22</td><td rowspan="3">1.088</td><td>148.66</td><td rowspan="3">15.62</td><td>466.74</td><td rowspan="3">49.04</td><td>307.42</td><td rowspan="3">32.30</td><td>-</td><td>28.95</td><td rowspan="3">3.04</td></tr>
<tr><td>s·tree^{-1}</td><td>s·tree^{-1}</td><td>s·tree^{-1}</td><td>-</td><td>s·tree^{-1}</td></tr>
<tr><td>161.73</td><td>507.77</td><td>334.45</td><td>-</td><td>31.50</td></tr>
<tr><td colspan="2" rowspan="4">Total</td><td colspan="4">s·m^{-3}</td><td colspan="5">%</td></tr>
<tr><td colspan="4">951.77</td><td colspan="5" rowspan="3">100</td></tr>
<tr><td colspan="4">s·tree^{-1}</td></tr>
<tr><td colspan="4">1035.46</td></tr>
<tr><th colspan="11">Trees that Needed Repositioning of TL Once</th></tr>
<tr><td rowspan="4">No. of trees</td><td rowspan="3">Average tree volume</td><td colspan="9">WT</td></tr>
<tr><td colspan="4">PW</td><td colspan="5">SW</td></tr>
<tr><td colspan="2">MW</td><td colspan="2">CW</td><td colspan="2">PT
RL</td><td>ST
RT</td><td colspan="2">AW</td></tr>
<tr><td>m^3·tree^{-1}</td><td>s·m^{-3}</td><td>%</td><td>s·m^{-3}</td><td>%</td><td>s·m^{-3}</td><td>%</td><td>-</td><td>s·m^{-3}</td><td>%</td></tr>
<tr><td rowspan="3">2</td><td rowspan="3">1.171</td><td>485.94</td><td rowspan="3">32.69</td><td>670.40</td><td rowspan="3">45.10</td><td>289.09</td><td rowspan="3">19.45</td><td>-</td><td>40.99</td><td rowspan="3">2.76</td></tr>
<tr><td>s·tree^{-1}</td><td>s·tree^{-1}</td><td>s·tree^{-1}</td><td>-</td><td>s·tree^{-1}</td></tr>
<tr><td>569.00</td><td>785.00</td><td>338.50</td><td>-</td><td>48.00</td></tr>
<tr><td colspan="2" rowspan="4">Total</td><td colspan="4">s·m^{-3}</td><td colspan="5">%</td></tr>
<tr><td colspan="4">1486.42</td><td colspan="5" rowspan="3">100</td></tr>
<tr><td colspan="4">s·tree^{-1}</td></tr>
<tr><td colspan="4">1740.50</td></tr>
</table>

Table 5. *Cont.*

Trees that Needed Repositioning of TL Twice										
No. of trees	Average tree volume	WT								
		PW				SW				
		MW		CW		PT / RL		ST / RT	AW	
	m^3·tree^{-1}	s·m^{-3}	%	s·m^{-3}	%	s·m^{-3}	%	-	s·m^{-3}	%
1	1.820	498.29	35.32	687.83	48.75	203.82	14.45	-	20.88	1.48
		s·tree^{-1}		s·tree^{-1}		s·tree^{-1}		-	s·tree^{-1}	
		907.00		1252.00		371.00		-	38.00	
Total		s·m^{-3}				%				
		1410.74				100				
		s·tree^{-1}								
		2568								

Note: WT—working time; PW—productive working time; SW—supportive working time; MW—main working time; CW—complementary working time; PT—preparatory time; ST—service time; AW—ancillary working time; RL—relocation time; RT—repair time.

Work productivity in the felling of spruce hung up trees with the hand winch was of:

- 3.782 m^3·h^{-1} or 3.477 trees·h^{-1} (volume of the average tree was 1.088 m^3) for trees that needed no repositioning of the TL;
- 2.422 m^3·h^{-1} or 2.068 trees·h^{-1} (volume of the average tree was 1.171 m^3) for trees that needed the TL to be repositioned once;
- 2.552 m^3·h^{-1} or 1.402 trees·h^{-1} (tree volume was 1.820 m^3) for the one tree that needed the TL to be repositioned twice. WT structure according to time elements is presented in Figure 5.

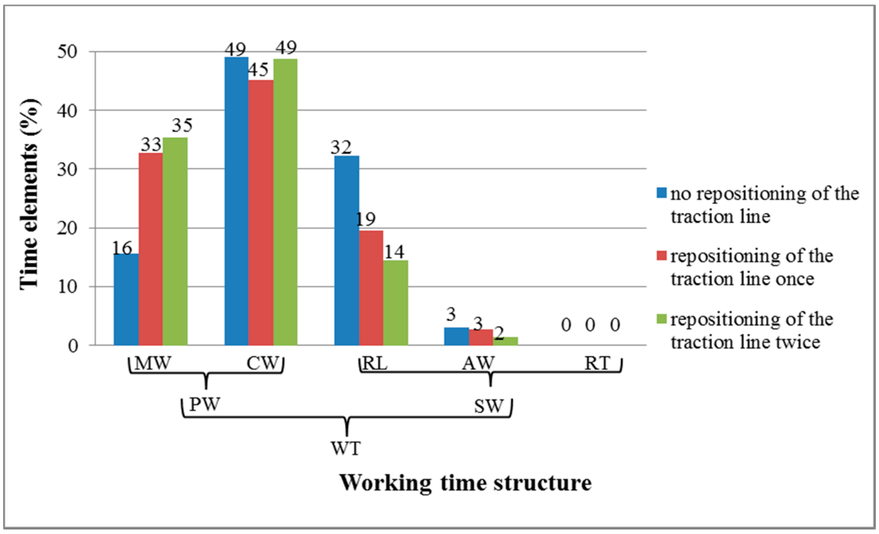

Figure 5. WT structure in the felling of hung up trees according to time elements: WT—working time; PW—productive working time; SW—supportive working time; MW—main working time; CW—complementary working time; RL—relocation time; AW—ancillary working time; RT—repair time.

One can notice that productive working time (PW) prevails. This increases with the number of times the repositioning of the TL is necessary—from 64.66% (in the case of trees where no repositioning is necessary) up to 84.07% of WT for the tree that needed the TL to be repositioned twice. This increase is determined by the increase in the working time used for the MLT stage and for the repositioning of the TL. In the case of working time for supportive activities (SW), the time element for repairing (RT) is null. This does not mean that the shearing of the safety bolt or some other sort of malfunction may not take place in the felling of hung up trees. However, such a thing did not happen in the case of the 25 trees under research. If the shearing of the safety bolt should take place, the average time for its replacement is about 10 min (it was measured separately in the field) when there is a spare safety bolt and necessary tools (mandrel for removing the sheared safety bolt, hammer or axe) for its replacement in the felling area. Other types of malfunction that may occur are the following: breaking of the anchor/tying slings, breaking of the grip hook or of the eyelet that is used to attach it to the main cable, slipping of the slings over the anchor stumps, problems with the hand winch traction system (in which case the hand winch must be replaced), abnormal sounds, etc. If such problems should occur, a correction of the WT is necessary by adding the working time literally consumed for fixing each problem.

WT consumption in the felling of hung up trees according to stages is presented in Figure 6.

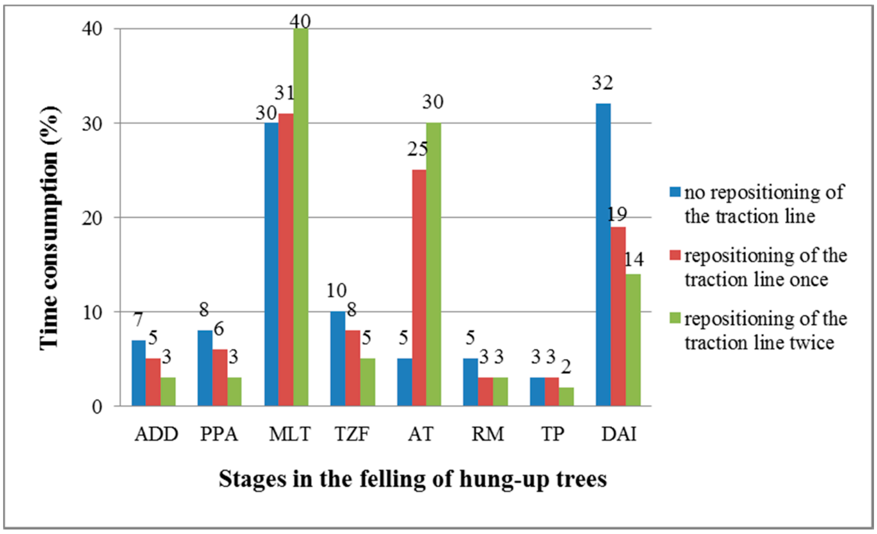

Figure 6. Working time consumption in the felling of hung up trees according to stages: ADD–choice of the felling direction, of the work technique and of the tree rotation direction; PPA–preparation of anchorage points and creation of escape routes; MLT–assembling the TL; TZF–cutting the hinge wood; AT–operating the hand winch; RM–workers' retreat, tree falling and workers' come back; TP–cutting the pivot; DAI–dismantling and packing the TL.

It is to be noted that stages MLT and DAI have the greatest share (62% in trees that required no repositioning of the TL). These stages include activities that involve the movement of the TL from the storage place to the anchorage points, its assembling process, and, following the felling of hung up trees, its packing and movement back to the storage place situated at a distance of maximum 30 m. Both chainsaw operators have an equal share of participation in these stages as the TL is made out of the hand winch, cable, operating lever, pulley, and three anchorage slings. All of these weigh 35 kg. If he distance from the hung up tree to the storage place is above 30 m, then the share of time elements CW and PT (RL) must be adjusted with the time needed for moving on that respective distance. The conditions in which the movement takes place must be taken into consideration—slope, obstacles such as: wood debris, undergrowth, seedlings, rocks, swamps, etc.

The number of times the repositioning of the TL takes place determines an increase in the working time corresponding to the AT stage. This increased from 54 s·tree^{-1}, in trees that needed no repositioning of the TL, to 434 s·tree^{-1} in trees that needed the repositioning once and it reached 780 s·tree^{-1} in the tree that needed the repositioning of the TL twice. Even in trees that required no repositioning of the TL, the variation coefficient of T-AT (62.48%) (Table 6) indicates a strong variation caused by the specific conditions under which the tree was hung up (how much the crown of the hung up tree is entangled in the crown of the support tree/trees, the position of the neighboring trees and the form of their crowns—flag or pyramid form). At the same time, the number of times the repositioning of the TL takes place may determine an increase in the working time corresponding to the PPA stage. Thus, depending on the working conditions in the felling area, the rethinking of the work strategy might be necessary along with the preparation of extra anchorage points or the creation of extra escape routes. Moreover, the variation coefficient of T-PPA (58.31%) (Table 6) supports the previously mentioned facts. There are situations in which the preparation of the place is not really necessary (the ground is clean, there are no obstacles and anchoring trees are present). Sometimes, the preparation of a single tree or of two trees is necessary or that of a stump or of two stumps for the anchoring process. T-TP (31.21%) varies according to the necessity of cutting wood fibers only from the stump or only from the stem or from both. The variation coefficients of the other working times corresponding to the other work stages vary between 11–21, the variation being considered normal for the characteristic studied. The total WT in the felling of hung up trees has a variation coefficient of 12.82%. Therefore, it suggests a compensation of the variation of WT according to stages.

Table 6. Statistical indicators of the variation of working time corresponding to the stages in the felling of hung up trees and of the operational variables measured.

Working Time	Mean	Median	Minimum	Maximum	Standard Error	Standard Deviation	Variation Coefficient (%)
Statistical indicators of working time (s) corresponding to the stages in the felling of hung up trees							
T-ADD	67.55	67.00	42	98	2.85	13.39	19.82
T-PPA	82.41	61.00	28	200	10.25	48.06	58.31
T-MLT	306.55	299.50	234	404	10.39	48.74	15.90
T-TZF	108.09	107.50	71	164	4.89	22.96	21.24
T-AT	53.64	43.00	15	150	7.14	33.51	62.48
T-RM	51.27	48.00	39	73	1.86	8.72	17.02
T-TP	31.50	29.00	20	56	2.10	9.83	31.21
T-DAI	334.45	348.50	260	385	8.00	37.51	11.21
WT	1035.46	993.5	818	1307	28.29	132.71	12.82
Statistical indicators of V (m^3), H (m), LC (%), DBH (cm), SD (cm), D (m), and α (°)							
V	1.088	1.082	0.458	1.670	0.061	0.29	26.71
SD	40.82	39.50	29.00	52.00	1.13	5.28	12.93
DBH	32.95	33.00	22.00	40.00	0.99	4.54	13.79
H	27.61	28.00	24.50	32.00	0.40	1.88	6.80
LC	44.32	44.90	29.63	54.55	1.56	7.13	16.09
D	4.47	4.62	3.43	5.78	0.14	0.68	15.19
α	80.59	81	76	83	0.41	1.92	2.38

Notes: Working time corresponding to the stages in the felling of hung up trees: T-ADD—working time corresponding to ADD stage; T-AT—working time corresponding to AT stage; T-DAI—working time corresponding to AT stage; T-MLT—working time corresponding to MLT stage; T-PPA—working time corresponding to PPA stage; T-RM—working time corresponding to RM stage; T-TP—working time corresponding to TP stage; T-TZF—working time corresponding to RM stage; The operational variables measured: V—tree volume; SD—stump diameter; DBH—breast height diameter; H—hung up tree height; LC—hung-up tree crown length; D—distance between hung-up tree and support tree; α–the inclination angle of the hung up tree.

The main statistical indicators of the variation of WT according to stages and of the operational variables measured for the trees that needed no repositioning of the TL are presented in Table 6

The need to reposition the TL must be regarded by the chainsaw operators as a warning because it creates frustration while the physical effort increases significantly. Hence, the tendency to work in dangerous areas that leads directly to an increased injury risk. The previously mentioned details are the main factors causing fatalities [14]. A number of situations when safety rules were broken were identified in trees that needed the repositioning of the TL. These are the following: crossing over the tensioned cable of the TL; the main chainsaw operator being positioned inside the triangle formed by the hung up tree, the anchorage point of the pulley, and that of the hand winch and the operator being positioned near the stem base of the hung up tree while the latter is being tied. That is why, if the TL needs to be repositioned a second time to fell a hung up tree, the logical question is—would it be better to give up manually felling the hung tree and resort to specialized equipment with a winch instead (tractor or skidder)? Under these circumstances, the danger area around the tree should be delineated and the team of workers should continue work at a distance equal with at least two tree heights.

One must not understand that the felling of hung up trees by using the tractor or skidder does not involve risks. It is well known that the work speed of the winch of the tractor is much higher than that of the hand winch. The tractor rips off the tree and there is the risk that the operator who ties the hung up tree might be injured. In the felling of hung up trees by using a tractor, the hinge wood should be fully cut as there is the risk that the hung up tree might slip over the stump at any point. If the crowns of the hung up trees and the support trees are very much intertwined, there is the risk of the support tree breaking or being uprooted and the trees being pulled over the equipment. In order to reduce injury risk, the tractor must be at a distance of at least two tree heights from the hung up tree, the pulley must be used, and there should be communication and perfect synchronization between the actions of the chainsaw operator and those of the tractor operator and the operator who ties the tree. When the hand winch is used for the felling of hung up trees, the movements for tensioning the cable are slow which allows well trained workers to notice the possible malfunction of the TL and anticipate the movements of the hung up tree.

The twenty-two trees that needed no extra repositioning of the TL, as well as the two trees that needed the repositioning once had a volume between (0.458; 1578 m^3·tree^{-1}). This was smaller than the average volume of the trees from the felling area that was 1590 m^3·tree^{-1}. The trees with a bigger volume are not normally hung up. Usually, they manage to get through the crowns of neighboring trees and fall on the ground. Moreover, in isolated cases, when the felling direction was wrongly chosen by the chainsaw operator, these trees break the top of the support trees and even uproot them. There are situations when the top of the felled tree is broken and it is thrown in a direction opposing the felling direction. A high risk of injury for the chainsaw operator occurs in these situations.

When trees with a big volume are hung up, such as the case of the tree that needed the TL to be repositioned twice (1820 m^3·tree^{-1}), it could be said that usually these trees lean on more support trees or they get caught between them. In such cases, an adaptation of the work technique to the specific conditions is necessary. For example: the repositioning of the TL, a change in the rotation direction of the tree, or pulling the respective tree out of the crowns of the support trees or out of the trees among which it gets caught. All these require intense physical effort, and still, sometimes, the felling of the hung up tree is not possible. There are trees for which the use of specialized logging equipment with a winch and cable is recommended. The manual felling of hung up trees takes a lot of time—2568 s·tree^{-1} (42.8 min) in the case presented in this paper—that leads to low work productivity of only 1402 trees·h^{-1}.

In all cases analyzed, trees were hung up when the distance between the hung up tree and the support tree was below 5.78 m, at an inclination angle (α) of the hung up tree between [76°; 83°]. The importance of the angle at which the tree was hung up is given by an accurate estimate of the direction in which the tree falls. The smaller the inclination angles are, the more easily it is to estimate the falling direction (usually it is the same as the inclination direction of the hung up tree, to the side of the support tree crown). Large angles, associated with big heights of hung up trees, may lead, at the moment of rotation, to breaking the pivot and the falling of hung up trees from the stump. They may also determine big lateral deviations from the falling direction caused by the constant pushing of the hung up trees by the support trees. No information regarding this was found in the literature in the field. As a result, future research will focus on determining the amplitude of these deviations. Therefore, the inclination angle of the hung up tree may become an indicator of injury risk and of accurate estimation of safety areas and distances.

Tree size, usually expressed by their volume or their DBH, is one of the main characteristics that influence time and work productivity both in the felling of trees and in processing them in the felling area [26,31,32,41–43]. The correspondence between WT and the independent variables measured and mentioned in Table 1 was tested in this paper by using simple linear regression. A moderate intensity correlation (r = 0.43) was determined between working time and DBH (Table 7). Even under these circumstances, DBH can account for at most 19% of WT variation (R^2 = 0.19). For the other variables in this study, the results of the simple linear regression analysis are presented in Table 8. It can be noticed that no correlations between working time and the independent variables in this study could be validated statistically.

Table 7. Linear regression analysis of the WT consumed for felling of hung-up trees in relation to DBH.

ANOVA				Significance of Variable Coefficient				
R^2	Standard Error	Degrees of freedom	F	Variable	Coefficient	Standard Error	t Statistic	p–value
Simple linear regression analysis of WT in relation to DBH								
0.19	122.668	Regression 1	4.580 *	Constant	1452.042	196.399	7.393	-
		Residual 20		DBH	−12.555	5.866	−2.140	<0.05 *

Note: Asterisks denote F significance and significant correlations: 0.01 < p-value * < 0.05.

Table 8. Analysis of the simple correlation coefficient and of the significance of test F.

Independent Variable	ANOVA		
	r	F	p-Value
V	0.34	2.620	>0.05
SD	0.34	2.541	>0.05
H	0.08	0.138	>0.05
LC	0.06	0.074	>0.05
D	0.02	0.012	>0.05

Note: Independent variables: V—tree volume; SD—stump diameter; H—hung up tree height; LC—hung-up tree crown length; D—distance between hung-up tree and support tree.

By analyzing the work technique and the structure of the felling operation, it can be noticed that stages and activities are defined in such a way as to meet, first and foremost, the need to provide protection to operators by accurately identifying injury risks. Two stages are influenced by tree size; namely, the TZF and the AT stage. Cumulated, these stages account for 15% of WT. T-TZF (10% WT) is influenced by tree size because the hinge wood is longer and it takes more time to cut it. According to Câmpu [2], the length of the hinge wood must be of at least 80% of the stem diameter in the cross-cutting area. DBH variation coefficient of approximately 13% shows a low variation in diameters which may explain the fact that no significant correlation could be identified between T-TZF and DBH. Another cause of the T-TZF variation could be represented by the need to make some extra cuts, in the case of thick trees. These cuts would make it easier to see the hinge wood and they would grant the guide bar access to the hinge wood (for example removing a piece of wood from the base of the hung up tree from the part opposing the falling direction). T-AT (5% WT) may be influenced by the weight of the hung up tree and by the specific conditions that made the tree to be hung up. For the felling of big hung up trees, greater traction forces are necessary. Regarding this, ARMEF-CTBA [4] states that, normally, a traction force of 1t is sufficient for the felling of hung up trees with the hand winch.

The felling of hung up trees is considered to be one of the most dangerous activities. First and foremost, it must be regarded and understood from the perspective of the need to reduce injury risks and protect workers. Thus, the work productivity of 3477 trees·h^{-1} may be considered acceptable in the case of trees that need no repositioning of the TL or when it does not take more than 17 min·$tree^{-1}$ to fell a tree. This time (17 min·$tree^{-1}$) does not include the time needed (about 11.6 min·$tree^{-1}$) [31] for activities that normally take place in the felling of trees until the moment when a tree is hung up (moving towards the tree to be felled, preparing the workplace, choosing the technical direction and creating escape routes, cutting the sink, making the cut from the part opposing the sink). That is why, the felling of hung up trees must be regarded as extra work that is part of the felling operation and that takes and additional time of 17 min·tree^{-1}.

The technique used in the felling of hung up trees along with the structure of the felling operation and that of the working time described in this paper are extremely useful in training chainsaw operators. The structure of the felling of hung up trees according to stages allows better identification and awareness of the injury risks corresponding to each separate stage. Moreover, activities corresponding to each stage are presented in such a way as to draw workers' attention to existing risks and guide workers through the felling process. Training and re-training is probably the best and only preventive method. It is a pedagogical challenge to determine the best training methods and make sure that they are properly understood by trainees [24].

4. Conclusions

The structure of the felling operation presented in this paper allows the naming of its stages, and, at the same time, it follows international safety standards in chainsaw operations. To these, certain characteristics required by working conditions are added. Thus, the share of each stage in the structure of the felling of hung up trees was established and the factors that influence the working time of each stage were identified.

Using the technique based on rotating the tree around a pivot with a hand winch and the structure of the felling operation presented in this paper, a productivity of 3.477 trees·h^{-1} was obtained and a working time of approximately 17 min·tree^{-1} in trees that needed no repositioning of the TL. This time might represent a warning for workers and the signal that they must give up the manual felling of hung up trees with a hand winch and use specialized equipment. In trees that needed the repositioning of the TL, the time consumed of 29 min·tree^{-1} (in trees that needed the repositioning once) and of 43 min·tree^{-1} (in trees that needed the repositioning twice) is much too long in order to be considered acceptable. Moreover, the highest number of situations when safety rules were broken by workers were detected in these trees.

Out of all variables measured, DBH has the highest influence on WT, the correlation intensity being moderate (r = 0.43). DBH determines WT variation in proportion of 19% (R^2 = 0.19), especially working times corresponding to TZF and AT stages. It is well known that cutting a longer hinge wood and operating the hand winch in order to rotate the hung up tree takes longer and a more intense effort from the part of workers.

The felling of hung up trees must be regarded and understood from the perspective of the need to reduce injury risks and protect workers. The proper training of workers with respect to assessing and identifying injury risks and with respect to work techniques corresponding to dangerous working conditions remains the only method that may reduce the frequency and severity of workplace accidents. At the same time, it will ensure higher productivity and the preservation of wood quality in hung up and in supporting trees.

Author Contributions: Conceptualization, R.V.C.; methodology, R.V.C., M.A.B., and M.C.; field data collection, R.V.C., M.A.B., and M.C.; data analysis R.V.C. and M.A.B.; writing—original draft preparation, R.V.C.; writing—review and editing, R.V.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: The authors would like to thank ABA International for the Erasmus+ Euro Skills Trainer Register project that helped them realize once again the importance of drawing up safety standards, including the ones for the felling of hung up trees.

Conflicts of Interest: The authors declare no conflict of interest.

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