UNIVERSITY OF LJUBLJANA
BIOTECHNICAL FACULTY

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COMPARISON OF TECHNOLOGIES OF WOOD BIOMASS UTILIZATION IN BEECH STANDS

Doctoral dissertation

Ljubljana, 2015

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DOCTORAL DISSERTATION

PRIMERJAVA TEHNOLOGIJ IZKORIŠČANJA LESNE BIOMASE V BUKOVIH SESTOJIH

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This doctoral dissertation represents final part of doctoral program in biosciences, scientific field Management of Forest Ecosystems at the Biotechnical faculty, University of Ljubljana.

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AB In this research were compared two harvesting methods. First method was felling the tree, processing it at the stump, and extraction the assortments to the landing site. Second was felling the tree, partially processing at the stump and skidding to the landing site where processing was finished. First harvesting method was understood as the assortment method (short-wood) and second as the half-tree length method (long-wood) as a modification of the tree-length method. The aim of the research was to identify advantages and disadvantages of introducing the half-tree-length method and the need for eventually modification of the present short-wood (assortment) method. It was examined possibilities for rational chipping of fuelwood and wood residues which occurred after processing at the landing site in half-tree length method. Investigation was conducted in the area of municipality Ribnik, Republic of Srpska, Bosnia and Herzegovina. Results showed that productivity of cutting was higher in the half-tree length method than in the assortment because some working operations were avoided or minimized in half-tree length method, like production and stacking of fuelwood. Costs of skidding were significantly lower in the half-tree length method. Within the same stand conditions, the average damage surface was larger on sample plots with the half-tree length harvesting method. The amount of residue which left after processing at the landing site in half-tree length method was 2 m^3 on 100 m^3 of roundwood. Investigation of productivity and cost calculation of chippers showed that chippers with bigger capacity had lower unit costs, but because of inability to achieve full capacity at forest landing site and because of their dimensions which hinder the manipulation, it can be recommended using of chippers of smaller capacity.

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AI V doktorski disertaciji smo prmerjali dve metodi sečnje gozdnih lesnih sortimentov. Pri prvi metodi smo drevo posekali ter obvejili pri panju, do gozdne ceste pa se je vršilo spravilo izdelanih sortimentov. Pri drugi metodi smo pri panju drevo podrli in obvejili, do gozdne ceste pa spravljali kombinirane sortimente, katere smo dokončno krojili ob cesti. Prva metoda spravila je bila metoda kratkega lesa, pri drugi metodi pa je šlo za metodo dolgega lesa (poldebelna metoda), kot modifikacijo debelne metode. Cilj raziskave je bil ugotoviti prednosti in slabosti metode spravila dolgega lesa ter predlagati izboljšave k trenutno najbolj razširjeni sortimentni metodi. Prav tako smo ugotavljali možnosti za učinkovito sekanje sečnih ostankov in prostorninskega lesa, ki je ostajal na skladiščih po delu s poldebelno metodo. Raziskava je bila izvedena v bukovih sestojih Bosne in Hecegovine. Ugotovili smo, da je bila učinkovitost sečnje višja pri uporabi metode dolgega lesa, saj smo nekatere delovne operacije skrajšali, ali se jim celo v celoti izognili. Pri uporabi sekanja lesa smo se nareč lahko v celoti izognili fazi izdelave in zlaganja prostorninskega lesa. Stroški spravila lesa so bili statistično značilno manjši pri metodi dolgega lesa. V enakih sestojnih razmerah smo ugotovili večjo poškodovanost stoječega drevja pri metodi spravila dolgega lesa. Ugotovili smo, da po sečnji in spravilu lesa z metodo dolgega lesa na skladišču ostane 2 m^3 ostanka na 100 m^3 okroglega lesa. Ugotovitve kalkulacij stroškov in učinkovitosti sekalnikov kažejo, da imajo sekalniki z večjo kapaciteto nižje stroške na enoto dela, a zaradi nizke izkoriščenosti in dimenzijske neprimernosti za delo na gozdni cesti uporaba takšnih sekalnikov ni priporočljva.

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1 INTRODUCTION

The limiting factors in forest operations in Bosnia and Herzegovina (BIH) mountainous stands are terrain slope, micro-relief with obstacles, bearing capacity of the soils during periods of increased moisture, snow and ice conditions in winter and selective managed stands. Forests have mainly co-natural structure, mixed and uneven-aged managed with selective felling, individual and group, with a 10-year cycle. European silver fir (*Abies alba*, M.), Norway spruce (*Picea excelsa*, K), European beech (*Fagus silvatica*, L.) and sessile oak (*Quercus petraea*, L.) are the most important commercial species.

Strip roads and skidding trails represent basic network of secondary forest accessibility, which provides the quickest and shortest way for felled and processed trees and to be constructed with the slope gradient up to between 30% and 60% with the terrain stone content, due to karst conditions reaching up to 90% (Sabo and Poršinsky, 2005).

State-of-art harvesting technology in forestry of BIH is felling and processing trees at the stump using chainsaw and skidder for roundwood extraction. Sometimes, when terrain and stand conditions require, animals and cable yarders are in use. Roundwood is skidded on the forest road (landing site) with the forest skidder or adapted agricultural tractors. Stacked wood (traditional fuelwood) is extracted by animals on the traditional way. Harvesting technology and method is still a question of research and discussion.

As a consequence of current methods of using forests is low usage of total tree biomass, i.e. significant amount of biomass remains unused in the forest or loses somewhere during the transport.

A consequence of wood processing on site is a short log which could have negative effects on the productivity and costs of skidding. Producing of stacked wood in the forest opens the problem of increased costs of cutting in the forest and increased costs of transport (Halilović, 2012).

Residue and stacked wood that occur during wood processing in the assortment method remain in the forest. In the tree length or the half-tree length method where wood processing is at the landing site, there is presumption that potential residue remains on the forest road and then can be used for chipping (wood energy).

2 RESEARCH PROBLEM AND HYPOTHESIS

2.1 FOREST HARVESTING

The harvesting methods in Bosnia and Herzegovina refer mostly to the motor-manual assortment method, half-tree length and tree length method, while the whole tree and chipping methods are not practiced. The assortment method is most common.

Such situation in forest harvesting, consequently, results with a low percentage of biomass utilization. A significant amount of wood could remain unused in forest. Stacked wood which occurs in forest in assortment method has to be carried out by animals, and due to the lack of animal labor force, on the labor market in effect, stacked wood often remains in the forest. Such situation is unacceptable and needs improvement.

Also, an problem in practice is that in assortment method cutters often crosscut (buck) tree and produce final assortments without help from specialist for quality classes (forestry technician) what is unacceptable, because in general cutters are not sufficiently qualified for that job. In state-of-art forestry such kind of practice is obsolete.

In the area of BIH several studies have been conducted on the introducing the tree length and the half-tree length harvesting methods (Kulušić et al., 1980; Kulušić, 1981; Ljubojević, 1990). Results of those investigations led to the conclusion that tree length and half-tree length methods are recommended with appropriate better organization of production process. Also, it is proved that tree-length method is more demanding for performing and causes higher damages in the stand, on the standing trees, juvenile plants and soil (Doležal, 1984; Meyer, 1966). Perhaps that is a reason why it is not widely accepted in local forestry practice. Other reasons could be difficult terrain conditions and selective forest management which is based on cutting of the single trees on the wide area.

According to standards and regulations in classification of wood products in Republic of Srpska (entity in BIH), most of calculations are based on wood assortments with diameters above 7 cm. In some conceptions, forest biomass calculations are based on total wood volume (Bojanin, 1987) with or without green mass - needles and leaves (Čokl, 1980).
Discrimination of the effective factors in each stage and developing their corresponding time models enables forest managers to choose wisely the method of wood extracting, and efficiently manage harvesting operation process. One of common ways to evaluate the harvesting system is time study and cost production assessment. This dissertation reports cost and time prediction models for motor-manual felling and processing, skidding with cable wheeled skidder and chipping with the mobile chippers.

Increasing demand for using of renewable energy resources is strongly emphasized during last decades. On the international level it is recognized through series of conventions, conclusions and recommendations (Roser et al., 2010). Forests are energy source through conversion of wood biomass into solid, fluent and gaseous fuels for industrial and domestic use. Bioenergy systems can use wood biomass which would, in other cases, remain unused because of low market price and high utilization costs. In conventional forestry biomass is utilized as a product of roundwood production (Roser et al., 2010). Almost all operations in forestry leave residues (tops, branches, needles, bark, etc.) which can be used for energy if there is a suitable technological solution. There are estimations that 25-45% of volume of harvested trees left in the forest (Dykstra et al., 1996). This residue is usually dispersed on the large area, what makes transport costs per energy unit very high (Spinelli et al., 2007; Richardson et al., 2002).

Forest biomass potential can be divided into theoretic and effective. The theoretic potential is present in the forest and the effective can be realized on the basis of management systems, harvesting technology, wood market and socio-economic situation of forest owners (Krajnc and Dolenšek, 2001).

Biomass is unfossilized plant material, originated from photosynthesis with creation of oxygen and consumption of CO_2 from atmosphere. Such constitution of biomass has an advantage in relation to other renewable energy sources, because it is very similar to classical fuels (oil and coal) and technology for biomass does not require such large changes in relation to the existing energy technology (Bogdan et al., 2006).

The hardwoods have high energy value, which provides opportunity for the part of biomass (branches, bark, peels, shorter parts of stem, branch rates, etc.) to be used as a row material for energy use. After regular harvesting, about 20% of total above ground tree volume remains in the forest (Bajić et al., 2007). Using of forest biomass need to be issue of ecology, especially in natural stands. Sustainable using of forest biomass cannot significantly affect biological stability and productivity of stands (Bajić et al., 2007).

2.2 CHARACTERISTICS OF WOOD PRODUCTS

2.2.1 Logs

Main products which attract most attention of forest manager in forestry of Republic of Srpska and whole BIH are logs. Broadleaves logs are defined according to JUS (JUS D.B4.021; JUS D.B4.028).

Classes and general characteristics of beech logs are presented in Table 1:

Table 1: Characteristics of beech hardwood logs

	F	L	I	II	III
Min diameter (without bark) d_s cm	40	35	30	25	25
Min length – m, L	2	2	2	2	2
Healthy knots (Ø < 10 mm)	unlimited	unlimited	unlimited	unlimited	
Healthy small knot (Ø = 11 - 20 mm)	1/m'				
Healthy middle knot (Ø = 21 - 40 mm)	not allowed	2/m'	1/m'		
Healthy large knot (Ø < 15 % d_s)	not allowed			1/m'	2/m'
Healthy large knot (Ø < 25 % d_s)			not allowed		
Healthy large knot (Ø < 30 % d_s)				not allowed	
Small blind-knot (height < 4 cm)			1/2 m'	unlimited	
Large blind-knot (height > 4 cm)				1/m'	2/m'
Ovality	< 20 % d_s	< 10 % d_s	unlimited		
Conicity	< 3 % *D*		< 4 % *D*	< 6 % *D*	< 10 % *D*
Longitudinal recesses	depth < 5 % *d*	depth < 3 % d_s	depth < 5 % *d*	depth < 10 % d_s	unlimited
Single curvature (arc height)	< 2 % *L*		< 3 % *L*	< 4 % *L*	< 5 % *L*
Slope of	< 5 % d_s	10 - 20 % d_s	5 - 10 % d_s	10 - 20 % d_s	> 20 % d_s
Wells of longhorn beetles	not allowed		1/2 m'	1/m'	< 5/m'
Wells of flies			3/m'		
Frontal cracks	< 10 cm at 1 front	< 10 cm at both fronts	< d_s (at both fronts)		< 2 d_s at both fronts
Mechanical injury (injuries and healed)	depth < 5 % d_s	depth < 10 cm	depth < 1/3 d_s (bonification of unusable part)		
Bark injuries by moving and transport	partly				
Healthy false core	< 20 % d_s	< 70 % d_s	< 50 % d_s	< 80 % d_s	unlimited
Central rot	< 10 % d_s	all core errors which influence on positioning in peeling machine			
Circular and radial cracks	< 10 % d_s				
Frost cracks	not allowed				
Eccentric core	not allowed	allowed			
Double core		not allowed			allowed
Frontal color change	not allowed			< 10 % *L* (both fronts	< 15 % *L* (both fronts
Number of allowed errors per log	4	5	4	6	

D – Diameter at thicker end; d_s – diameter at middle of lengths; *d* – diameter at thinner end *L* - Length
*) usable edge part measured at the narrowest place of the front is 1/6 of diameter at least: if error is < 10 cm without bonification, > 10 cm with bonification

2.2.2 Fuelwood

Fuelwood is defined according to JUS (JUS D.B5.023)

Fuelwood is divided into:

- ✓ Wood of hardwoods: beech, hornbeam, oak, locust, maple, ash, elm, maple and wood of fruit trees;
- ✓ Wood of softwoods: birch, alder, linden, poplar, willow;
- ✓ Wood of conifers: pine, spruce, fir, larch.

2.2.2.1 Classification by level of humidity

According to the degree of humidity or time elapsed from cutting wood is classified to:

- ✓ Dry, if the cutting was at least six months ago; cutting was in winter or summer;
- ✓ Raw, if the cutting was less than four months ago.

2.2.2.2 Classification by form

According to the form in the fuelwood is included:

- ✓ Billets: pieces of wood of 1 m length obtained by splitting the roundwood with a diameter of at least 15 cm, which were cut on both ends with a chainsaw. Chord of arc or flat side of billet should be 10-25 cm wide. Allowable deviation of the length is at most +/- 5 cm;
- ✓ Small logs: pieces obtained from roundwood by cutting with saw. They are 1 m in length, and diameter 7-25 cm. Permissible deviation of length is +/- 5 cm;
- ✓ Small round billets pieces of roundwood, obtained by cutting with ax or saw, a diameter of 3-7 cm. Length of 90-120 cm;
- ✓ Gnarl: lumpy, split or difficult to split pieces of wood from 25 to 40 cm, and in length from 0.5-1.2 m;
- ✓ Stump wood: pieces of wood obtained by breaking or splitting the stumps of deforested trees with thickness of 15-40 cm;
  Waste: pieces of wood which fall out during cutting, splitting, trimming and debarking of wood in the forest or during the wood processing in sawmills and other wood processing plants, the thickness of pieces of wood varies 0.5 - 25 cm, width 2- 25 cm and length 15-120 cm.

2.2.2.3 Classification by quality

I class –The fuelwood of the first class is billets and small logs (small roundwood).

The following errors are allowed:

- ✓ Lumps all types and sizes
- ✓ Decaying pieces up to 10% of the delivered quantity
- ✓ Incipient rottenness pieces up to 30% of the delivered quantity
- ✓ Curvature of the arc height up to 15 cm

II class –The firewood of the second class includes all logs and logs that for whatever reason do not fit in the first class. This class includes gnarled wood with length of 0.50-1.20 m and thickness of 25-40 cm.

The following errors are allowed:

- ✓ Lumps all types and sizes;
- ✓ Curvature and slope of unlimited;

- ✓ Pieces cut with one or both ends;
- ✓ Decaying pieces up to 20% of the delivered quantity;
- ✓ Incipient rottenness pieces up to 50% of the delivered quantity;
- ✓ Short pieces that together make up to 10% of the delivered quantity.

Dry wood for distillation

Fuelwood of hardwoods of class quality I and II can be used for dry distillation, as well as the small billets.

2.2.2.4 Roundwood for the fuelwood

Fuelwood can be delivered in the form of roundwood, length of 1 m and above. Diameter is rounded to whole centimeters, and the length is rounded to 10 cm. Oversize is not given. Roundwood is measured along with the bark in m^3 or kg. According to the quality it is divided into I and II class.

I class - includes roundwood with the following permissible errors:

- ✓ Lumps all types and sizes;
- ✓ Decaying pieces up to 10% of the delivered quantity;
- ✓ Incipient rottenness pieces up to 30% of the delivered quantity;
- ✓ Curvature of the arc with arrow height up to 15 cm;
- ✓ Slope of, unlimited.

II class - includes roundwood with the following permissible errors:

- ✓ Lumps all types and sizes;
- ✓ Curvature and slope of, unlimited;
- ✓ Pieces cut with one or both ends;
- ✓ Decaying pieces up to 20% of the delivered quantity;
- ✓ Incipient rottenness pieces up to 50% of the delivered quantity.

2.2.2.5 Stacked fuelwood

Stacked wood fits in the stacks in the form of a prism, and the volume is expressed in m^3 based on converting volume stack in a compact wood volume (without holes).

Stacking of stacked wood in the form of a prism should be done in such way that a stack has the same height and width along its length. Cross-stacking is allowed at the end of one stack. When measuring the height of the cross-stack, the height is reduced by 20% (giving oversize). The stack of roundwood in the forest is increased by 10%.

Converting volume of the stack into a compact mass is performed by reduction coefficients (coefficients of conversion), depending on the size and intent that are identified by this JUS (JUS D.B0.022). Reduction coefficients vary in range from 0.37 to 0.80 depending on the form of the wood.

2.2.3 Forms of wood biomass for energy

Wood biomass is used in various forms for energy purposes. Technology depends on biomass characteristic; such as size, size distribution, moisture content, ash content and contaminants (stones, earth and sand).

The biomass energy content is shown as the energy value which depends on the physicochemical characteristics, primarily from feedstock moisture content. The calorific value is expressed as an upper (gross calorific value - GCV) or as a lower value of firewood (net calorific value - NCV). Upper calorific value represents the energy content of the biomass without free water while in the case of lower calorific value, the energy required to evaporate the water is taken into account.

Calorific value of wood also depends of the wood species respectively of it density. In average, gross calorific value of wood is about 19.5 MJ/kg. Moisture content of wood biomass is usually expressed with regard to wet basis, as well as with regard to dry basis. The average wood moisture content is about 50% (wet basis), while after drying period is about 18% (wet basis), which largely depends on the method and duration of storage after harvest.

Natural ash content in needles and leaves exceeds 5%, in brushwood and crust is about 3%, while in logs is about 0.6%. Also, different pretreatment techniques of raw material are currently used to increase density which achieves higher energy value relative to the volume, which reduces transportation costs and facilitates handling of raw material. Thus, the density of biomass can vary from 150 kg/m^3 to over 600 kg/m^3. Technologies related to the pre-treatment of raw materials include well-known mechanical technologies, such as logging and production of wood chips, but also little less known and used thermo-mechanical and thermo-chemical technologies to increase the density of raw materials, such as production of pellets or torefication which produces product similar to coal which increases energy value, energy density and the ability to crush raw materials.

Wood chips is form of biomass, size of 5-50 mm, which is obtained by chipping of lower quality logs, trees, brushwood and wood residues. For the automatic use of the wood chips it is good to be evenly sized. Moisture of wood chips obtained by chipping just harvested wood is about 50%, but after the summer drying in period of 3-6 months, the moisture is lowered to 30-40%. Further drying with hot air, moisture can lower to 20%. Ash content in the wood chips depends on the type of wood and leaves, brushwood and logs. Wood chips, depending on the method of manufacture and storage, can be contaminated with stones, earth and sand which increase the ash content. Calorific value of wood chips depends on the moisture and the raw materials from which it was obtained.

Applicable provisions of JUS standards for wood chips are

- ✓ Wood for making cellulose, hemicellulose and pulpwood (JUS D. B5. 020);
- ✓ Wood for wooden boards (JUS D. B5. 024).

These standards define types, measures and quality of the wood used for the production of cellulose, hemicellulose, pulpwood and wooden boards.

For production are used:

- ✓ Conifers;
- ✓ Softwood and hardwood broadleaves.

By the form, wood can be:

- ✓ Stacked wood in the form of billets and small roundwood;
- ✓ Roundwood;
- ✓ Sawmill waste and forest residues;
- ✓ Wood chips.

Table 2: Measures and percentage of fractions of wood chips for production (JUS D.B5.020)

Woodchips	Length (mm)	Width (mm)	Mass content (%)
Large	up to 50	above 9	up to 10
Normal	above 10 to 25	above 6 to 8	at least 80
Small	above 5	above 3	up to 10

Delivery:

- ✓ Wood chips is placed on the market in loose m^3 with the bark permissible content of 2% (relative to mass);
- ✓ Every wood species is placed on the market separately.

Quality:

- ✓ Wood for the production of wood chips should meet the general requirement - it should be healthy, and other errors are allowed unlimited and not measured.

Quality of wood chips for energy purposes depends on several factors that determine its further use. Those are:

- ✓ Size of fractions (dimensions and homogeneity)
- ✓ Water content (moisture of wood chips)
- ✓ Bark share (related to the amount of ash)

In international market it is usually classified into class fractions: up to 16 mm (P16), up to 45 mm (P45), up to 63 mm (P63), up to 100 mm (P100) or more (EN 14961-1).

On the energy value of wood chips water content mostly affects, somewhat little less the wood species, the content of resin and the content of other substances. The water content was determined as the ratio between the weight of water and the weight of the moist wood (1).

$$w = \frac{m_w}{m_b + m_w} = \frac{u}{1+u} \quad \ldots (1)$$

Where is:

- ✓ w - moisture content (%)
- ✓ m_w - water mass in wood (kg, t)
- ✓ m_b - dry wood mass (kg or t)
- ✓ u - wood moisture content

For the evaporation of water from wood a constant amount of energy is consumed so we can easily calculate the heat value of the raw material. Fuel values of the absolute dry wood for all domestic species are not considerably different. The equation for calculation of the calorific value of wood with water is (2):

$$H_w = \frac{H_b(100-w) - 2.44 \cdot w}{100} \quad \ldots (2)$$

Where is:

- ✓ H_w - calorific value of raw wood (MJ/kg)
- ✓ H_b - calorific value of dry wood (MJ/kg)
- ✓ 2.44 - energy of evaporation of water (MJ/kg)

Heating value can be represented in kWh/kg where, 1 kWh = 3.6 MJ, or 1 MJ = 0.278 kWh.

Moisture content depends on the season of harvesting, type of biomass, time after harvesting etc. Moisture content of the raw wood chips is over 40% and even over 50%, the forest dry wood 20-40% (depending on the time spent in the forest), up to 20% (air dry wood) and technical dry wood with a moisture content of 6-15% (Košir et al., 2009).

Raw wood with the water content of 50-60% has a calorific value of about 7.1 MJ/kg, wood with the water content of 25-35% has a calorific value of about 12.2 MJ/kg, and stored through the summer wood with the water content of 15-25% has a calorific value of about 14.4 MJ/kg (Košir et al., 2009).

When it comes to transport of wood for energy it should be noted that the selling price essentially does not need to depend on the water content. The wood could be sold to a buyer by ATRO weight (weight in absolutely dry state). Water is not included in the price, but the water content has important impacts on the cost of transportation. Water content increases transportation costs, but it is significant for the transport economy only when energy wood (chips) is paid by heating value and not by weight or by volume only. Therefore, it is recommended drying before chipping and transport. Before drying it is recommended chopping of wood.

2.3 RESEARCH HYPOTHESIS

Aim of this research is to compare the productivity, costs, biomass utilization and stand damages of two methods:

1. Felling the tree, processing at the stump, and extraction the assortments to the landing site.
2. Felling the tree, partially processing at the stump and skidding to the landing site where processing is finishing and fuelwood is chipping.

First harvesting method was understood as the assortment method and second as the half-tree length method, as a modification of the tree length method. The aim of the research was to identify advantages and disadvantages of introducing the half-tree length method in beech forest utilization.

On the basis of research aim we set next hypotheses:

1. The half-tree length harvesting method is more efficient than the assortment, productivity is higher and it is cost effective;
2. In the half-tree length method there is a better utilization of wood biomass, quantitatively and qualitatively, than in the assortment method;
3. When processing assortments on the forest road, a certain amount of residue remains which can be used for chipping;
4. The half-tree length harvesting method required better design of skidding roads and better work organization than the assortment method in order to keep damages on the level of the assortment method;
5. When performing the half-tree length harvesting method there is greater possibility for rational utilization of wood residue than in the assortment method;
6. Raising demand for wood energy makes cost effective chipping on the forest road.

3 PREVIOUS INVESTIGATIONS

When choosing the optimal harvesting solutions (technology, transport, machinery, etc.) a large number of factors should be taken into account. Quality and economy depend of choosing an optimal technology. Technology is optimal when provides maximum efficiency of energy utilization with minimum unit costs (Bajić et al., 2007).

3.1 FELLING

Felling is the process during which a standing tree is cut from its stump and felled on the ground that following logging operations may be undertaken. Felling is one of the most important processes in forest harvesting. Felling is the first step of changing the tree to monetary value (Mousavi, 2009). With felling, value is added to the standing trees in the forest. From an economical point of view, standing trees in the forest have no value, although from the ecological and environmental point of view, a forest is highly valued as an ecosystem (Mousavi, 2009).

The chainsaw is still the most common tool for felling and processing trees. Its relatively low purchase price, low weight and ability to be carried by one person have made it a commonly used tool for working in the forest (Schmincke, 1995). Motor-manual felling, using a chainsaw, is one of the logging components that are directly related to human labor performance. In spite of the introduction of new machineries in forestry, which have decreased the reliance on human power, labor still plays an important role in motor-manual felling. In felling trees with a chainsaw, stumps should be as close to the ground as possible because the most valuable part of tree is its butt, additionally it should be cut at an angle to minimize hang-ups (Han and Renzie, 2005).

Felling should be carried out mainly in winter time in order to avoid fungi attack. For more than 2000 years, certain forestry practices and rules regarding tree felling have been carried out in observance to Moon cycles. A general review of the different types of rules followed (known in Europe and on other continents and stemming from both written sources and current practitioners) shows that special timber uses are mentioned in relation to a specific felling date which supposedly ensures advantageous wood properties (Zürcher, 1999). Moon timber is said to have some special and unusual characteristics: it does not rot, it is not attacked by insects, it does not burn, it is drier, it does not shrink, it does not crack, it does not bend, and it is very hard (Torelli, 2005).

In felling, finding a clear path eliminates lodged trees, throwback and damage to the tree being felled as well as the other trees. All technical, environmental and safety issues should be considered for finding a clear path. Conway (1979) found that about 40% of the value loss occurs in timber felling alone. Felling the tree in a desired direction is called directed felling. The objective of directed felling is to save time and unnecessary work by directing the tree according to the transport route or skidding trails. This decision should be based on the safety of the feller, the field situation, tree position, log skidding, timber breakage, residual stand, transport route, natural obstacles, and working methods.

Skillful felling is the first stage of transport, bringing the logs closer to their intended destination. The general terrain features are a very important variable in the felling operation, because slope has the greatest effect on timber damage. Heavy brush decreases productivity as it hinders walking between trees and decreases the productivity per hour. Stand density and tree concentration affect the felling operation. In low–density stands or stands with selective cutting the cuts are scattered and walking distances are increased, where cutting is performed by the worker or machine. Weather conditions may interfere with the efficiency of the worker and machines, for example, heavy snow fall, or an extended rainy season. In partial cutting, hanging-up is common, while in clear-cutting it is not a problem.

Time consumption of felling and productivity depends on several variables, such as harvesting intensity, DBH (or stump diameter) and inter-tree distance (Kluender and Stokes, 1996). Time studies of felling in different areas showed that felling, delimbing, bucking, and finding the tree are the most time consuming elements (Schmincke, 1995).

Productivity is more related to the stem diameter than harvest intensity (Lortz et al., 1997). Felling productivity is also affected by environmental conditions. Mitchell (2000) showed that in colder climates, felling efficiency decreased, because it is harder when the wood is frozen. This issue was also raised by Renzie (2006).

Barreto (1998) discovered that the productivity is affected by the number of workers in each group. The productivity was higher for a group with two workers rather than a group with three workers.

Processing is usually understood as a process whereby a felled tree is debranched and cut into logs in preparation for skidding or yarding phase of logging. After a tree is felled, the operator assistant measures it before cross-cutting. While measuring the logs, the operator (bucker) should carefully examine them for changes in the surface characteristics such as knot size and rotting.

Delimbing is one of the most dangerous parts of tree processing and involves many safety aspects because when the tree is laid on the ground, branches may be storing enormous potential energy. This energy can be released suddenly when a branch is cut. Delimbing and topping is done before cross-cutting and it starts from the side with the fewest branches (Kantola and Harstela, 1988).

Medved and Poje (2003) examined accidents in Slovenian forestry. They established that main causes for the accidents were parts of trees, some other objects, or the forest ground. Most of the injuries were inflicted to: head, shin, arm fingers, chest, knee, ankle and eyes. The accidents occurred primarily in even-aged (one canopy layers) stands, stands with mature trees, on fields with 0-30% slope by thinning. Handling an assortment method with trunks with volume 0.3-0.5 m^3, which are made from trees of 0.5-1.5 m^3 volume, caused most of the accidents.

Characteristics of accident occurrence show that changes in society, forestry and stricter legislation did not significantly influence improvement of safety (Medved et al., 2007).

A decrease in the number of work-related accidents and deaths in forests is only possible with an integral approach to suitable training and use of appropriate organisational and technological solutions (Klun and Medved, 2007).

Bucking is technically one of the most important elements of processing because a cut tree should be bucked in a length that maximizes profit. Sickler (2004) found that bucking has direct impact on the logging profitability. Bucking optimization requires simultaneous consideration of species, tree stem quality, tree stem dimensions, log lengths, current market demand and prices, in addition to other factors (Wang et al., 2007). Poor bucking practices may result in 20% loss of value in comparison to what is considered good practice (Wang et al., 2007).

A harvesting system refers to the tools, equipment and machines used to harvest an area while harvesting method refers to the form in which wood is delivered to the logging access road, and depends on the amount of processing (Pulkki, 1997).

Pulkki (1997) differs five harvesting methods in use throughout the world: cut-to-length, tree length, full tree, whole tree, and complete tree.

Various researches have been conducted to show the weakness and advantages, as well as the influencing factors, of each harvesting system in order to find the most appropriate system for a particular situation.

Naghdi (2005) compared the production rate and cost, as well as damage, to the residual stand when using the unmechanized cut-to-length and tree length method. The productivity of the tree length method was higher than of the cut-to-length method. Damage to the residual stand in the cut-to-length method was higher than in the tree length method.

Adebayo et al. (2007) studied productivity and cost of the whole tree method and cut-to-length method. His results proved that the whole tree method was more productive than the cut-to-length method, and consequently the production cost was lower. Although comparison of cut-to-length method and tree length method provides important information about the effect of log length on the productivity and cost and also damage to the residual stand, it is not sufficiently detailed, because performing cut-to-length method involves large variations in log length that require more detailed studies. Therefore comparative studies on the short-log and long-log method are needed to determine various positive and negative aspects of both methods applied under similar conditions (Adebayo et al., 2007).

According to Rebula (1988), working method indicates a form and size of assortment which is transported from the forest. It may differ following methods: assortment, half-tree length, tree length, full-tree method, part-tree method and chipping method.

Problem of stacked fuelwood which occurs in the assortment method can be solved if instead classical stacked fuelwood, long (roundwood fuelwood) is made. Making of long wood is a rational solution because productivity is increasing and human labor is decreasing, (Bajić et al., 2007).

Kulušić and Miodragović (1979) investigated different technological processes in harvesting, processing and skidding in pine and oak forest, determined effects and productivity and for each technological model they estimated standard times. They emphasized advantages and disadvantages of each method.

Jovanović (1980) conducted time study for two harvesting technologies in forest utilization, assortment and tree length method. He used method of moment observations for data collection.

Bojanin et al., (1989) were comparing harvesting in oak and alder stands. They applied assortment harvesting method where technical roundwood and long industrial transport lengths wood is processed.

Bojanin and Krpan (1994) investigated application of motor-manual assortment, tree length and half-tree length method in different working conditions, where whole day time and work study was performed, 24 days in mountain area and 59 days in lowland area.

Krpan and Zečić (1996) investigated effective work time in harvesting of poplar by using group work, where harvesting was done with modified tree length, after which skidding on the forest landing site was done where processing continued.

Zečić and Marenče (2005) examined characteristics of work and efficiency of a work team. Standard time for two cutters was 25.92 min/m^3. Allowance time is made of parts of delay times necessary for executing the work order. Allowance time is determined in order to establish standard times and standard efficiencies and it is added to effective time in form of allowance time coefficient or in a form of absolute value. They establish coefficient of allowance time for cutters 1.55 and 1.70.

Some other studies have reported that tree diameter (DBH), ground slope and species of tree influence felling time in motor manually felling (Kluender and Stokes, 1996; Hartsough et al., 2001; Wang et al., 2004; Ghaffariyan and Sobhany, 2007).

The time distribution of various elements of the time study on manual felling using chainsaw are moving to tree 12%, reconnaissance 11%, undercut 27%, back cut 31% and delays 19%. Notably, the back cut has the highest share of the felling time, and delay times account for about one-fifth of total working time. Tree diameter (DBH) was found to be the most important determinant of time consumption and productivity. In addition to the DBH, distance between trees was also found to influence productivity of felling operation. Tree diameter

(DBH) was found to be the only variable significantly influencing felling time using chainsaw in the study area (Ghaffariyan et al, 2013).

Although, safety hazards are increasing, chainsaw felling is not as limited by the ground slope or tree size as mechanized felling; motor-manual felling is also used to meet management objectives such as pre-commercial thinning, salvage operations, and selective harvesting (Behjou et al., 2009).

Wang et al. (2004) developed a productivity model for chainsaw felling, which included variables such as diameter at breast height and the distance among harvested trees. Holmes et al. (2002) conducted a time study on the forests of eastern Amazon; they found that the productivity and costs of motor-manual felling were 20.46 m^3/h and 0.46 USD/m^3, respectively.

Behjou et al. (2009) performed a time study in uneven-aged beech forests in Iran with the average growing stock 320 m^3/ha. The variables such as distance between harvested trees, diameter at breast height (DBH), slope in the stump area, and slope between two harvested trees were entered into the general model for predicting felling time as significant variables, which can be applied in harvesting planning. The felling cycle time per tree and felling productivity were mostly affected by DBH of the tree being felled but they were also affected by the distance between harvested trees. Increasing distance between harvested trees will increase felling time, but if DBH increases, the felling time decreases. The average productivity of 26.1 m^3/productive machine hour (PMH) or 20.6 m^3/schedule machine hours (SMH) provided the weekly production of 470.58 m^3 and 371.10 m^3 for chainsaw felling. Its total hourly cost was 0.81 USD/PMH/m^3 and 1.05 USD/SMH/m^3, respectively. The delay time was 0.81 min per turn, where 0.22, 0.44 and 0.15 min per turn were for operational, mechanical and personal delays, respectively.

Poje and Potočnik, (2007) studied group work in forestry and concluded that group work demands a highly skilled worker who is able to perform any work in the group and that requires constant education and employment stability.

Behjou (2012) established that felling time per tree was most affected by diameter at breast height and distance among harvested trees in single-tree selection method and diameter at breast height in group selection method. The production rate in single and group selection cutting was 21.2 m^3/h and 28.4 m^3/h for one person, respectively. Considering the gross and net production rate in single and group selection cutting, the unit cost was 1.11 USD/m^3 and 0.88 USD/m^3, respectively. The results indicate that group selection cutting can be more profitable than single-tree selection method.

In Greece, the use of tree length system is introduced mainly in the stands with terrain with low inclination (Galis and Spyroglou, 2012). Cutting of stacked wood into length by petrol chainsaw is a typical technical and technological wood harvesting solution. Due to the fact that wood harvesting is most commonly performed with the use of tree length system (TLS) or long-length system (LLS), cutting into length, in Poland, it is performed either after the first stage of skidding stems or logs to the skidding route or after the second stage of transport, that is at the depot (Szewczyk et al., 2012).

In central Sweden, for motor-manual logging, differentiated processing method was found to be recommendable for agronomical, economical, and efficiency reasons (Bjoerheden, 1998).

Researchers suggest that it would be better option that firewood is skidded together with roundwood what would cause lower transport costs (Košir et al., 2009).

3.2 SKIDDING

Transport in forestry performs in two stages. The first is called primary transport which includes all movement of logs or trees, after felling and processing, from the stump to the landing site.

Primary transport may be performed by animals, tracked machines (crawler tractors), wheeled skidder, forwarder, harwarder, anyone of several cable systems, or aerial logging systems. Ground and stand conditions are the most important considerations to choose either of these systems.

Different classifications have been applied all over the world for terrain difficulty. For example, Kantola and Harstela (1988) divided the terrain difficulty into five classes: level (0-15%), gentle (15-30%), moderate (30-50%), steep (50-70%), and very steep (>70%). In Bosnia and Herzegovina, the maximum slope gradient acceptable for skid trails varies between 45% and 60%, depending on the equipment available.

The extraction of forest products from forest is a difficult, risky, expensive and time-consuming operation, especially in mountainous areas. An important issue concerning forest transport is the extraction of forest products without loss of quality where the value of log for veneer production and saw logs usually is most considerable.

Kluender and Stokes (1996) found that grapple skidders were consistently faster and more productive than cable skidders; however, grapple skidder has not been used in Bosnia and Herzegovina yet. Harvest intensity strongly affected grapple skidding productivity, but cable skidding productivity in lesser extent. This was explained by the fact that the grapple skidder had to approach to the each stem individually, while the cable skidder could reach them without moving.

Egan and Baumgras (2003) in West Virginia, USA examined the relation among several ground skidding and harvested stand characteristics. They found a direct relation between skidding distance and cycle time, and an inverse relationship between percent of trees removed in the stand and total cycle time. The number of residual trees per hectare and number of trees per hectare in the pre-harvest stand were not significant in explaining total skidding cycle time. Skidding is directly constrained by the number of pieces and maximum volume per cycle.

A detailed time study about skidding with Timberjack 460 was done by Wang et al. (2004). They found that the skidding cycle time was mainly affected by payload size and skidding distance. They also tried interaction between different variables in the different components of skidding. Stand density, slope, undergrowth, soil and volume per tree, and skidding distance were the most important factors in winching and ground skidding. The cost of skidding is typically the most expensive component in whole tree harvesting operation and directly depends on skidding distance (Mitchell, 2000).

Stand density increases the skidding time, but it concentrates the volume in one place and therefore the skidder does not have to move around as much. Proper design of skid trails can reduce skidding costs by 38% and ground area disturbed by 50% (Applying reduced …, 2002).

Slope can be uphill or, more favorable, downhill. The rule is to skid downhill to the landing whenever is possible. Skidding uphill should be avoided if possible.

Researchers have already suggested that better option would be if fuelwood is skidded together with roundwood what would cause lower transport costs (Košir et al., 2009).

Mousavi (2009) compared the effects, economical efficiency and damages which occur when using the long-tree and short-tree harvesting method. Conclusion was that efficiency is higher and unit costs lower when performing long-tree method but also it is necessary that forestry planers and workers should be extra trained in order to keep efficiency while damages are on acceptable level.

Zečić and Marenče (2005) examined characteristics of work and efficiency of a work team. They established standard time for two tractors ranges between 25.05 min/m^3 for distance of 150 m and 33.20 for distance of 650 m. Allowance time is made of parts of delay times necessary for executing the work order. Allowance time is determined in order to establish standard times and standard efficiencies and it is added on effective time in form of allowance time coefficient or in form of absolute value. They established the coefficients of allowance time for tractors 1.29 and 1.24.

Zečić and Krpan (2004) examined group work for felling, processing, skidding and quality inspection activities in mountainous broadleaf thinning stands with approximately the same terrain and stand conditions. The stands were 55 and 70 years old. Productivity was examined on two groups. The first comprised of five workers (A) and the second of four workers (B). The first group was equipped with two tractors and three chainsaws while the second used two tractors and two chainsaws as well as other necessary equipment. The effective time for the cutters in felling ranged from 36% to 42.9%, in finishing and measurement 21%, while the effective time for the tractors ranged from 42.4% to 59%. The effective time per tree ranged from 3.62 to 3.77 minutes, i.e. per unit it ranged from 8.46 min/m^3 to 12.91 min/m^3. The daily output achieved by the Ecotrac and Torpedo tractors at a distance of 300 meters was for group A 20.77 m^3/day while the optimized output was 67.02 m^3/day. The output achieved by both tractors in group B was 17.25 m^3/day while the optimized was 30.72 m^3/day. The average performance per worker in group A was 4.15 m^3/day, while the optimized was 8.38 m^3/day. For group B the average performance per worker was 4.31 m^3/day and the optimized was 7.68 m^3/day. The optimization of the groups lowered the unit cost of production (300 m distance) for group A from 21.36 €/m^3 to 6.62 €/m^3, and for group B from 22.09 €/m^3 to 12.41 €/m^3 (Zečić and Krpan, 2004).

Most of statistical studies on skidding operations indicated that skidding distance, piece size, load volume, winching distance and slope of the trail impact strongly on the production of this step of the logging process (Ghaffariyan et al., 2013; Sabo and Poršinsky, 2005; Zečić et al., 2005).

Skidding time per cycle is a regression function of skidding distance, winching distance, and slope of the trail and piece volume. The average net and gross productions were 18.51 m^3/h and 14.51 m^3/h respectively (Ghaffariyan et al., 2013). They found that the productivity of processing, skidding and hauling increased when using the long timber method. Total unit cost of the long timber method in processing, skidding, loading and hauling is lower than under the short-wood method (Mousavi, 2009).

Ghaffariyan et al. (2012) showed that increasing average load volume will result in lower cost of extraction thus to reduce the extraction cost. They emphasized that it is necessary to use the harvesting equipment with maximum working capacity. Also, they suggested that increasing load volume may increase machine repair costs, an aspect which requires further investigation.

Average load volume of Ecotrac 120V skidder in selective cutting in beech dominantly stands is 5.34 m^3 and consists of 5.7 pieces in average with length of 7 m and volume of 0.93 m^3 (Horvat et al, 2007). At the hilly working site the effective time was 8.06 min/m^3 and in selective felling the effective time was 9.88 min/m^3. Daily efficiency of 57.49 m^3/day (100-500 m distance) can be achieved at the hilly working site. At the mountain working site the daily output of 48.53 m^3/day to 35.54 m^3/day can be achieved for the same distance (Horvat et al., 2007).

Total allowance time of the skidder Ecotrac 120V at the hilly working site is 34.25% of effective time and on mountain working site 17.95% of effective time. Respectively factors of allowance time are 1.34 and 1.18. Costs were between 3.74 and 6.01 €/m^3 for preparatory felling and between 4.45 and 6.05 €/m^3 in mounting site (Horvat et al., 2007).

Bembenek et al. (2011) showed that mean overall operational productivity during extraction with HSM 904Z skidder was 30.5 m^3/h, with the average tree volume 1.8 m^3. The obtained productivity seems to be very good when compared with e.g. 11.6 m^3/h achieved by the

Timberjack 240 C in a mountainous fir stand when skidding very large trees up to 3.9 m^3 (Sabo and Poršinsky, 2005). Using a cable skidder LKT81 Turbo in the mountain conditions in 82-year-old fir stand productivity can reach 7.15 m^3/h (Porter and Strawa, 2006).

Machine rate of Timberjack 240 C according to the calculation based on 1600 operating hours per year was 26.89 €/PMH. With skidding distance of 250 m the productivity under described work conditions is 12.0 m^3/PMH (5.0 min/m^3) with the skidding costs of 2.2 €/m^3. Productivity depends on skidding distance ranges between 16.9 m^3/h (50 m) and 9.9 m^3/h (400 m). Skidding costs ranges from 1.6 to 2.7 €/m^3 (Sabo and Poršinsky, 2005).

Holmes et al. (2002) studied the productivity of a rubber-tire skidder in conventional felling. They showed that the productivity of the skidder was 22.39 m^3/h and the unit cost was 1.99 USD/m^3 in Amazon forests in Brazil.

Behjou et al. (2008) investigated skidding capacity of the wheeled skidder Timberjack 450C in Caspian forests. The skidding cycle time and the travel loaded time as well as cable winching productivity was primarily affected by skidding distances and winching distances. The interaction between skidding distance and the ground slope was other major factor that also influenced elemental times and productivity. The empty travel time was dominantly affected by skidding distance. The gross (SMH) and net (PMH) production rate they achieve was between 20.51 m^3/h and 22.93 m^3/h for different skidding distance. The average production cost considering the gross and net production rate was between 6.31 \$/m^3 and 6.22 \$/m^3.

Due to combined use of skidders and trucks for primary and secondary transportation of roundwood, forest harvesting depends on a network of forest roads. Forest roads need to reduce the distance and costs of wood extraction, and strip roads and skid trails to reduce winching and mobility of loaded vehicles on mountainous terrain.

3.3 CHIPPING

Chipping of wood is defined as a procedure for forest biomass processing into a form suitable for use in power generation, and the need for forest biomass chipping is based on enabling the automation handling of wood chips, economical transport and easier drying and combustion of wood chips (Šušnjar, 1998).

Räisänen and Nurmi, (2011) examined the amount of wood residues remaining after felling in the stand and depends on the place of slicing on the thinner side of the tree.

Westbrook et al., (2006) examined the addition of a small chipper to a conventional harvesting operation in Georgia (US). They found that the logging residues could be produced for about the chipper operating cost. When additional understory biomass was harvested to supplement chipper production, the resulting forest biomass cost slightly more. An alternative approach to hand-carrying slash is to use a forwarder to collect and transport the piles of residues. A forwarder is basically a self-loading off-road truck. Usually the load space is defined by log bunks, although different types of bins or dump boxes have been used for more efficient slash carrying. While working, the forwarder drives through the stand collecting biomass from the piles into the load space. The full load is driven to roadside and dumped or unloaded with the crane.

Klepac et al., (2006) evaluated productivity of a forwarder for slash transport in western fuel thinning. The average productivity 4.8 m^3/PMH resulting in forwarding cost of about $17/oven dry ton. The most critical functional specification of the forwarder is the payload. Loose slash piles have low density making it difficult to get a reasonable load. A solid-sided load box allows the operator to pack material with the crane. There are also modified forwarders with bunks that compress the load (e.g., Continental Biomass Industries Brush Transport System), or with bunks that expand to increase the load volume. In any case, the payload is defined by the load volume and the biomass density.

Biomass can also be chipped in the stand and then transported to roadside in some form of chips carrier (referred to as terrain chipping in Europe). The most sophisticated machine in this class is the Valmet 801 Combi Bioenergy, a harvester equipped with a chipper and a 27 m^3 chips containers (about 4 ATRO tones).

Wood biomass, in the form of slash or loose stems, has a solid volume factor (ratio of solid wood volume to total volume) of 0.15 to 0.25. Comminuted biomass in the form of chips or chunks has a SVF (solid volume factor) of 0.35 to 0.45, more than double the density of loose slash (Johnson, 1989).

Bundled material has a SVF approaching to 0.7. SVF is a critical factor affecting the productivity and cost of wood biomass feedstocks (Rummer, 2004).

In investigations of (Bjorheden and Eriksson, 1989; Hakkila, 2003; Talbot and Suadicani, 2005) three different chipping methods were compared. They are classified on the basis of place of comminution and chipping where a chipper characteristic is very important.

Chipping systems are grouped in literature as: terrain chipping method, chipping at the forest road, chipping at the landing site and chipping at the terminal (Ranta, 2005; Cuchet et al., 2004; Junginger et al., 2005; Johansson et al, 2006).

Chipping and transportation are the key processes for production and can be completed in closed or interrupted work chains. Direct chipping in to transportation machine requires larger operating areas and results in operational delays of chipper (20% of the total work time) and the truck. In mountainous areas the separation of chipping and transportation can be appropriate and reduce costs by 24-32%. Choosing the right chipper is crucial in projection of chipping system (Stampfer and Kanzian, 2006).

3.4 TIME STUDY

Time study is one of most common practices of work measurements. It is used worldwide, in many types of work analysis in order to determine the input of time in the performance of a piece of work (Björheden, 1991).

Empirical performance models are generally developed by collecting field data and testing the statistical significance of any relationships with regression analysis (Samset, 1990). This technique is used to calculate an equation capable of representing the relationship between a dependent variable (typically time consumption or productivity) and one or more independent variables (Costa et al., 2012).

A time study is usually done either as a comparative study, a correlation study or a combination of the two (Eliasson, 1998). The objective of comparative studies is to compare two or several machines, work methods, etc., while the objective of the correlation or relationship study is to describe the relationship between performance and the factors influencing the work (Nurminen et al., 2006). Time studies can be carried out using continuous time study methods such as continuous or repetitive timing or indirect work sampling (Samset, 1990; Harstela, 1991).

Technical and economic utilization of forest biomass depends on various factors related to terrain conditions, transport networks and harvesting technologies, as well as systems, silviculture and forest operations management (Piccio et al., 2011). Time studies are very often used for the analysis of productivity of various forest biomass harvesting systems (Magagnotti et al., 2012; Picchio et al., 2009; Savelli et al., 2010).

Time study is defined as the analysis of methods, material, tools and equipment used in the production process (González, 2005) or as time measurement, classification and data analysis in order to increase work efficiency (Forest work nomenclature, 1995). A detailed time study is comprised of time consumption for each work element. This refers to determining the influential factors, the time consumption, and the data collection method (Samset, 1990).

In a time study, all conditions speeding up or hindering the progress of work should be recognized. The environment of the time study performance should be equal to the normal forest work. All the workers should be aware of reasons of the study as well as the methods. They should be experienced in the forest operation studying methods. The quality of production and the result should be clear and recorded because high quality work usually takes more time. All conditions of work such as weather, terrain conditions, type, shape and age of equipment should be well described.

The time study starts with work selection and all relevant data relating to conditions, methods and elements of the activity should be recorded, and then the recorded data should be examined to ensure that the most suitable method and technique are used. Choosing workers and training them for the time study, planning the measurement procedure and measurement technique should also be considered (Harstela, 1991).

Time studies not only measure time and production, but also identify time categories according to the action. Total time recorded is subdivided into main time (productive) and general time (unproductive). Main time appears in the production process and also includes auxiliary times (e.g. fasten chain to log in skidding). General time that interrupts the productive process is divided into times for preparation and conclusion, maintenance, rest, technical and personal interruptions (Commercial timber…, 2002).

The time study is a basis for the evaluation system establishment. The results of time studies have been used to set the piece rate and rationalize the production (Björheden, 1991; Nurminen et al., 2006). Time study methods are used by public forest agencies in timber sale appraisal and by companies that employ operation research staff or consultants, as well as in determining the input – element of productivity, in studying the factors affecting productivity and in developing work methods by eliminating ineffective time (Harstela, 1991).

The time study can also be used for assessing the different harvesting methods for finding the most profitable one. According to González (2005) the time study is used for finding the most economical way of doing the work, standardizing the methods, materials, tools and equipment, as well as in assisting in worker training to employ a new method. The problematic aspect of time studies is that several working elements are carried out at the same time, for example, processing is done when the skidder is in skid trails or landing and therefore it is not possible to study both of them simultaneously.

Forest operations are dispersed across a large area thereby requiring several people to perform the time study throughout the work site (González, 2005).

In order to compare and apply the results of different studies, a time concept should be identified. According to the Nordic Forest Work Study Council recommendations, time concept includes total working time (moving time, change-over time, work place time, interruption time and meal time) and unutilized time. The main portion of total working time is work place time that is divided into productive time and delay times (Harstela, 1993).

A new time concept was introduced by the International Union of Forest Research Organization (Forest work nomenclature, 1995) (Figure 1). In the concept, total time includes work place time and non-work place time. Non-workplace time is a portion of total time that is not used for the completion of a specific work task like traveling and resting away from the work place. Work place time is a portion of total time that a production system is engaged in during a specific work task. Work place time is divided into productive work time and supportive work time. Productive work time is a portion of work place time that a production system is directly or indirectly involved in while completing a specific work task (Forest work nomenclature, 1995). Work place time is divided into productive work time and supportive work time.

Supportive work time is a portion of work time that does not directly add to the completion of the work task, but is performed to support it; for example, preparation of work, service time for repairing the tools and refueling (Forest work nomenclature, 1995).

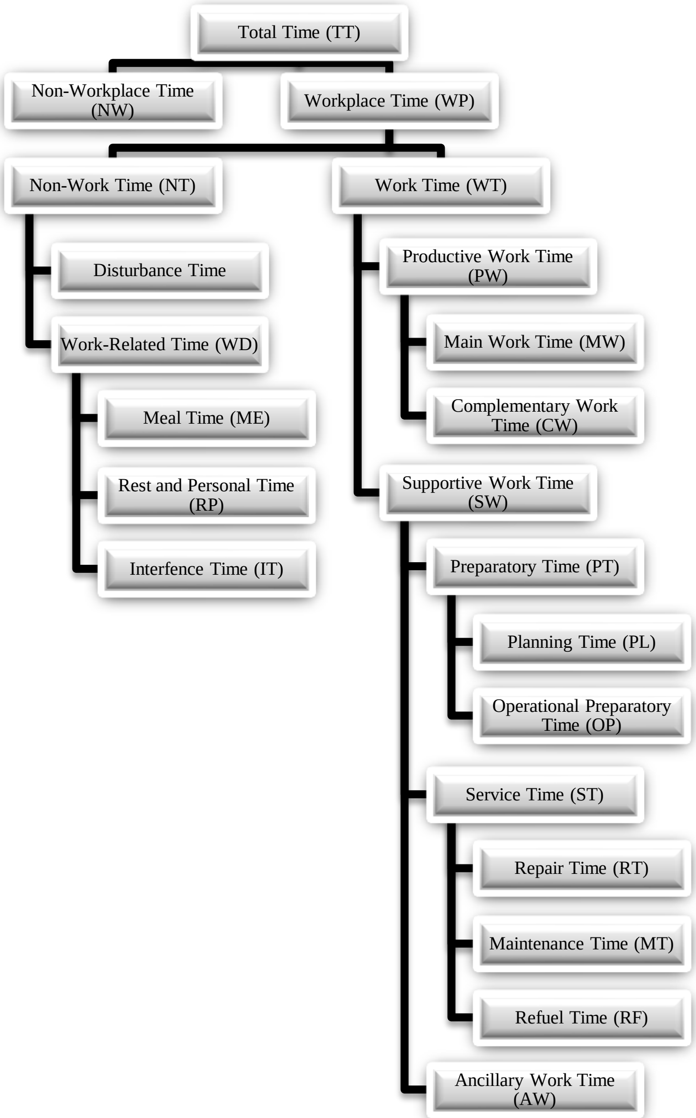


Figure 1: Time concepts according to IUFRO recommendations (Forest work nomenclature, 1995)

Productive work time (PWT) is a portion of work time that is spent contributing directly to the completion of a specific work task, typically occurring on a cyclic basis (also direct work time).

Supportive Work Time (SWT) is a portion of work time not directly related to the completion of the work task, but is performed to support it (also indirect work time).

Ancillary work time (AW) is a portion of supportive work time used to perform ancillary work functions that allow the work to continue in the production system; such as assisting another machine or worker, blading skid trails, laying boughs in wet spots, etc.

Production rates are based upon estimates of average output per unit of work time. Work time, often referred to as scheduled machine hours (SMH) is divided into productive time and non-productive time (Wenger, 1984).

Productive time is a fraction of time that is actually spent producing output. It is often measured as productive machine hours (PMH). It is the time spent by a machine performing its primary task as well as time spent on support tasks. Short periodic delays that cannot be easily separated from production activities as refueling chainsaws, or short road changes in cable yarding are lumped into productive time. Productive time is often referred to as the effective hour.

Non-productive time is a fraction of time that is spent changing landings or in some other form of delay such as scheduled maintenance, unscheduled maintenance or miscellaneous delays. Scheduled maintenance covers regular servicing and replacement of parts, lines and ringing.

Time measurements are done by using either direct or indirect methods depending on the required accuracy. In direct timing, the time for each work element is measured with a stopwatch or a handheld computer. Direct timing can be classified as continued timing and repetitive timing. In continued timing, the time is recorded continually and the elements are the differences between recorded times. In repetitive timing, the recording of very short elementary times is possible through applying snap back timing (Saarilahti and Isoaho, 1992). The stop watch is snapped back to zero at the end of each time element (Saarilahti and Isoaho, 1992). Repetitive timing is more suitable in the time study of harvesting, especially motor-manual felling and processing (Sarikhani, 2001).

Continued timing is a very time consuming process, requiring many calculations, but it is more flexible if any mistakes happen during the time study. Usually it is done by hand held computers. Indirect timing is used in forestry for predicting time consumption of different elements. It is used in the case when there are a lot of work elements which are repeated frequently. During work samplings, the person conducting the study observes what the machine or worker is doing at specific points of time. These points are separated by either a random or a fixed time interval. The large advantages with work sampling are that elements of short duration can be studied. Another advantage is the possibility to study more than one worker or machine simultaneously (González, 2005).

Methodologically, there are two different types of time studies: correlation studies and comparative studies. Correlation studies are done to establish relationships between the time consumption for the work task and the factors influencing the work (Mousavi, 2009).

Samset (1990) found that correlation studies emphasize how time consumption varies with the difference of influencing factors. In order to determine the variation of factors, two research areas may be considered: one with small dimension and the other one with large dimensions (e.g. with easy and difficult conditions). The objective of the correlation study is to describe the relationship between performance and the factors influencing the work (Bergstrand, 1991; Nurminen et al., 2006).

Comparative studies compare the time consumption or productivity for different equipment and work methods used to perform the same work task. They are usually done to evaluate the performance of new equipment or work methods compared to the prevalent way of doing work. According to Samset (1990), in order to compare two methods or machines, not only all conditions in the research unit (e.g. stands) but also other factors including tree shape, dimension, stand density and terrain should be similar. However, the normality around the average should also be considered as an important factor.

Harstela (1991) found that the comparative study objective is the assessment of the impact of different conditions on productivity, when the other influencing factors (e.g. workers) are almost fixed. The basic statement in comparative time studies is that the relative time consumption by using different working methods and conditions is constant and does not depend of the worker. In a comparative time study, the same workers should be employed in both working methods being compared or in varying working conditions if the aim is to study the influence of factor condition on time consumption (Harstela, 1993).

In the time study it is necessary to eliminate the influence of the worker's performance especially when different methods are carried out in different places by different workers (Samset, 1990). Therefore, normal (average) workers should be evaluated (Acuna et al., 2012). Two relevant issues related to workers are training and motivation. Vocational training is very important in work progress. According to Harstela (1993), a proportion of variance of more than 50% between productivities can only be partly explained by work condition factors. The main part of it is most probably explained by the operator skills and motivation (Harstela, 1993). In order to evaluate the worker, the time consumption for performing an operation should be compared with the standard time. Standard time is the time required for the work to be done by an average, qualified worker. Standard time is a sum of basic time, relaxation allowance and contingency allowance, including unavoidable delays (Harstela, 1993).

Basic time is observed time multiple rating. Rating means the subjective estimation of a performance in relation to standard performance that depends of the worker quality (Harstela, 1993). For instance, if the worker's work rate is estimated to be 20% higher than the average, the performance rating is 1.2 (Harstela, 1993). If the rate is higher than the average, it may show the workers are trying hard to get paid more or the tariff is not accurate and this level of work may be harmful to the worker's health in the long term (Sarikhani, 2001). If the worker spends more time to perform an action than the average worker, it means that they need more training to reach the required level or the tariff may not be accurate (Sarikhani, 2001). In general, rating is a difficult task. In this way, economic speed has been defined to illustrate the aim of rating and to determine an effective speed (Harstela, 1993).
One of the main problems of work studies is how to produce results which can be generalized (Harstela, 1996). Due to practical and economical limitations to study the whole phenomenon,

a sample is used as a representative of the whole population. The sample should be sufficiently representative with the measurements being reliable as much as possible. In a small sample it may not be possible to generalize the results. If the results cannot be generalized they will have little scientific value.

Samset (1990) found that the number of observations required depends on the variation of influencing factors. He felt that at least 10 observations should be collected for each of the influencing factors when the variation is large. The issue of result generalization refers to different working conditions, equipment and tools, as well as workers.

Harstela (1996) defined internal and external reliability as two important concepts in generalization. Internal reliability emphasizes data collection, tools, techniques, and precision, in addition to validity of the model. On the other hand, external reliability focuses mostly on the results. It determines how much the results are representative of the whole population. According to Harstela (1996), techniques, including choosing the standard time study and performance rating (normal worker), comparative time studies, and large amount of statistics, are possible solutions for generalization (Harstela, 1996).

The main application of the time study is in calculation of productivity. According to Harstela (1993), productivity is the ratio between output (volume of wood) and input (time consumption or fund). One of the most important issues in appraisal of productivity is how to bring factors like weather conditions and operator motivation into the calculation. One way is to assume all the factors should be fixed, repeating the study or making use of a simulation model (Bergstrand, 1987). Simulation models help us to find out how productivity and cost change in different conditions, different machines and different methods.

3.5 COST CALCULATION

The cost calculation for different work phases is one of the most important parts of the work efficiency evaluation (Kantola and Harstela, 1988). Logging costs are calculated for determining the wood price and costs in production management, for planning and budgeting, to determine the right level of mechanization, and to compare different logging and transport methods. Cost calculation is also used to find the optimal phase, economically, to replace the machine, to establish piece work and bonus rates as well as to determine the profitability of the operation.
Costs are classified by fixed costs and variable costs. Fixed costs are constant over a definite period and thus independent of the production level. They will continue whether or not any timber is harvested. They include most of overhead costs and capital investments. Variable costs depend on the production amount. The costs of fuel, lubricants, service, maintenance, repair and wages increase in relation to machine cost (Kantola and Harstela, 1988).

Costs may be divided into labor and machine costs. Labor cost is comprised of direct wages and fringe benefits including annual leave, etc. (Kantola and Harstela, 1988). Machine costs

are more complicated than labor costs. The higher the machine purchase price is, the higher the machine hourly cost gets.
Annual work capacity determines the size of the machine that needs to be purchased. Machine times include scheduled in-shift time (SMH) and scheduled out of shift time. SMH is broken down into productive machine time (PMH) and machine down time due to service and repair and non-technical delay (Kantola and Harstela, 1988).

Mechanical availability and machine utilization are used to show the machine efficiency. Machine availability is the ratio between productive machine hour and sum of productive machine hour and maintenance time. Mechanical availability is mainly dependent on the machine reliability.

Mellgren (1989) concluded that in order to improve the complex machine availability, the number of components has to be simplified and reduced and/or the mean time between failures of the components has to be increased by using higher quality materials or through derating techniques (increased dimensions, lower hydraulic pressures, lower engine rpm, etc.). However, the use of derating techniques may mean a weight or cost increase. That is why the designer has to compromise between high reliability and low weight or cost to achieve the goal of designing reliable multifunction machines.

Technical weakness of the machine and unskilled operator influences the machine availability (Kantola and Harstela, 1988). Machine utilization indicates the machine reliability and operational efficiency of using the machine.

Machine utilization is derived from dividing the productive machine hour by scheduled machine hour. Machine utilization rate is always less than machine availability (Harstela, 1993).

Since the machine and operator’s cost changes with over time, it is necessary to estimate the uncertainty regarding the changes. Uncertainty by word means lack of certainty which is a state when there is more than one possible outcome available for an experiment. So the true value cannot be achieved, however its expected value can be measured by assigning probability to each outcome. Uncertainties in parameters such as price of services and equipment vary by time. The sensitivity analysis of uncertainties is used for predicting the dependent variable (e.g. unit cost) in a case when service and equipment prices change.

Brinker et al., (1989) synthesized available input data from literature, equalized them and published collection of machine work cost calculations for selected machines in the logging process, whose second edition (Brinker et al., 2002) except for the direct newer machine work cost calculations contains very useful information about changes in calculative direct costs of the machine work for comparable models of machines in a twelve-year period.

Turk (1977) published the second edition of the manual for mechanical work calculation by the modified FAO method adapted to contemporary conditions in local forestry. Winkler and associates reissued calculations (Winkler et al., 1994).

3.6 DAMAGE ASSESSMENT

Damages which occur in the stand during felling and transport depend on harvesting system, density of forest roads, terrain condition, etc. That is showed in a several studies (Doležal, 1984; Sabo, 2003; Košir, 2000).

During the harvesting, especially when winching and skidding, the residual stand is always damaged. Residual stand damage includes damage to the stem (scarring or removal of bark), crown (breaking), and root (exposed). The extent of damage is highly related to the methods used. Ground skidding with skidder, used in primary transportation because of the low cost and high efficiency, is highly damaging residual stand and forest soil (Naghdi, 2005).

For posting harvesting assessment of a logging operation, it is important to get an accurate measure of residual stand damage (Stephen and Craig, 1997). An application for residual stand damage study occurs when different harvesting systems are being compared for their ability to decrease damage to the residual stand (Stephen and Craig, 1997).

Damage to the residual stand has been reduced significantly through the low impact logging introduction in developing countries (Forest harvesting…, 1998; Reduced impact…,1998; Appling reduced…, 2002; Commercial timber…, 2002; Environmentally sound…, 2002).

Using techniques, such as pre-harvest inventory, pre-harvest planning of roads, skid trails and landings, as well as appropriate felling and processing techniques has led to a reduction in the level of damage to the residual stand (Sist et al., 1998).

Hendrison (1990) pointed out that damage to the residual stand can be minimized by means of better timber harvesting planning and proper harvesting operation techniques. Ostrofsky (2001) found that rotation lengths, cutting period, type of equipment used, operational plan, and operator skills influence the residual stand damage and also stand quality. One of the most important points about damage to the residual stand is the severity and frequency of damage. Any damage to the bark may result in injury to the cambium or sapwood which can be graded as deep or light injury (Stephen and Craig, 1997).

Serious damages to the residual stand can affect the income of the forestry industry, forest owner and future crops. This type of damage can result in the death of the tree or volume losses due to decay (Han and Kellogg, 2000). Although damage to the residual stand due to the felling operation is considerable, it has been proved that ground skidding is one of the most important phases of wood extracting considering damage to residual stand (Vasiliauskas, 1993).

In a study of Meyer et al. (1966) skidding damage to the residual stand has been compared for an articulated rubber-tired skidder using two different methods: log skidding and tree length skidding. The study found that the damage to the residual stand in the tree-length skidding was higher than the log skidding.

Different criteria and parameters are using for reporting damage. For example, Bettinger and Kellogg (1993) described the damage in terms of percentage of damaged trees by species, total scar area per hectare, and percentage of scars in three scar size categories by species.

Lamson et al. (1985) used number of trees per hectare destroyed, percent of residual basal area destroyed, bent over or leaning, broken crown branches, and number of trees per hectare with exposed sapwood wounds on the tree bole or root, due to the logging operation.

Fairweather (1991) used basal area by species and percent of basal area damaged. Damage may be reported in more detail such as diameter, species, and type of injury and interactions of them such as species by diameter classes (Naghdi, 2005).

Damages may also be reported by type or severity of injuries. Injuries to boles and roots can be classified into five classes: none, light, moderate, and severe and broken over (Meyer et al., 1966). Uhl and Viera (1989) classified injuries to trees into four classes: very hard, broken crown, offing root, and barking off. A thorough, 100-percent inventory of damage to the residual stand gives accurate rate of damage; however, sampling plots are used mainly to determine the damage as a result of attempts to save both time and costs.

Lamson et al. (1985) studied damage to residual stand due to harvesting in 12 ha of forest. They used 22 randomly distributed (800 m^2) sample plots. All studied trees inside the plots were classified into four groups, including rooting off trees, barking off, leaning of trees and broken crown. Bettinger and Kellogg (1993) used 35 randomly located 400 m^2 sample plots which represented 25% of the total stand area. They found 39.8% of the residual trees sustained some damage.

Han and Kellogg (2000) studied damage to the residual stand using four sampling methods including systematic sampling, randomly plot, systematic transect method, and sampling plot along skidding trails and cable corridor. The results showed that the systematic sampling result is closer to a 100% inventory. Because residual damage evaluations are done for a variety of reasons, no single sampling strategy is applicable for all objectives. However, it is still possible to construct a good, general purpose strategy which can be widely applied to a large number of applications (Stephen and Craig, 1997).

Timber harvesting is performed several times during the rotation period and, consequently, damage to the residual stand accumulates and tends to reach as much as total number of trees (Košir and Cedilnik, 1996).

Košir (2008a) studied tree damage in a remaining stand using two models for assessment of stand damage during the entire production period. Damage accumulates on the trees and in the stand, which is why the total share of damage tends towards the limit 100% if the number of thinning increases. Motor-manual and cut-to-length technologies were analyzed and compared according to the total number of damaged trees and the structure of trees according to the number of injuries. It was found that motor-manual technology causes more damage to trees and results in worse tree structure, meaning more than one injury.

In some another research different types of shelterwood system and group selection forests were studied to discover the extent of damage caused by logging (Košir, 2008b). Motor-manual cutting and mainly tractor skidding were included. The whole research area was regenerated on average 31%, of which 21% was damaged. A higher density of designated and undesignated skid trails was found on larger regeneration areas.

Damage to young forest and damage to remaining productive stands were compared. In this respect the whole rotation period was divided into three time intervals, the first of which designated a mixed pattern of young forest area and younger phases prior to commercial thinning, in which the last of the old mature trees are removed. The second phase is a mix of currently productive stands and some young forest, in which the first and second commercial thinning begin, until the final stage, in which young forest becomes increasingly abundant and perspective. In the last period, damage to productive stands is high (around 70%), since they have accumulated over a long time period. The fact that better forest stand opening with skid trails means less damage to young forest, but slightly more damage to mature stands the conclusion is that the abundance and position of young forest patches should dictate the density and position of skid trails.

4 MATERIAL AND METHOD

4.1 RESEARCH PROGRAMME

Research programme of study is presented in Figure 2. More detail explanation of programme is in the next chapters.

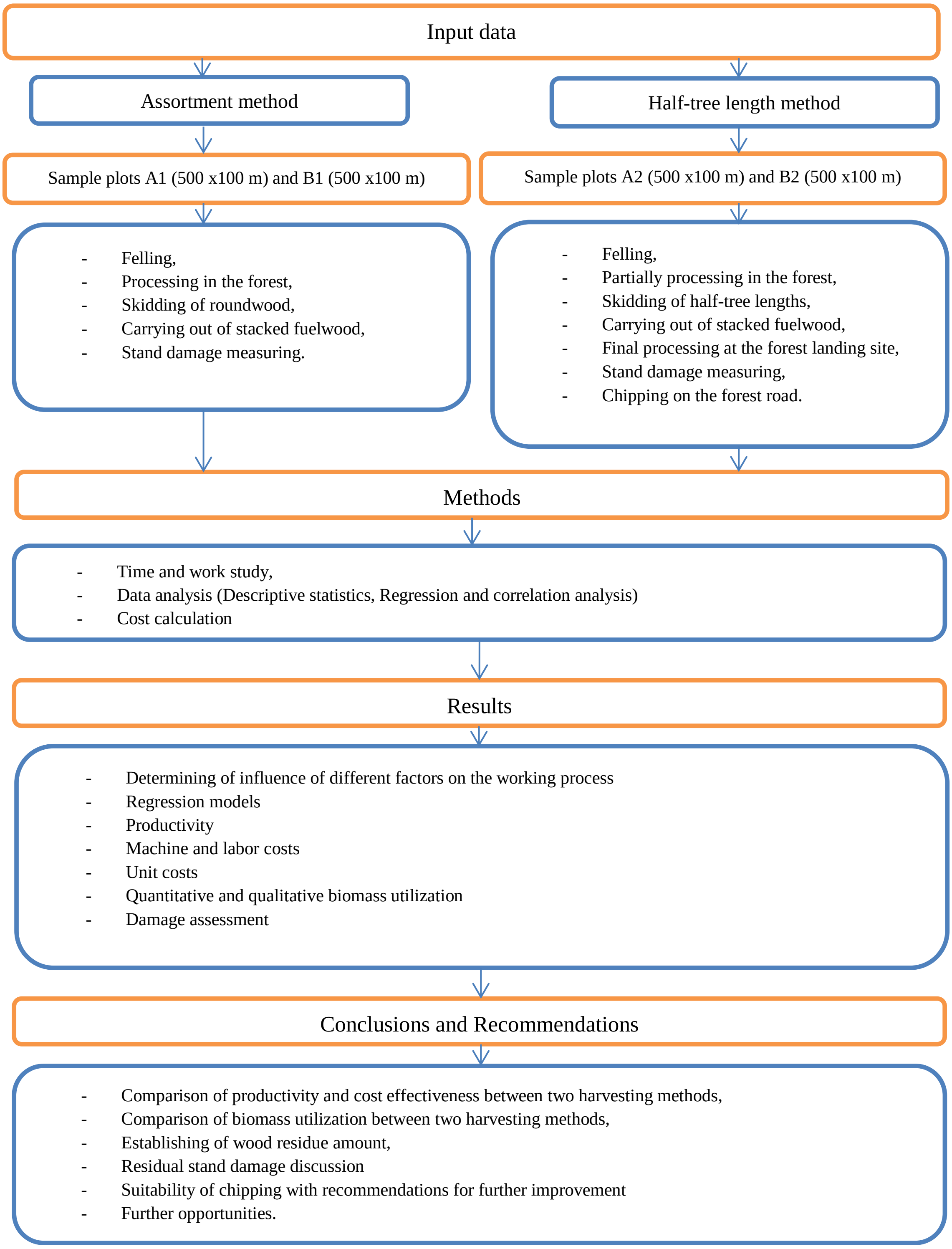


Figure 2: Research programme

4.2 STAND DESCRIPTION AND STUDY SITES

Investigation was conducted in the northern part of the Republic of Srpska in the area of municipality Ribnik (Figure 3).

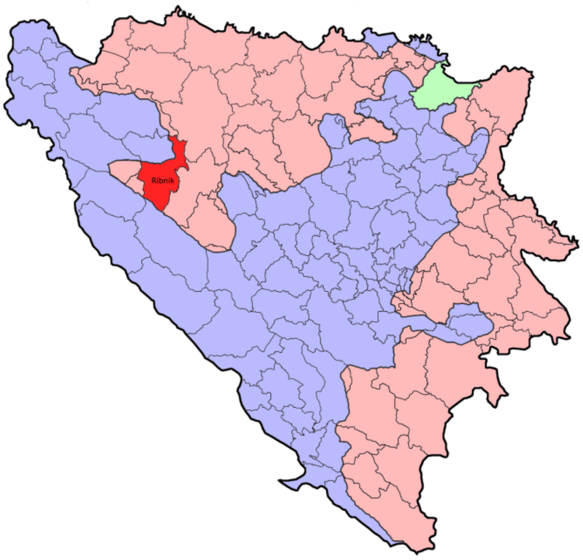


Figure 3: Location of research area

The terrain was mountainous, winter period without or with minor amount of snow. Temperature varied from 0 to 7 °C. Sample plots were placed in two compartments, 98 (A) *section a*, M.U. "Potoci-Resanovača" and 65 (B), *section a*, M.U. "Šiša-Palež" (Figure 4 and 5, Table 3).

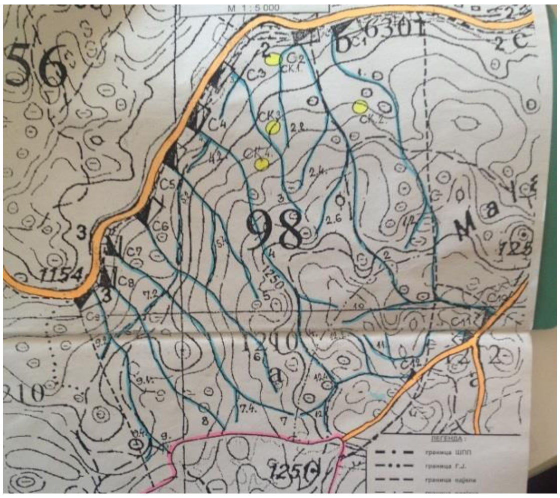


Figure 4 and 5: Compartments 65 and 98.

Altitude varies from 690 m to 1230 m. In compartment 98 is the forest of beech and fir with spruce on a series of limestone, predominantly deep soil but the beech is very dominant and was subject of investigation. In compartment 65 is the high beech forest on predominantly deep limestone and illimerised soil. Management system is group-selective in both compartments. Average diameter of trees marked for felling is 21 cm in compartment 98 and 35 cm in compartment 65. When choosing compartments it was taken into consideration that stand conditions and forest infrastructure characteristics would be average that is prevalent in beech forests in Republic of Srpska.

In each compartment 2 sample plots i.e. work fields were selected, (A1, A2, B1 and B2). Sample plots were selected in the ways that have as much as possible similar stand and habitat conditions.

Table 3: Research object description

Stand description	**Felling site A - Sample plots A1 and A2**	**Felling site B - Sample plots B1 and B2**
Method	A1 - assortment; A2 - half-tree length	B1 - assortment; B2 - half-tree length
Compartment	98 section a M.U. Potoci-Resanovaca	65, section a M.U. Sisa-Palez
Altitude	970-1150 m	690-1230 m
Inclination	15-30°	15-30°
Exposition	S-SE	W-NW
Geologic surface	Limestone, medium or deep rocky land	Limestone and dolomite, medium or deep rocky land
Climate	Mountain, humid	Mountain, humid
Stand	GK 1210 - The forests of beech and fir with spruce on a series of limestone, predominantly deep soil. (*Picea-Abieti-Fagetum*)	GK 1114 - The high beech forests on predominantly deep limestone and illimerised soil (*Fagetum montanum illyricum*)
Canopy	Dense (0.7)	Dense (0.8)
Management system	Group-selection	Group-selection
Growing stock	513.72 m^3/ha	343.74 m^3/ha
Cutting intensity	14.53 %	20.94 %
Average diameter of marked trees	21 cm	35 cm
Regeneration	Medium dense	Medium dense

Actually plots differed only by felled tree diameter and harvesting method. In this way it was isolated as much as possible factors in order to compare technologies in more reliable way.

4.3 WORK ORGANIZATION

On the each sample plot there was cutting with chainsaw and skidding with LKT 81T skidder. In order to avoid the skidding trails position influence, position of each work field was linked to the skidding trail. The research plots width was 100 m. Length of the each work field (sample plot) was 500 m.

Skidding distance is the distance from the landing sites to the place where load is formed. Skidder is not allowed to get of the skidding trail. In this experiment, because each sample plot was linked to the one skidding trail, maximum skidding distance was from the landing site (truck road) to the end of the sample plot. A landing site was formed at the end of the each skidding trail included in the research.

Winching distance is the distance on which skidder winches logs with the cable mounted on the winch. Usually skidder is positioned on the skidding trail and winches logs from the side to the trail where load is formed. Winching distance depends on the cable length. Maximum cable length on the winch was 60 m, but maximum winching distance did not exceed 50 m. Skidder was equipped with two drums winch with two cables. Skidding distance was estimated as an average distance of the each log in the load.

On sample plots A1 and B1 the assortment harvesting method was performed, where cutters cut trees with chainsaw and tree processing was done at the site. Working group consisted of two cutters. Technical and fuelwood roundwood assortments were made and staked wood (fuelwood) was produced and piled. Fuelwood was made from thinner part of stem and branches. Assortments were skidded on the forest road (landing site) with the skidder LKT 81T.

On the sample plots A2 and B2 the half-tree length harvesting method was performed where cutting trees, delimbing and partially bucking were done at the site. Stem stayed whole or cut on the transport lengths to allow easier skidding. Stacked wood was made only from branches. After that, a parts of the stem was skidded on the landing site where processing was finished.

Cutters were in group of two. Both of them were licensed cutters. While one of them worked with the chainsaw the other was an assistant. The assistant was equipped with the axe and worked on operations like cleaning the work place, moving branches away and collecting and stacking the stacked wood. After a half of working day, they switched roles. This is typical organization in local forestry. Switching of role is important because of ergonomic aspects. There is limitation that one cutter should not work with the chainsaw more than 4 hours during one day. All work was performed by the same working group in order that the influence of workers skill and devotion was avoided. The workers are elected in the way that annual productivity sheets from all cutters employed in Forest Management "Ribnik" were compared and the group with average productivity was chosen and consultations with their supervisors were made, in order to include their suggestions in workers selection. They worked with professional chainsaw Husqvarna 372XP. Skidding group was selected in the same way and consisted from tractor driver and choker-setter.

Chipping was done at the landing site. Subject of chipping was long and stacked fuelwood and residue which left after processing. During time study, the time consumption data were collected and wood input and chips output were measured. The way of measuring the fuel consumption of chipper was filling the chipper fuel tank to the top at the beginning of chipping, and refilling it again after the chipping was done. The amount of refilled fuel was measured. Water content in logs was measured with the PCE-WMH 3 hygrometer at the moment of chipping. Several measurements were done on each log and an average value was calculated. Water content of the wood was implied as water content of the chips. It was assumed that chipping process had no influence on water content.

Wood input was measured before chipping and wood chips was measured in the transport container after chipping. The conversion coefficient from solid wood volume into loose chips volume was calculated in that way.

4.4 DATA COLLECTION

4.4.1 Time study performance

Aim of the time and work study was collecting data which were used for calculation of productivity and costs of cutting and skidding of wood in comparable conditions on the sample plots for the assortment and the half-tree length method.

Cutters productivity was investigated by time and work study method (Björheden et al., 1995; Acuna et al. 2012). Time was divided into work operations. Time consumptions for work elements were measured by continuous chronometry method and records. The distance between marked trees was measured by measuring tape. Marking of place for assortment bucking was done by forest technician employed in Forest Management "Ribnik". He was not the subject of the time study.

After that, stem or parts of the stem were skidded on the forest road where processing was continued. Skidder performance was investigated by time and work study method also (Björheden et al., 1995; Acuna et al. 2012). The distance of unloaded and loaded drive were measured by measuring tape, slope gradient was measured by clinometers and the load data were collected by measuring the diameter and length of each piece of roundwood.

Processing at the landing site was done by cutters who were in groups of two workers.

Carrying out of stacked fuelwood was done with the animals (horses). This was not part of the time study but it was included in productivity and cost calculation on the basis of the standard time projected in the official planning documents for compartments 98 and 65.

When data were collected the influence of different variables on the all phases of technological process was examined. Statistical methods were performed (Descriptive statistics, Multiple Regression and Correlation analysis, etc.) using Statistica 10 software. The correlation strength was defined according to Roemer–Orphal's scale (Sabo and Poršinsky, 2005).

A preliminary investigation was conducted before the start of the official data collecting in order to make structure of working process and prepare for work. Preliminary investigation was performed where several days investigator observed working process, harvesting, skidding and chipping in order to make working process scheme by working operations. Test data collection was done and recording sheets for data collection were made.

A caliper and a measuring tape were used for measuring of wood dimension. For time consumption data collection, chronometer (stop-watch) was used. For skidding and chipping snap-back chronometry was used. The distance of unloaded and loaded drive were measured by measuring tape, slope gradient was measured by clinometers and the load data were collected by measuring the diameter and length of each piece of roundwood.
Data collection was performed during 2012 and 2013 year. Field data collection, together with preliminary investigations and damage assessment lasted 69 working days. During that period 318 trees were felled and processed and 113 skidding cycles were made. Detail review of collected data is in the chapter 5.

As a basis for preparing of structure of working time, IUFRO time concept was used, which was modified to some extent for purpose of this investigation.

Work time of cutters was divided into productive work time and allowance work time. Productive work time consists of moving, work place preparation, felling, delimbing, processing, fuelwood production and stacking. Allowance work time consists of preparatory-final time, organizational delay, technical delay and personal delay (Figure 6).

Figure 6: Structure of work time for cutters

An 8-hour working day was measured by time study. The complete work process was measured by working operations. All interruptions were also recorded. Other collected data were diameter at breast height of felled trees, diameter and length of all assortments produced and the stacked wood amount. Wood classification was done according to currently valid standards in Republic of Srpska (JUS D.B0.022; JUS D.B4.020; JUS D.B5.023; JUS D.B4.028).

Main variation in work of cutters in the assortment and half-tree length method was in the fact that in the assortment method all work operations were done in the forest, on site, but in the half-tree length method work operations up to processing (part of processing was done in the forest) were done in the forest and all other work operations at the landing site, after skidding. Producing and stacking of stacked wood (traditional fuelwood) in the half-tree length method in the forest was done from the branches only. Remaining fuelwood was produced at the landing site in the form of roundwood after skidding.

In the assortment method, final assortments were skidded and in the half–tree length method whole stems were skidded when it was technically possible, or the stem was cut on "transport lengths" to enable easier skidding. Decision on places and number of cuts was made in accordance with the position of the stem toward skidding trail, position of other standing trees, density regenerations, terrain, etc.

Work time of the skidder was divided into productive work time and allowance work time also. Productive work time consists of: empty drive, pulling out of cable, hooking, winching, load forming, loaded drive, unhooking and land stacking. Allowance work time consists preparatory-final time, organizational delay, technical delay and personal delay (Figure 7).

During the time study performance, several other factors were evidenced also: temperature, terrain inclination, exposition, precipitation, etc.

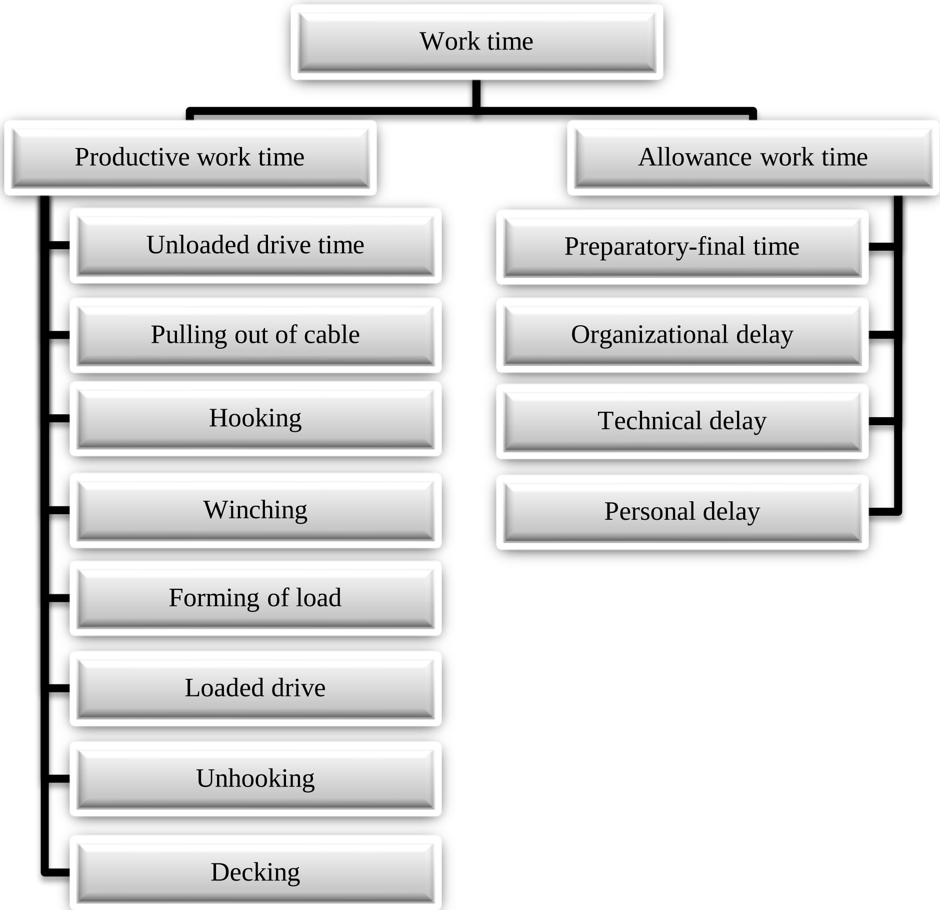


Figure 7: Structure of work time of the skidder.

Data collecting regarding wood chippers was done at the landing site and from other investigations. Wood chipping was done with different chippers. Data which could not be collected in the field were taken from other sources.

4.4.2 Damage of residual stands

After cutting and skidding, damages were evidenced on all sample plots. Measuring was done on all damaged trees above 7 cm DBH. Total survey was done and different parameters were measured:

- ✓ Height of damage;
- ✓ Breadth of damage;
- ✓ Height of damage on the tree;
- ✓ Distance from skidding trail;
- ✓ Distance from the landing site;
- ✓ Tree species;
- ✓ DBH of damaged tree;
- ✓ Other remarks (damages occurred from other, unknown reasons; existence of some obstacles in the stand...etc.)

Figure 8 and 9: Measuring of damages on the standing trees.

4.5 MACHINE DESCRIPTION

Chainsaw

Cutting was done with the professional chainsaw Husqvarna 372XP. Characteristics are presented in the Table 4.

Table 4: Characteristic of Husqvarna 372XP

Characteristics the engine	
Displacement	4.3 cu.inch / 70.7 cm³
Output Power	5.3 hp(I) / 3.9 kW
Speed idle	2700 o/min
Maximum speed	9600 o/min
Bore Cylinder	1.97 inch / 50 mm
Stroke cylinder	1.42 inch / 36 mm
Ignition system	SEM AM50
Spark plug	NGK BPMR7A
Spark plug gap	0.02" / 0.5 mm
Carburetor	HD68
Fuel tank capacity	1.62 US pint / 0.77 litre
Fuel tank oil	0.84 US pint / 0.4 litre
Oil pump	Adjustable flow
Oil pump capacity	4-20 ml/min
Cutting equipment	
Chain step	3/8"
Guide bar length, min-max	15"-28" / 38-70 cm
Chain speed, max	70.21 fts / 21.4 m/s
Dimensions	
Weight (excl. cutting equipment)	13.4 lbs. / 6.1 kg

Figure 10: Crosscutting with Husqvarna 372 XP

Skidder

Skidder used for the investigation was LKT 81T, Slovakian forestry cable skidder. Characteristics of the skidder are presented in Table 5.

Table 5: Technical characteristics of the LKT 81T skidder

	LKT 81 T
Total weight (kg)	7145
Max. Speed (km/h)	30
Engine power (kW/hp)	72.25/96.82
Engine manufacturer	DS Martin
Engine type	Z 8002.138
Number of cylinders	4
Cylinder volume (cm³)	4562
Max. fuel consumption (l/h)	17
Max. oil consumption (l/h)	0.072
Cable length (m)	60
Cable diameter (mm)	14
Fuel tank capacity (l)	70

Figure 11: Work site with LKT 81T skidders

Wood chipper description

Wood chipping was done with the Jenz HEM 700 and Pezzolato PTH 1300/1500. In calculations Jenz HEM 561 DQ was also included in order to cover wider range of chippers by the capacity. Characteristics of chippers are presented in Table 6.

Table 6: Chippers characteristics

Chipper	**Jenz HEM 700**	**Jenz HEM 561 DQ**	**Pezzolato PTH 1300/1500**
Max. input diameter (cm)	70	56	90
Woodchips output (loose m/h)	160	120	260
Engine power (kW/hp)	522/700	360/482	858/1150
Fuel consumption (l/h)	60	45	80
Feed width (mm)	1000	1000	1200
Feed height (mm)	700	650	900
Rotor diameter (mm)	1040	820	1500
Number of blades	10	10	2
Total weight (kg)	17500	13300	33000

Figure 12: Jenz HEM 700 and Pezzolato PTH 1300/1500

Truck and crane description

Truck used for feeding of chippers was Mercedes Actros 2654 with Palfinger Epsilon 120Z plus crane (Table 7).

Table 7: Truck and crane description

Truck	Mercedes ACTROS 2654
Load capacity (t)	27.5
Engine	Mercedes-Benz OM 502 LA turbocharged/intercooled V8
Engine power (kW/hp)	395/537
Maximum torque	2.500 Nm at 1.800 rpm
Fuel injection	Single unit pumps with solenoid valve controlled injection
Turbocharger	Twin turbocharger
Transmission	G 240 - 16 / 11.7 - 0.69, 16 speed synchromesh with intelligent ® Electronic Gearshift II
Number of cylinders	8
Cylinder volume (cm³)	15928
Fuel tank Capacity (l)	385
Crane	**Palfinger Epsilon 120 Z Plus**
Lifting moment (kNm)	111
Slewing torque (kNm)	28
Slewing angle (degrees)	425
Max. outreach (m)	9.6
Operating pressure (bar)	260
Weight (kg)	2080

Figure 13: Mercedes ACTROSS 2656 with Palfinger Epsilon 120 plus crane

4.6 WORKING OPERATION DESCRIPTION

All activities from felling to delivering were classified into several working operations.

4.6.1 Moving

Work operation Moving is the operation during which working group (cutter and assistant) walks from one tree, where they finished the work, to another marked tree. During that, they carry chainsaw and other support equipment. Usually they move along cutting field which are marked with the red color lines on the standing trees in the stand. Cutting field is an area where one cutting group is working. The cutting field width should be equal to the double height of the average tree in the stand. Cutters start from the landing site and move uphill, cutting tree by tree.

4.6.2 Preparing of work place

Preparing of workplace starts at the moment when workers reach to the next tree and finish when Felling starts. This operation includes setting of chainsaw into operation and workplace cleaning. Workplace is cleaned from all obstacles which could hinder felling, like rocks, regeneration, etc. A cutter and an assistant are both engaged in this work. Also within this work operation shaping of stem base is done, because irregular stem base could obstruct directed felling. Decision in which direction tree should fall is also made. This is very important for safety. In forestry practice there are two felling direction, general and individual. General felling direction is projected in the technological map of felling area and it is based on the terrain shape and position of skidding trails. Individual felling direction depends on the position of each tree in the stand toward other trees, regenerations, obstacles and other factors, which could influence the felling direction. Cutters are allowed to change general felling direction for individual tree if they have reasonable explanation like safety, regeneration preserving, etc. Technological map is created in scale 1:5000 or 1:2500 and in the map are drawn skidding trails, landing sites, felling and skidding direction, etc.

4.6.3 Felling

Felling begins when the cutter starts to perform sink-cut and lasts until the moment when the tree falls to the ground. This operation consists of sinkcut, backcut and using of wedge if necessary (Figure 14).

Figure 14: Felling the tree

4.6.4 Delimbing

Delimbing begins after felling and lasts until all branches are cut off from the stem. Both workers are engaged in this work operation. The cutter starts from the thicker side of the stem and the assistant removes branches which could hinder and cuts off some thinner branches with an axe (Figure 15).

Figure 15: Delimbing of the tree

4.6.5 Processing

Processing follows after delimbing and implies cutting of stem in assortments and assortment processing (Figure 15 and 16). Bucking and crosscutting is performed after forest technician who is an expert for JUS standards, marks the places on the stem where they should be cut. In the assortment method cutting is performed in the forest, and in the half-tree length method, in the forest stem is only cut in the transport lengths and final cutting is done at the landing site. Processing also includes forming of the assortment front because of easier skidding, removing of knots, etc.

Figure 16 and 17: Processing of the stem

4.6.6 Production of fuelwood

Production of fuelwood in the assortment method is a production of billets and small billets from less quality parts of the stem and branches up to 25 cm diameter. Dimension of billets are 95-105 cm length and 7-25 cm diameter and small cuttings 90-120 cm length and 3-7 cm diameter (JUS D.B5.023). One part of fuelwood remains as roundwood. In the half-tree length method stacked fuelwood was made only from branches.

4.6.7 Stacking of fuelwood

Fuelwood is stacked in the piles (Figure 18). This job is done by the cutter’s assistant and the cutter helps if necessary. In general, wood is stacked in piles because of measuring of cutters productivity and as a preparation for carrying out with animals.

Figure 18: Stacking of fuelwood

4.6.8 Preparatory - final time

Preparatory-final time includes all activities related to workers arriving at the working place, taking and studying of work orders, machinery preparation for work, etc. At the end of the day it includes cleaning tools, service and maintenance (Figure 19). This is related to all work phases.

Figure 19: Maintenance of skidders

4.6.9 Unloaded drive

Unloaded drive begins when the skidder starts going from landing site and finishes with positioning of tractor for collecting wood. In these investigations empty drive was always uphill.

4.6.10 Pulling out of cable

During work operation Pulling out of cable, the choker-setter, and sometimes with help of skidder driver, pulls out the winching cable in the felling site to the assortments which are dispersed. Winch has two main cables and each cable has 5 or 6 binding hooks.

4.6.11 Hooking

Hooking is a work operation during which the assistant and sometimes the skidder driver bind the assortments or part of the stem (Figure 20). By using hooks they bind several assortments for one cable. Number of assortments usually depends of their volume and position in the felling stand.

Figure 20: Hooking of assortments

4.6.12 Winching

Winching is wood skidding on the ground to the skidder which is on the skidding trail (Figure 21). Cycle could be repeated several times while all assortments for full load are not collected.

Figure 21: Winching of assortments

4.6.13 Forming of load

Forming of load begins when all assortments are winched to the skidder (Figure 22). Usually, the assistant repeats binding in order to prepare them for rising of assortment fronts of the ground and for skidding. Skidder driver is in the skidder and winches assortments on the skidder ramp. This work operation may be dropped in some cases, especially when number of assortments in the load is less and assortments have less volume.

Figure 22: Forming of load

4.6.14 Loaded drive

Loaded drive starts after forming of load and ends when the skidder arrives at the landing site, it is done only on the skidding trails (Figure 23).

Figure 23: Loaded drive

4.6.15 Unhooking

Unhooking is unbinding of load on the landing site (Figure 24). This job is done by the skidder driver while the skidder assistant stays in the felling site to find assortments for the next cycle.

Figure 24: Unhooking of assortments

4.6.16 Decking

Decking is work operation during which the skidder removes unhooked load from the road in order to make space for other wood (Figure 25). The skidder has specially constructed rump on its front side for that purpose.

Figure 25: Decking

4.6.17 Processing at the landing site

Processing at the landing site is done in the half-tree length harvesting method. Landing sites in the forest are placed at the linking between forest road and one or more skidding trails. Surface of landing site depends on the expected amount of wood, work intensity and speed of wood delivery. Also terrain characteristics are often limiting factor for size of landing site. Usually construction works consists of surface enlargement, land clearing, filling with gravel and construction of drainage canals. In some cases, when the wood transport by trucks goes continuously, the skidded wood can be temporary stored along forest road without creating the special area for the landing site.

In the assortment harvesting method, the purpose of landing site is temporary wood storage between primary and secondary transport. In the half-tree harvesting method at the landing site, processing of skidded stems or part of stems is done. Processing is bucking into the logs and roundwood fuelwood (Figure 26).

Figure 26: Processing at the landing site

4.6.18 Chipping

Chipping of wood is defined as a procedure for the forest biomass processing in the form suitable for use in power generation, and the need for chipping of forest biomass is based on enabling the automation of handling wood chips, economical transport and easier drying and combustion of wood chips (Šušnjar, 1998). Chipping is performed mainly at the forest landing site. Chips can be produced from small branches, twigs, leaves, residue processing and all other wood assortment. In case of this research, there was no technological solution for carrying out branches, twigs and others felling residue and for chipping was available fuelwood in stacked and roundwood shape and other logs. Residue which could occur during wood processing at the landing site in the half-tree length harvesting method could be available for chipping also. Possibility for such occurrence is one of the research hypotheses. Feeding of chipper was done with the crane mounted on the truck (Figure 27).

Figure 27: Chipping of roundwood fuelwood at the landing site

4.6.19 Delay times

Delay times are times that are associated to productive working time. It can be said that delay time is unwanted time consumption in each work phase. The aim of each work organization is that delay times would be as reduced as possible.

There are three types of delay time:

- ✓ Personal delay time is the interruption or non-working time such as resting, physiological needs or any other breaks related to the personnel.

- ✓ Technical delay time consists of delay types including chainsaw chain breaking and replacing with a new one, chain sharpening, chain pinching, down time of the skidder etc.

- ✓ Operational delay is related to untimely planning. For example, when there was no accessible fuel during working time, and therefore it should be transported from another place, or required spare parts are unavailable, it falls in this category. In skidding, when the wood is not ready for skidding or the operator has to wait for preparing logs, it falls in this category etc.

4.7 DATA ANALYSIS

4.7.1 Time study analysis and calculation of productivity

Field data were collected in prepared recording sheets. Data processing followed the data collection. The data about all assortments and achieved times were processed with the descriptive statistics, in the first place. Dimension of processed wood were measured according to JUS (JUS D.B0.022). Assortment volume was calculated with Huber or

Smalian's equation if length was above 6 meters. It was calculated: mean volume per tree, average number of assortments per tree, relative share and structure of quality classes.

In skidding, average number of assortment per cycle, average diameter, average length, average volume of pieces and average volume of loads were calculated.

In time analysis sum and average time for all working operations were calculated in the first, for both, cutting and skidding. After that, there was the examination of different variable influence on time consumption of individual work operations, for example, the examination of breast height diameter (DBH) of the tree on felling time, delimbing time, etc. During the skidding, there was the examination of distance and load volume impact on time comsumption of unloaded and loaded drive, forming of load, etc.

All investigations were done with single or multiple regression analysis. Mathematical models were made for work operations where significant influence was being proved.

After statistical data processing, productivity was calculated. Cutting productivity was calculated for DBH classes of 5 cm and for each working method. In work operations where dependence on one or more variables was evidenced, the value for specific independent variable was included in productivity model, while in work operations where no influence was evidenced, mean values were used for productivity model calculation (Nurminen et al., 2006).

Productivity was calculated according to the time for each work operation calculated by the regression equation in cases where significant dependence from influencing factors was established or the mean values were used if there was no dependence. The sum of work operations was multiplied with coefficient of allowance time and divided with the volume of wood.
General form of equation for productivity is (3):

$$P_e = \frac{y_1 + y_2 + \cdots + y_n}{V} \times At \qquad \ldots(3)$$

- P_e - productivity (min/m^3),
- $y_1, y_2 \ldots y_n$ - work operations time consumption (min),
- V - wood volume m^3,
- At - coefficient of allowance time.

4.7.2 Statistical analysis

Statsoft Statistica 10 for Windows was used as the statistical package for the data analysis. F-value and R were chosen as statistical parameters for selecting the best-fit model. The F-value and R-value are statistical measures used to determine the amount of influence that an independent variable has on the dependent variable. The p-level represents the level of significance of the statistical test. The p-value can be set at different alpha levels depending on how precise results should be. In this case alpha level is set at 0.05. The F-value shows level of influence that variable has on the dependent variable. The null hypothesis would be rejected if the test results indicated p-value larger than 0.05 and difference in time consumption could be result of random variation (Mousavi, 2009; Nurminen, 2006).
Graphical analyses were based on the scatterplots of data. Comparison between methods was done with Multiple Regression with dummy variables.

4.8 COST CALCULATION

For comparison of some machine suitability in different working conditions or for different technologies in similar working conditions, it is useful to compare productivity expressed in measuring units. Beside productivity it is necessary to compare costs too.
As a measuring unit can be used unit costs expressed per product unit and it is calculated as quotient of working cost per time and productivity unit (Vusić, 2013). Time is usually 8-hour working day or working hour where 30 min main break (lunch time) is included. For comparative cost analysis in utilization of wood it is best option to use direct cost of machine work (machine rate) which consists of fixed and variable costs. It is especially important when comparing costs in public forest companies and private company costs. Namely, in integral forest management, possibility of selection of the so-called overhead cost (general, indirect cost) is very limited which is related only for wood production.

So, traditionally overhead cost are awarded to direct costs according to some key and that way labor costs of wood production are gained. Taking into consideration that other staff employed in public forest company can be appointed in preparing and supervision and even in performing work, uncritical comparison of labor costs in public and private forest company should be avoided (Vusić, 2013).

Direct machine work cost is determined by cost calculation using some calculation method and on the base of the input data. Depending on availability of the input data, calculation can be distinguished as calculation backward, calculation forward and middle calculation. Most used calculation methods in forestry are according to Miyata (1980) and according to FAO (1992). These methods are often modified in dependence of the input data availability and target precision of calculation.

For machine work calculation it is necessary to calculate fixed costs of the machine (depreciation, investment costs and possible tax costs, insurance and garaging) and variable machine costs (the cost of fuel, lubricants, spare parts, replacement and maintenance of wear parts) and the cost of workers. In the case where all or most of the data needed for calculations are available and based on their true records of an engine in a sufficiently long period, direct cost calculation of machine work is done backwards.

For newly purchased machines for which there are no their own data to determine direct machine work cost, forward calculation is used, based on estimated data, or generalized data for a particular group of machines. During the machine use, most often way to calculate the direct labor cost are medium calculations based on their own specific and comparative data available.

Basic concept in direct cost calculation of machine work in wood production is the calculation of direct machine cost per hour during exploitation period. Fixed and variable costs are usually calculated for part of working time during which motor of machine is operating, i.e. machine hour and is later recalculated in hours in order to be connected with labor costs.

Fixed machine costs in contrast to variable arise as a consequence of time rather than increasing of work. So these costs do not depend of machine usage intensity, but of machine lifetime usage in years or machine hours. Machine hour is the most suitable unit for the time usage expression, but also a logical basis for the allocation of variable costs (fuel, lubricants, spare parts, replacement and maintenance of wear parts). Also, depending on the evidence method, working hour can be used in calculations.

In ideal conditions machine lifetime usage should match to normal usage time in which working costs are lowest. Namely, the shorter the machine service life is, the higher labor costs are; due to larger amount of depreciation, and if extended labor costs are higher due to rising costs of maintenance and repair of the machine (Turk, 1977).

Depreciation cost of the machine reduces its value at the end of the depreciation period. For the purpose of machine work direct cost calculation, depreciation life should match service life of the machine as opposed to the accounting calculations whose goal may be reduction of profit before tax, using the minimum legally allowable amortization period.
Discrepancy between depreciation period and service lifetime is the most noticeable in examples when machine continues to work without accounting value after depreciation period is finished by accounting rules (Cost control…, 2002). Although this could be a consequence of willingness for tax saving; most often this situation is a consequence of insufficient investments, which are compensated with machine lifetime expansion even if the risk from extra costs for maintenance and repairing arises.

The investment cost depends on the origin of funds for purchasing the machine. When using own funds, the investment cost is equal to the sum of purchase price and interest on capital that could be realized on financial market over the lifetime of the investment. In case of using loan funds, the investment cost is equal to the sum of purchase price and load costs – insurance, procedures, interest over the life of the investment.

Specially, it is important to evaluate costs properly when comparing the work cost of machines considerably different purchase prices (Cost control…, 2002).

In some cases wheeled forest machines, depending on the need, can be registered for traffic on roads, if they meet the technical requirements for vehicles on the road, and they have certain costs and taxes. Insurance costs depend on the agreed insurance premium, and costs of garaging depend on the annual utilization of the machine and work organization. The above costs are usually stated in the annual percentage from the purchase value of the machine (Vusić, 2013).
Variable costs are calculated on the basis of an average cost of service, the unit price and the average prices of fuel, lubricants, spare parts and replacement of wear parts in the analyzed period.

In the event of the inaccessibility of specific data, the cost of the fuel can be calculated on the basis of specific fuel consumption, engine power and the estimated load factor (Miyata, 1980) and the cost of the lubricant can be estimated at 5-10% of the cost of fuel (Cost control…, 2002).

The maintenance cost, together with spare parts can be estimated as a percentage of depreciation in case of inaccessibility of specific data (Miyata, 1980; Cost control…, 2002) and the cost of the replacement of consumable parts (chain, guides, gear, tires) is determined on the basis of normative life.

The worker cost consists of gross wages, benefits and contributions to gross wages and material labor costs. For calculation of calculative machine work, overall worker cost in analyzed period is reduced on working hour.

4.8.1 Data collection for cost calculating

For calculation of direct machine work costs modified FAO methodology was used (FAO, 1992) according to calculation scheme used in Public Company "Šume RS". For all investigations 8-hour working day was used. For chainsaw and animals average number of working hour per year is 1680, for skidder 1640 and for chippers 1600.
The machine depreciation (D) was calculated by linear method on the basis of purchase price (C_p) and service payback period (c) (4). Payback period for chainsaw was 2.5 years, animals 9 years, skidder 5 years and chippers 8 years.

$$D = \frac{C_p}{t} \left[\frac{EUR}{year}\right] \quad \ldots (4)$$

The investment cost (C_i) was calculated on the basis of depreciation (D), machine service lifetime (t) and annual interest rate (p) of 7 % (5).

$$C_i = 0.0p \times \frac{D}{2} \times (t+1) \left[\frac{EURO}{year}\right] \text{(Turk, 1977)} \quad \ldots (5)$$

The insurance cost (C_{is}) was calculated only for forest truck and consists of registration costs, road fees and insurance premiums. Remain machine value at the end of depreciation period was calculated as 10% of purchase price. Annual cost for spare parts and maintenance (Cspm) for all machines was estimated as 50% of depreciation costs.

Costs for fuel and replacement spare parts were calculated on the basis of normative consumption and unit prices.

Annual fixed and variable costs were recalculated on the working hours and associated with the labor costs according to calculation used in Public Company “Šume RS”.

5 RESULTS

5.1 CUTTING

5.1.1 Description of cutting sample

In the study 318 trees were felled of which 163 in the assortment method (sample plots A1 and B1) and 155 in the half-tree length method (A2 and B2). Average diameter of felled trees on sample plot A1 is 30.01 cm and varies from 9 to 54 cm, on sample plot B1 49.24 cm an varies from 23 to 78 cm. On sample plots A2 and B2 average tree diameter is 27.22 cm and 50.67 cm respectively and varies from 10 to 49 cm on A2 and 18 to 69 cm on B2 (Table 8). DBH distribution of felled trees is presented in Figures 28, 29, 30 and 31.

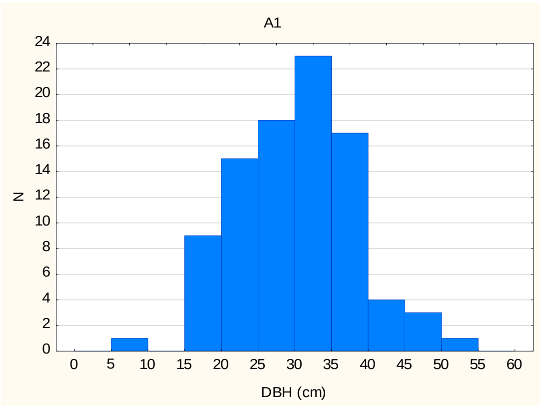


Figure 28: DBH structure of felled trees – A1

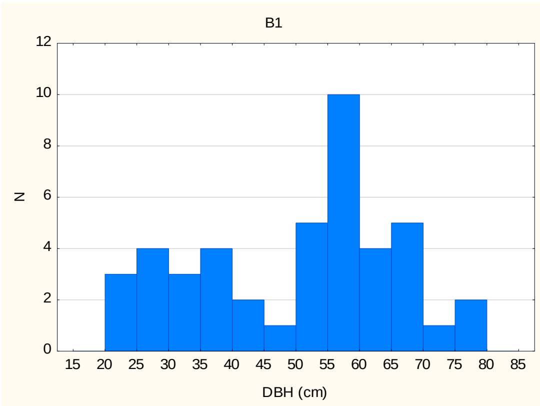


Figure 29: DBH structure of felled trees – B1

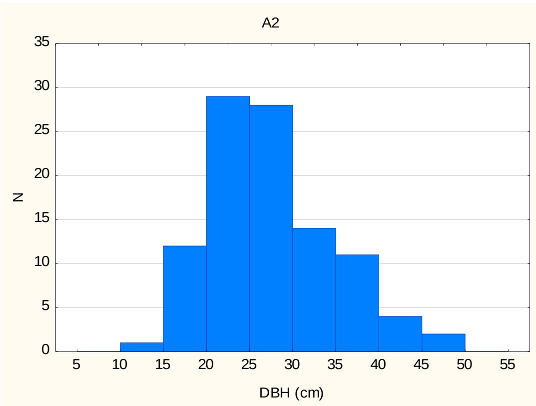


Figure 30: DBH structure of felled trees – A2

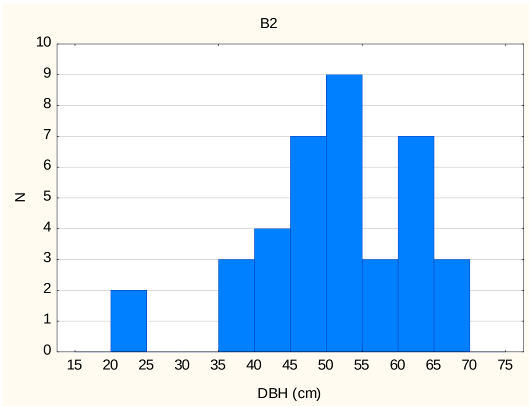


Figure 31: DBH structure of felled trees – B2

Total volume of produced wood was 507.25 m^3, of which 277.82 m^3 in the assortment method and 229.43 m^3 in the half-tree length method. From total amount of roundwood 231.67 m^3 was produced in the assortment method and 215.12 m^3 in the half-tree length method (Table 8).

Table 8: Cutting sample description

Sample plot	Method	N	DBH (cm)				$V_{fuelwood}$ (m^3)			$V_{roundwood}$ (m^3)			V_{total} (m^3)		
			Aver	Min	Max	Std.Dev.	X_{aver}	Sum	%	X_{aver}	Sum	%	X_{aver}	Sum	%
A1	assortment	113	30.01	9	54	8.39	0.124	14.001	*15.53*	0.705	76.172	*84.47*	0.798	90.173	*100*
B1	assortment	50	49.24	23	78	15.78	0.643	32.149	*17.13*	3.173	155.500	*82.87*	3.762	187.649	*100*
A2	half tree-length	110	27.22	10	49	7.47	0.072	1.362	*1.95*	0.629	68.593	*98.05*	0.636	69.955	*100*
B2	half tree-length	45	50.67	18	69	13.39	0.288	12.942	*8.12*	3.256	146.530	*91.88*	3.544	159.472	*100*
Σ **Total**		318						60.454			446.795			507.249	100
A1 and B1	assortment	163	35.91	9	78	14.33	0.297	46.150	*16.61*	1.469	231.672	*83.39*	1.712	277.822	*100*
A2 and B2	half-tree length	155	34.03	10	69	14.30	0.247	14.304	*6.23*	1.397	215.123	*93.77*	1.480	229.427	*100*

Share of stacked wood on sample plots with the assortment method (A1 and B1) was 15.53% and 17.13% respectively. On sample plots where the half-tree length method was performed (A2 and B2) share of stacked wood was 1.95% and 8.12%. Relative share of stacked wood was significantly lower in the half-tree length method. It was expected, if we consider described working methods. The difference in amount of stacked wood was higher on the sample plots with smaller average tree diameter if the harvesting method was the same (Figure 32).

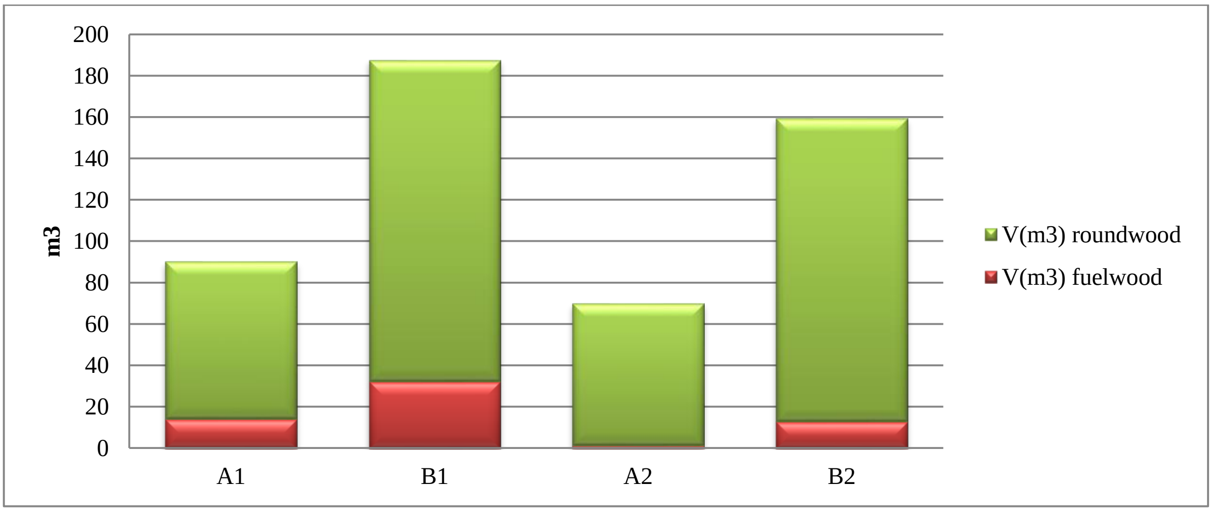


Figure 32: Ratio of roundwood and fuelwood on the sample plots

Average number of pieces per tree in the assortment harvesting method was 2.23 (A1) and 6.23 (B1). In the half-tree length method number of pieces per tree was 1.81 (A2) and 4.77 (B2).

Average length of pieces was 5.16 m (A1) and 4.95 m (B1) in the assortment method and 8.83 m (A2) and 8.66 m (B2) in the half-tree length method.

Average diameter of pieces was 25.73 cm (A1), 34.83 cm (A2), 20.01 cm (B1) and 26.90 cm (B2).

Average volume of pieces in the assortment method was 0.26 m^3 (A1) and 0.50 m^3 (B1). In the half-tree length volume was 0.30 m^3 (A2) and 0.69 m^3 (B2) (Figure 33).

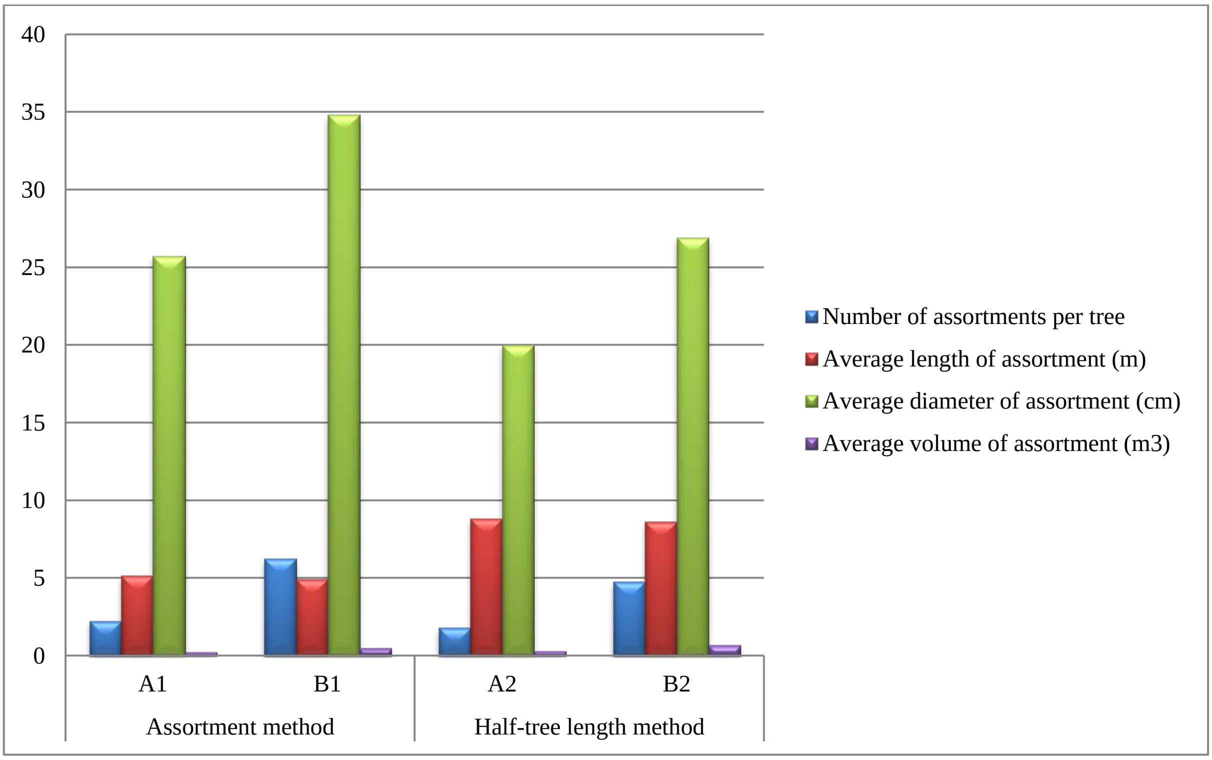


Figure 33: Characteristics of produced roundwood

5.1.2 Analysis of work operations

Total studied work time was 4519.44 min on the sample plots in the assortment method and 2502.72 min on the sample plots in the half-tree length method. Productive work time was 3469.12 min (assortment) of total time and 1913.29 min (half-tree length) with relative share of allowance time 30.28 % and 30.81 % respectively (Table 9). Consequently, coefficients of allowance time for cutting are 1.30 and 1.31.

Table 9: Descriptive analysis of cutting work time

Working method	**Assortment**	**Half-tree length**	**Assortment**	**Half-tree length**	**Assortment**	**Half-tree length**	**Assortment**	**Half-tree length**	**Assortment**	**Half-tree length**
Work operation	Average/tree (min)		Std.Dev.		SUM (min)		min/tree (MIN)		min/tree (MAX)	
Moving	2.14	1.81	1.53	1.07	348.26	279.72	0.13	0.35	8.23	5.23
Preparing of work place	0.76	0.46	1.04	0.73	123.33	71.59	0.03	0.08	7.38	4.80
Felling	1.44	1.21	1.18	0.78	234.23	187.87	0.12	0.10	6.98	3.37
Delimbing	4.44	4.16	3.37	3.07	723.69	645.38	0.30	0.67	18.63	21.08
Processing	2.44	0.96	4.19	1.81	398.42	148.44	0.12	0.12	35.35	8.85
Production of fuelwood	3.78	1.14	3.45	2.01	615.66	176.47	0.17	0.20	19.27	10.35
Stacking of fuelwood	6.29	2.61	7.17	7.11	1025.53	403.82	0.42	0.33	35.00	40.00
Productive work time (min)					**3469.12**	**1913.29**				
Allowance time (min)					1050.32	589.43				
Allowance time %					30.28	30.81				
∑ Total					**4519.44**	**2502.72**				

Productive work time was divided into work operations. Each work operation was recorded and analyzed. Most time consuming work operation in the assortment method was Stacking of fuelwood with 6.29 min/tree, then followed Delimbing, 4.44 min/tree and Production of fuelwood with 3.78 min/tree. In the half-tree length method most time consuming operations were Delimbing with 4.16 min/tree, Stacking of fuelwood with 2.61 min/tree and Moving with 1.81 min/tree. The shortest time operation in both methods was Preparing of work place (Figure 34).

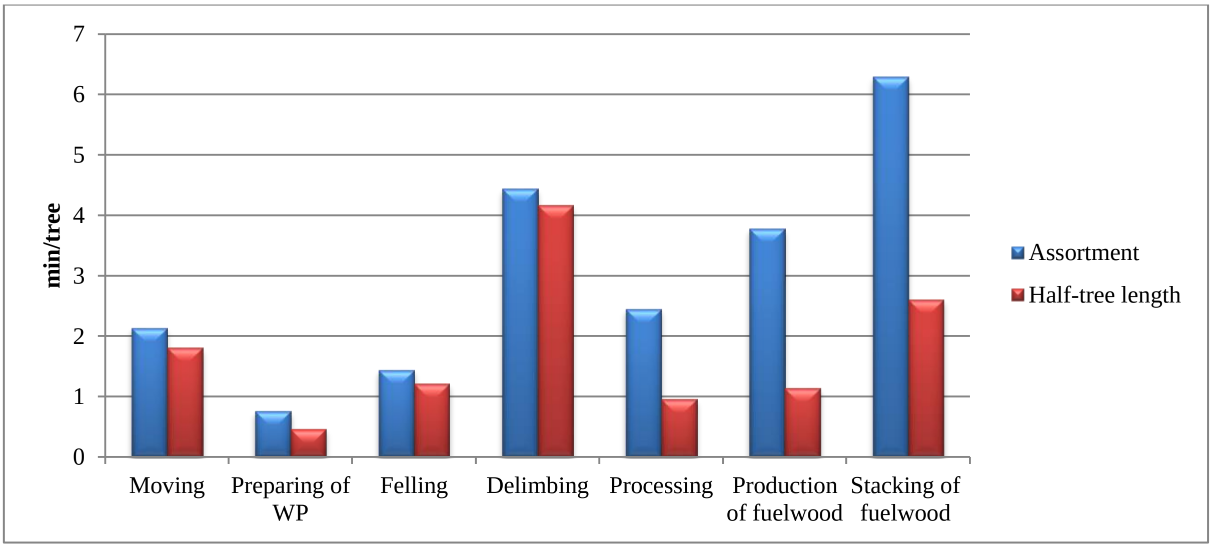


Figure 34: Structure of productive work time

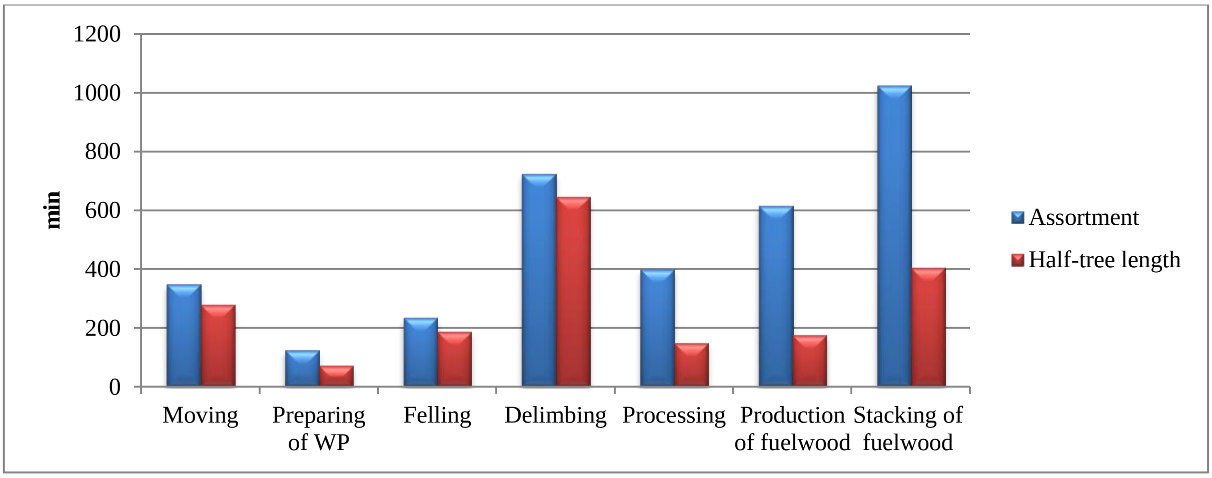


Figure 35: Total studied productive work time

Relative share of work operations in productive work time and relative share of work operations in relation on total work time is presented in the Table 10. It can be seen that the largest share in the assortment method stands for Stacking of fuelwood (29.56%), Delimbing (20.86%) and Production of fuelwood (17.75%) In the half-tree length method largest share stands for Delimbing (33.73%), Stacking of fuelwood (21.11%) and Moving (14.61%).

Table 10: The relative share of work operations in total productive work time

	Work operation	Assortment	Half-tree length	Assortment	Half-tree length
Productive work time		% of productive work time		% of total work time	
	Moving	10.04	14.62	7.71	11.18
	Preparing of work place	3.56	3.74	2.73	2.86
	Felling	6.75	9.82	5.18	7.51
	Delimbing	20.86	33.73	16.01	25.79
	Processing	11.48	7.76	8.82	5.93
	Production of fuelwood	17.75	9.22	13.62	7.05
	Stacking of fuelwood	29.56	21.11	22.69	16.14
	∑	100	100	76.76	76.45
	Allowance time %	30.28	30.81		

Structure of allowance time is presented in Table 11 and Figure 36 and 37. In both methods most of time belongs to the Personal delays, 43% in the assortment method and 51% in the half-tree length method. The following are Technical delays with share of 26% and 30%, Preparatory-final time with 19% and 11% and Organizational delays with share of 12% and 8%, respectively.

Table 11: Structure of allowance time

	Assortment	Half-tree length
	min	
Preparatory - final time	201.20	61.13
Organizational delays	120.34	47.78
Technical delays	275.34	178.39
Personal delays	453.44	302.13
Total	1050.32	589.43
Total (% of PWT)	30.28	30.81

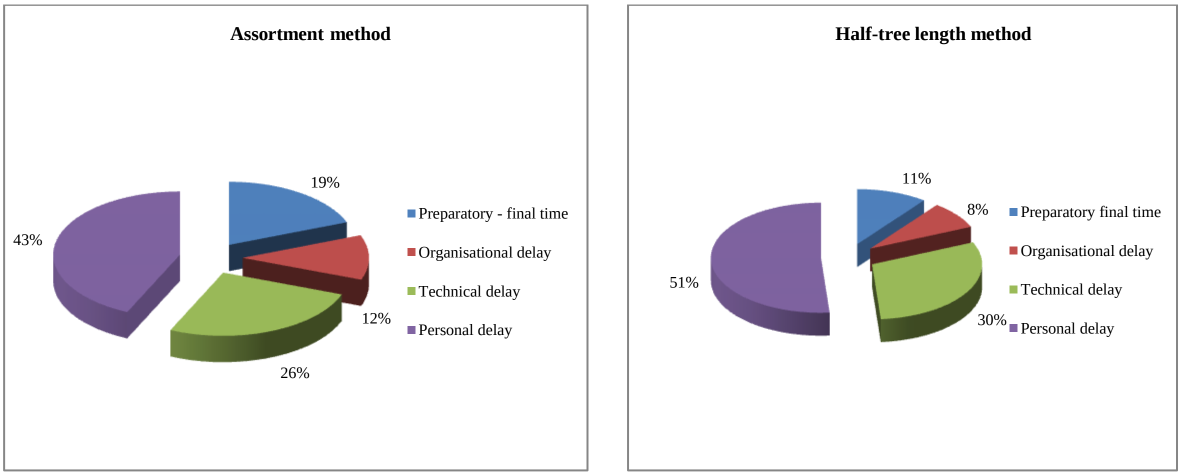


Figure 36 and 37: Relative structure of allowance time

5.1.3 Comparing of sample plots by methods

Multiple regression with dummy variables was performed in order to determine which factors influence effective work time per tree. Results showed that working method and DBH have significant influence on the level p≤0.05 (Table 12). These results indicated that further analysis should be done separately for both examined work methods.

Table 12: Regression summary for effective time per tree

N=318	**Regression Summary for Dependent Variable: min/tree** R= 0.88 R^2= 0.784 Adjusted R^2= 0.78 F(2.315)=547.31 p<0.0000 Std.Error of estimate: 7.4098					
	b^*	Std.Err. of b*	b	Std.Err. of b	t(314)	p-value
Intercept			-18.6480	1.155564	-16.1376	0.000000
Method	0.231480	0.026693	7.2248	0.833110	8.6721	0.000000
DBH	0.835179	0.026693	0.9108	0.029110	31.2889	0.000000

Analysis of variance showed strong reliability of regression model (Table 13).

Table 13: ANOVA for effective time per tree

Effect	**Analysis of Variance; DV: min/tree**				
	Sums of Squares	df	Mean Squares	F	p-value
Regress.	60100.68	2	30050.34	547.3116	0.00
Residual	17295.19	315	54.91		
Total	77395.86				

5.1.4 Analyses of influencing factors on the cutting work operations

The examination of different factor influence on the harvesting work operation time was done with regression and correlation analysis. The influence strength was presented with R, with the level of significance p≤0.05 and assessed according to Roemer-Orphal's scale (Figure 38). Mathematical models which on the best way show dependence between variables were represented with regression equations. Models were used for discussion and productivity calculation. During work operations, where no significant dependences were evidenced, mean values were used for productivity calculations.

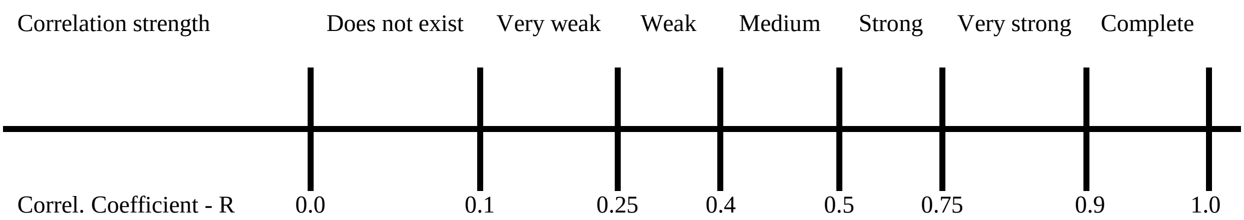


Figure 38: Roemer-Orphal's scale

5.1.4.1 Assortment method

Work operations Moving and Preparing of Work Place did not show significant difference from any examined variables. Their mean value was used for productivity calculation. Felling showed very strong dependence on the diameter breast height (DBH) of the tree with correlation coefficient R=0.82. This dependence was presented with quadratic function (Table 14). Delimbing showed very strong dependence on the DBH with correlation coefficient R=0.84. This dependence best fits linear function. Processing also showed very strong dependence on DBH. Correlation coefficient was R=0.81 and dependence was presented with quadratic function. Production of fuelwood showed strong dependence on DBH, R=0.75. The dependence was also presented with quadratic function. Stacking of fuelwood showed very strong dependence on DBH, correlation coefficient is R=0.86 and it was presented with quadratic function.

Table 14: Time dependence analysis – assortment method

Work operation	N	Independent Variable	Parameters			F test	R	p	Std.err
			intercept	b_1	b_2^2				
Moving	158	Distance (m)	No significance			0.04	0.02	0.849	1.54
Preparing of work place	130	DBH(cm)	No significance			3.93	0.17	0.049	1.03
Felling	161	DBH(cm)	0.3810	-0.0075	0.0009	315.30	0.82	0.000	0.69
Delimbing	162	DBH(cm)	-2.1889	0.1794	-	384.04	0.84	0.000	1.83
Processing	127	DBH(cm)	0.2109	-0.0699	0.0031	234.61	0.81	0.000	2.48
Production of fuelwood	161	DBH(cm)	1.2539	-0.0215	0.0021	203.89	0.75	0.000	2.29
Stacking of fuelwood	156	DBH(cm)	1.8507	-0,1583	0.0068	430.71	0.86	0.000	3.69

5.1.4.1.1 Moving

There was the examination of distance between trees influencing the work operation Moving. Results showed that correlation factor is R=0.02 and on the basis of R it can be said that there was no influence proved. The mean value, y_1=2.14 min/tree, was used for productivity calculation.

5.1.4.1.2 Preparing of work place

There was the examination of DBH influence on Preparing of work place. Results on the basis of 130 observations showed, that correlation coefficient is R=0.17 on the significance level p≤0.05. R and Figure 39 show that no significant influence was proved. The mean value, y_2=0.76 min/tree was used for productivity calculation.

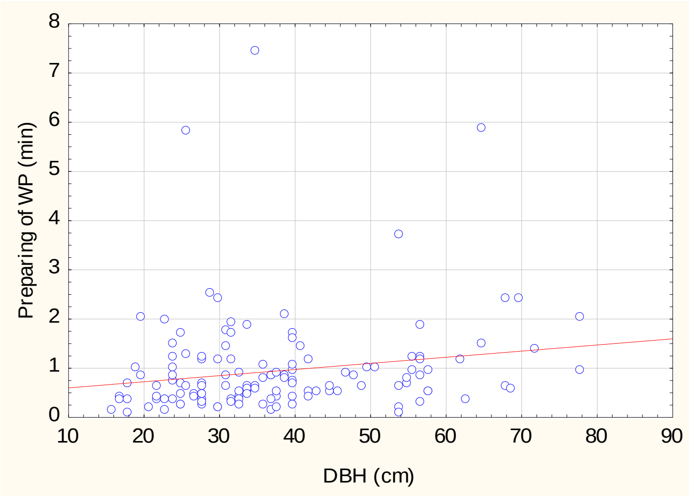


Figure 39: Preparing of work place in dependence from DBH

5.1.4.1.3 Felling

There was the examination of DBH influence on Felling. Results on the basis of 161 observations showed that correlation coefficient is R=0.82 on the significance level p≤0.05. F-test result is 315.30 and standard error is 0.69. R and Figure 40 show that significant influence was proved. The dependence was presented with quadratic function (6).

$y_3 = 0.381\text{-}0.0075x_1\text{+}0.0009x_1^2$; where: y_3-felling (min/tree), x_1-DBH (cm) … (6)

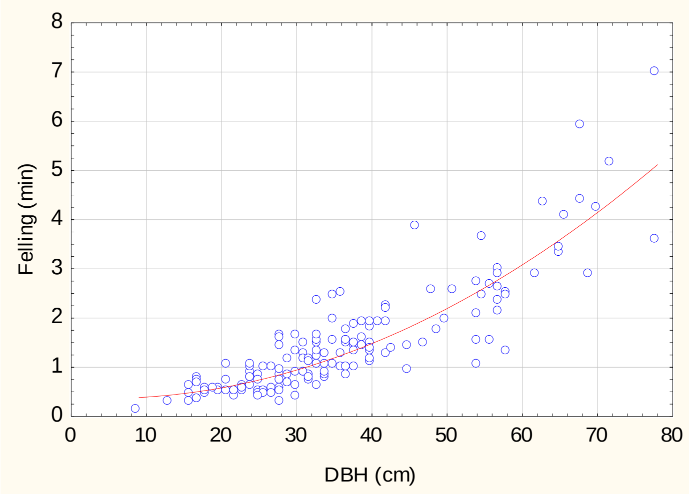


Figure 40: Felling in dependence from DBH

5.1.4.1.4 Delimbing

There was the examination of DBH influence on Delimbing. Results on the basis of 162 observations showed that correlation coefficient is R=0.84 on the significance level p≤0.05. F-test result is 384.04 and standard error is 1.83. R and Figure 41 show that significant influence was proved. The dependence was presented with linear function (7).

y_4= -2.1889+0.1794x_2; where: y_4-delimbing (min/tree), x_2-DBH (cm) … (7)

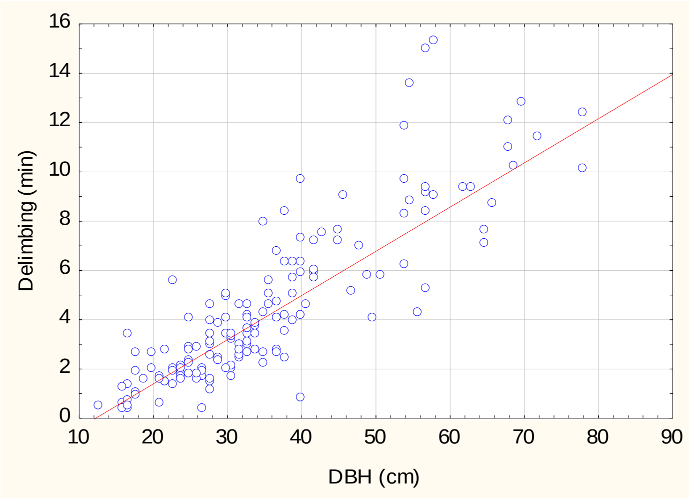


Figure 41: Delimbing in dependence from DBH

5.1.4.1.5 Processing

There was the examination of DBH influence on Processing. Results on the basis of 127 observations showed that correlation coefficient is R=0.81 on the significance level p≤0.05. F-test result is 234.61 and standard error is 2.48. R and Figure 42 show that significant influence was proved. The dependence was presented with quadratic function (8).

y_5= 0.2109-0.0699x_3+0.0031x_3^2; where: y_5-processing (min/tree), x_3-DBH (cm) … (8)

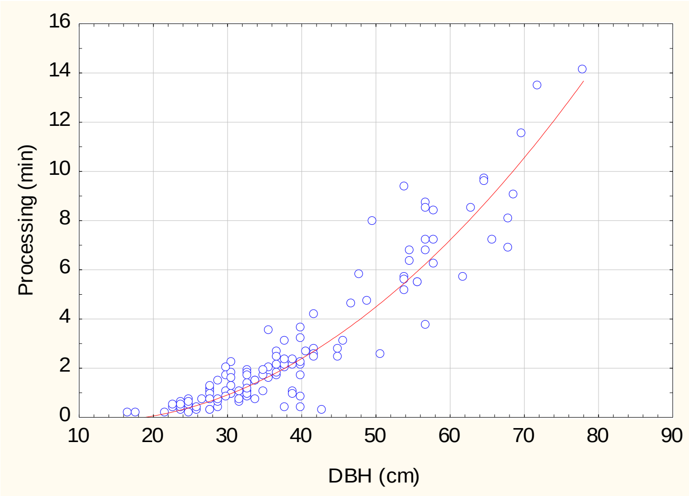


Figure 42: Processing in dependence from DBH

5.1.4.1.6 Production of fuelwood

There was the examination of DBH influence on Production of fuelwood. Results on the basis of 161 observations showed that correlation coefficient is R=0.75 on the significance level $p \leq 0.05$. F-test is 203.89 and standard error is 2.48. R and Figure 43 show that strong correlation was proved. The dependence was presented with quadratic function (9).

$y_6 = 1.2539 - 0.0215x_4 + 0.0021x_4^2$; where: y_6-production of fuelwood (min/tree), x_4-DBH (cm) … (9)

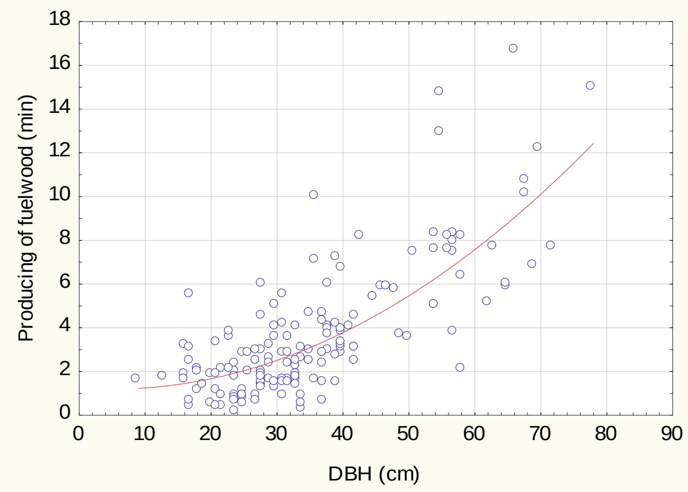


Figure 43: Dependence of production of fuelwood from DBH

5.1.4.1.7 Stacking of fuelwood

There was the examination of DBH influence on Stacking of fuelwood. Results on the basis of 157 observations showed that correlation coefficient is R=0.86 on the significance level $p \leq 0.05$. F-test is 430.71 and standard error is 0.86. R and Figure 44 show that very strong correlation was proved. The dependence was presented with quadratic function (10).

$y_7 = 1.8507 - 0.1583x_5 + 0.0068x_5^2$; where: y_7-stacking of fuelwood (min/tree), x_5-DBH (cm) … (10)

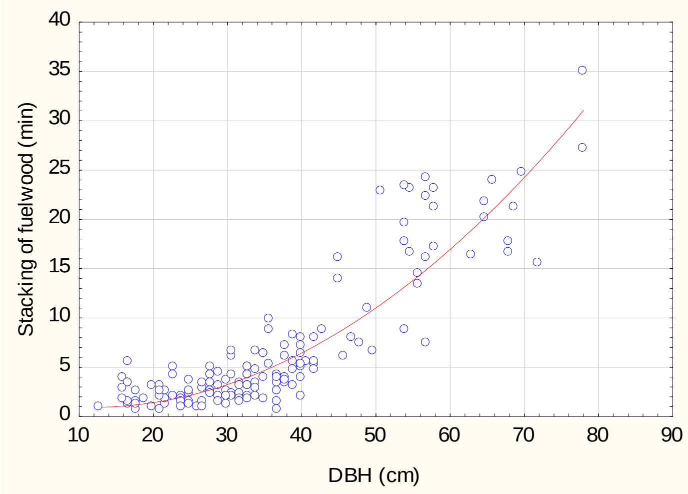


Figure 44: Dependence of stacking of fuelwood from DBH

5.1.4.2 Half-tree length method

Moving and Preparing of WP did not show significant difference from any examined variables. Their mean value was used for productivity calculation. Felling showed very strong dependence on the DBH of the tree with correlation coefficient R=0.89. This dependence was presented with linear function (Table 15). Delimbing showed very strong dependence on the DBH with correlation coefficient R=0.81. This dependence best fits linear function also. Processing also showed very strong dependence on DBH. Correlation coefficient is R=0.85 and the dependence was presented with quadratic function. Production of fuelwood showed strong dependence on DBH, R=0.70. The dependence was presented with linear function. Stacking of fuelwood showed strong dependence on DBH, correlation coefficient is R=0.68 and it was presented with quadratic function.

Table 15: Time dependence analysis – half-tree length method

Work operation	N	Independent Variable	Parameters			F test	R	p	Std.err
			intercept	b_1	b_2^2				
Moving	155	Distance (m)	No significance			8.97	0.23	0.003	1.04
Preparing of work place	91	DBH(cm)	No significance			2.14	-0.15	0.147	0.72
Felling	155	DBH(cm)	-0.4833	0.049		565,73	0.89	0.000	0.36
Delimbing	154	DBH(cm)	-1.4454	0.1600		293,90	0.81	0.000	1.80
Processing	100	DBH(cm)	0.5013	-0.0618	0.0019	260,80	0.85	0.000	0,95
Production of fuelwood	59	DBH(cm)	-1.428	0.0904		55,68	0,70	0.000	1,44
Stacking of fuelwood	51	DBH(cm)	0.0264	-0.0916	0.0045	41,65	0,68	0.000	5,28

5.1.4.2.1 Moving

There was the examination of distance between trees influence on work operation Moving. Results showed that correlation factor is R=0.23 on the significance level $p \leq 0.05$. R shows that very low correlation was evidenced. The mean value, y_1=1.81 min/tree was used for productivity calculation.

5.1.4.2.2 Preparing of work place

There was the examination of DBH influence on Preparing of work place. Results on the basis of 91 observations showed that correlation coefficient is R=-0.15 on the significance level p=0.147. R and Figure 45 show that very low negative correlation was proved. The mean value, y_2 =0.46 min/tree was used for productivity calculation.

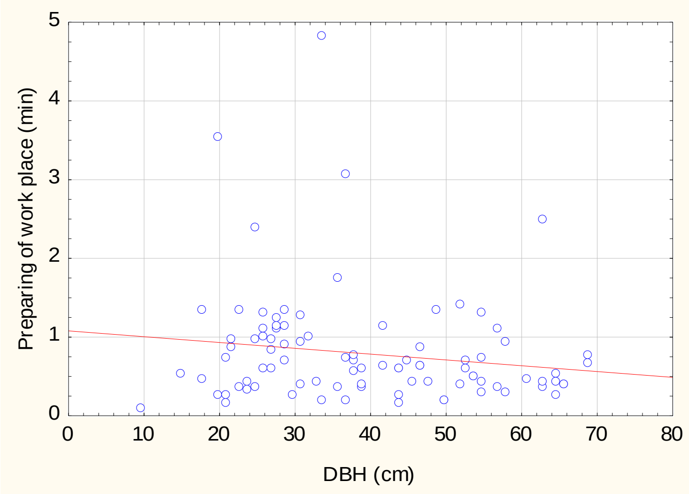


Figure 45: Preparing of work place in dependence from DBH

5.1.4.2.3 Felling

There was the examination of DBH influence on Felling. Results on the basis of 155 observations showed that correlation coefficient is R=0.89 on the significance level p≤0.05. F-test result is 565.73 and standard error is 0.36. R and Figure 46 show that very strong correlation was proved. The dependence was presented with linear function (11).

y_3= -0.4833+0.049x_1; where: y_3-felling (min/tree), x_1-DBH (cm) … (11)

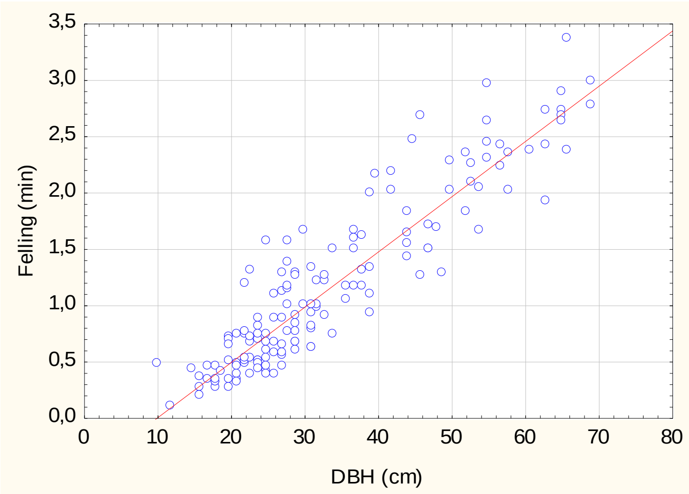


Figure 46: Felling in dependence from DBH

5.1.4.2.4 Delimbing

There was the examination of DBH influence on Delimbing. Results on the basis of 154 observations showed that correlation coefficient is R=0.81 on the significance level p≤0.05. F-test is 293.90 and standard error is 1.80. R and Figure 47 show that very strong correlation was proved. The dependence was presented with linear function (12).

y_4= -1.4454+0.16x_2; where: y_4-delimbing (min/tree), x_2-DBH (cm) … (12)

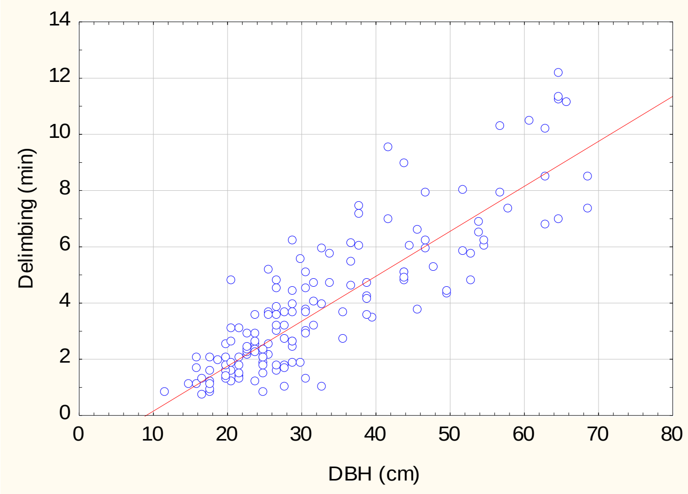


Figure 47: Delimbing in dependence from DBH

5.1.4.2.5 Processing

There was the examination of DBH influence on Processing. Results on the basis of 100 observations showed that correlation coefficient is R=0.85 on the significance level p≤0.05. F-test is 260.80 and standard error is 0.95. R and Figure 48 show that very strong correlation was proved. The dependence was presented with quadratic function (13).

y_5= 0.5013-0.0618x_3+0.0019x_3^2; where: y_5-processing (min/tree), x_3-DBH (cm) … (13)

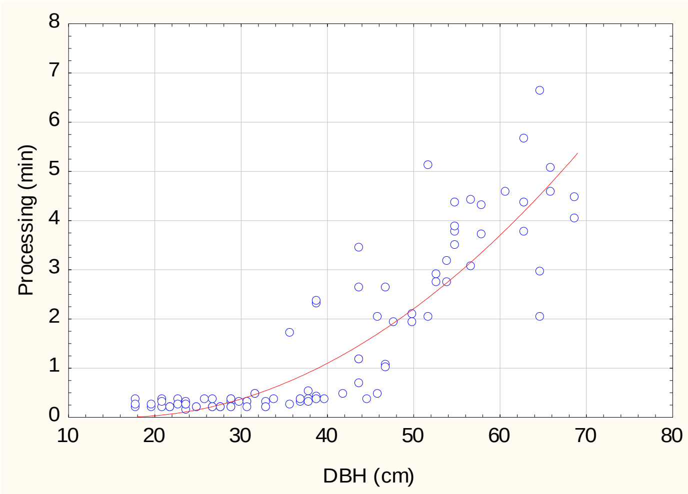


Figure 48: Processing in dependence from DBH

5.1.4.2.6 Production of fuelwood

There was the examination of DBH influence on Production of fuelwood. Results on the basis of 59 observations showed that correlation coefficient is R=0.70 on the significance level $p \leq 0.05$. F-test result is 55.68 and standard error is 1.44. R and Figure 49 show that strong correlation was proved. The dependence was presented with linear function (14).

y_6=-1.428+0.0904x_4; where: y_6-production of fuelwood (min/tree), x_4-DBH (cm) … (14)

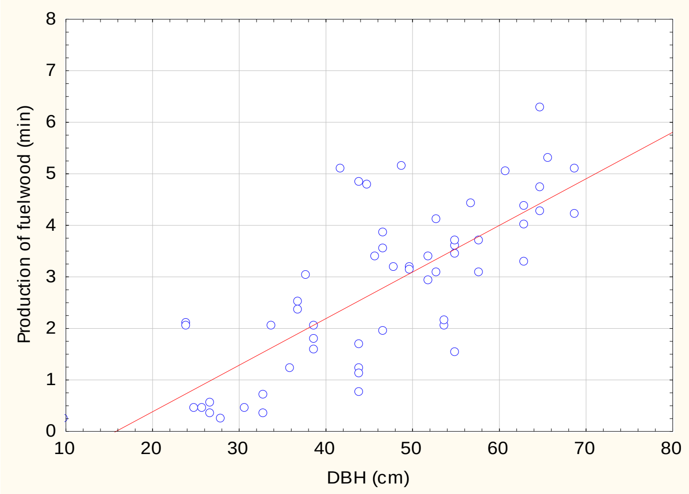


Figure 49: Dependence of production of fuelwood from DBH

5.1.4.2.7 Stacking of fuelwood

There was the examination of DBH influence on Stacking of fuelwood. Results on the basis of 51 observations (trees) showed that correlation coefficient is R=0.68 on the significance level $p \leq 0.05$. F-test result is 41.65 and standard error is 5.28. R and Figure 50 show that strong correlation was proved. The dependence was presented with quadratic function (15).

y_7= 0.0264-0.0916x_5+0.0045x_5^2; where: y_7-stacking of fuelwood (min/tree), x_5-DBH (cm) … (15)

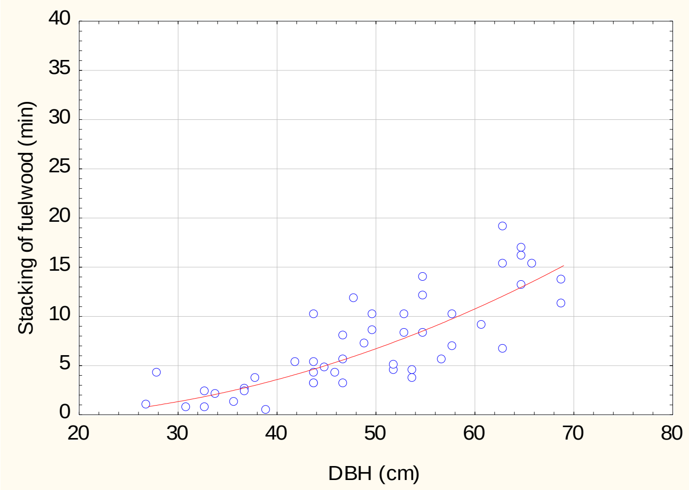


Figure 50: Dependence of stacking of fuelwood from DBH

5.1.5 Productivity of cutting

Productivity was calculated in the way that time for each work operation (y_1, y_2...y_n) was calculated with regression equation for cases where significant dependence of influencing factors was established or using the average values if there was no dependence. The sum of work operation time was multiplied with allowance time coefficient and divided with the volume of produced wood. Productivity was presented for both methods.
Relation between standard time for cutting is presented in the Figure 51. It can be seen that it takes less time for producing the unit of products in the half-tree length harvesting method than in the assortment method. The difference is decreasing with increasing of DBH.

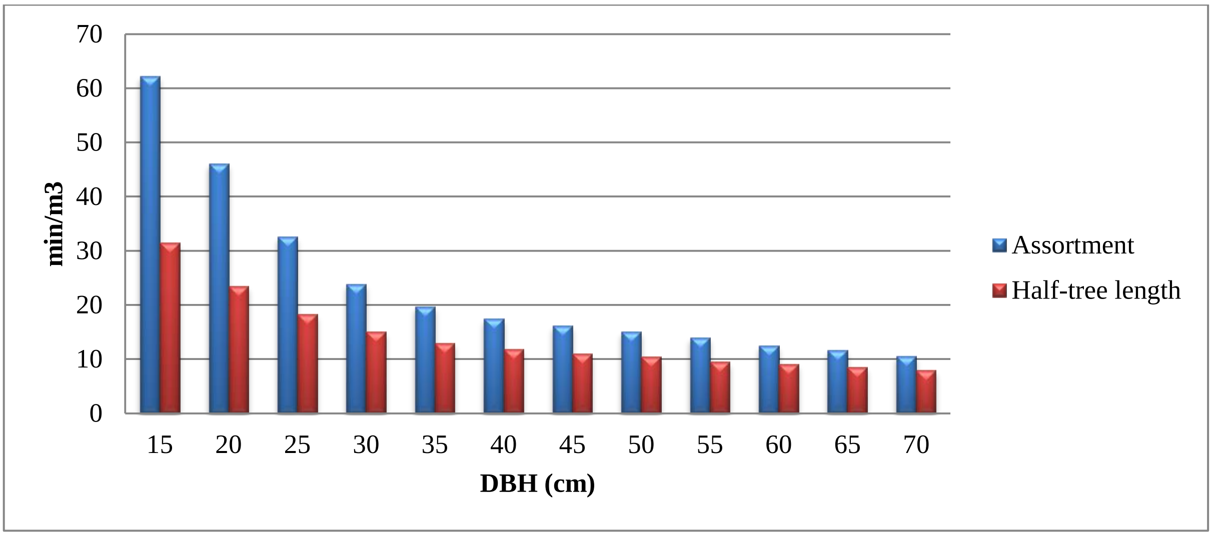


Figure 51: Relation between standard times for cutting

Productivity calculated for 8-hour working day is presented in Figure 52. Productivity constantly increases with the increase of DBH and it is higher in the half-tree length method than in the assortment method.

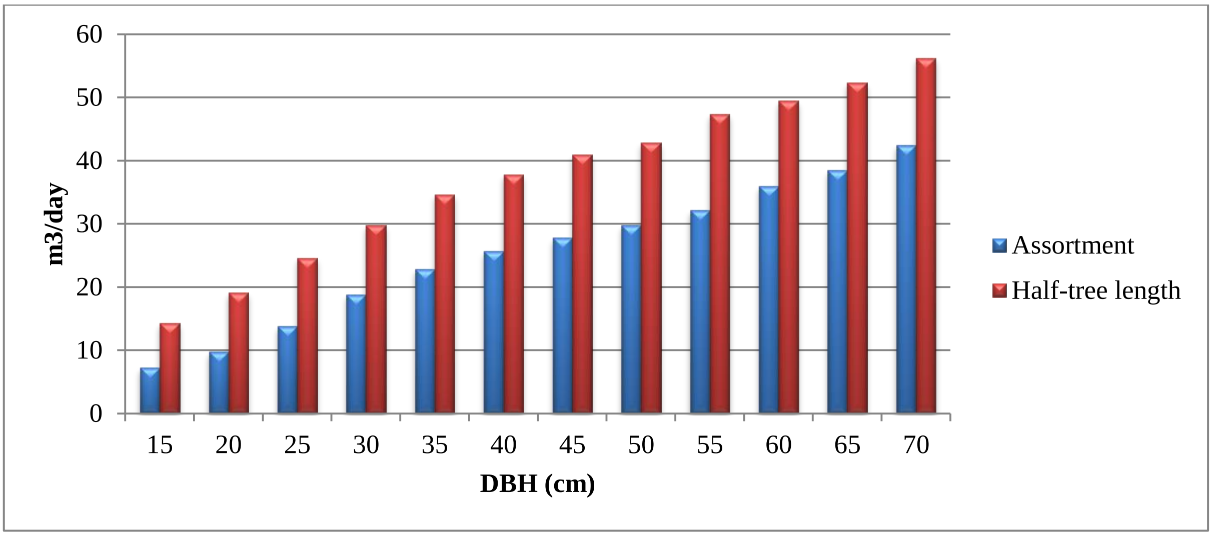


Figure 52: Daily cutting productivity for the assortment and the half-tree length method

Higher productivity in the half-tree length method confirms the research hypothesis. Reason for that is that in half-tree length method cutters do not spent much time on operations Production of fuelwood and Stacking of fuelwood as in assortment method. Part of the processing was also transferred from the stand to the landing site.

5.2 SKIDDING

5.2.1 Description of loads

Total number of studied cycles was 113. From total number, 68 cycles were the assortment method, 34 cycles on the sample plot A1 and 34 on the sample plot B1. On the plots where the half-tree length harvesting method was performed, A2 and B2, 45 cycles were studied, 22 on A2 and 23 on B2 sample plot. Descriptive statistics of load parameters was presented in the Table 16.

Table 16: Load parameters – descriptive statistics

Sample plot	Method	N cycles			Mean	Sum	Min	Max	Variance	Std.Dev.	Standard Error
A1	Assortment	34	Number of pieces in load	n	9.94		6.00	13.00	2.42	1.56	0.27
		34	Average volume of piece	m^3	0.28		0.19	0.40	0.00	0.04	0.01
		34	Load volume	m^3	2.80	95.33	1.65	4.12	0.33	0.58	0.10
		34	Piece length	m	5.38		4.28	7.31	0.74	0.86	0.18
A2	Half-tree length	22	Number of pieces in load	n	11.09		8.00	15.00	2.85	1.69	0.36
		22	Average volume of piece	m^3	0.33		0.16	0.49	0.00	0.07	0.01
		22	Load volume	m^3	3.56	78.36	0.82	5.43	1.28	1.13	0.24
		22	Piece length	m	8.97		8.08	10.53	0.52	0.72	0.20
B1	Assortment	34	Number of pieces in load	n	9.00		5.00	12.00	3.27	1.81	0.31
		34	Average volume of piece	m^3	0.57		0.25	1.02	0.05	0.22	0.04
		34	Load volume	m^3	4.98	169.25	1.27	8.68	2.68	1.64	0.28
		34	Piece length	m	5.30		3.83	7.66	0.80	0.89	0.18
B2	Half-tree length	23	Number of pieces in load	n	9.57		5.00	13.00	4.35	2.09	0.43
		23	Average volume of piece	m^3	0.75		0.20	1.64	0.10	0.32	0.07
		23	Load volume	m^3	6.62	152.31	2.03	8.48	1.91	1.38	0.29
		23	Piece length	m	9.19		6.12	14.40	4.08	2.02	0.54

Average number of pieces in load was in the assortment method 9.94 (A1) and 9.00 (B1) and 11.09 (A2) and 9.57 (B2) on plots in the half-tree length method (Figure 53). The number of pieces in load was more or less similar on all sample plots. It represents full hooking capacity of the skidder, based on the number of skidding chokers.

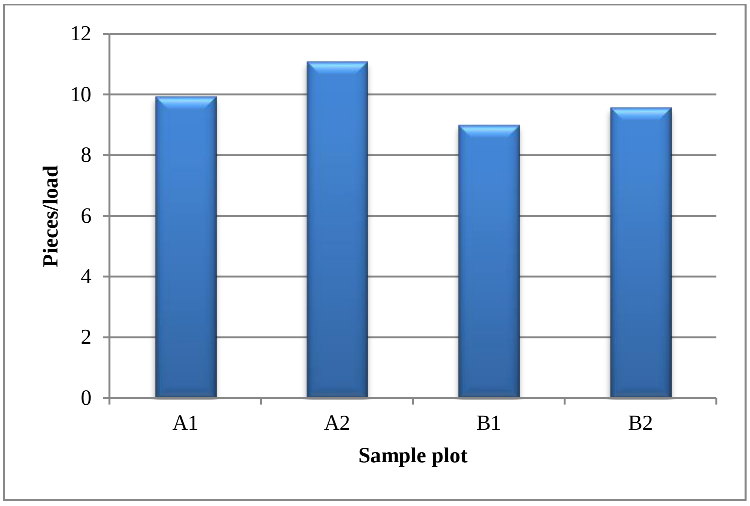


Figure 53: Number of pieces in load

The average volume of pieces in loads in the assortment method was 0.28 m^3 (A1) and 0.57 m^3 (B1) and 0.33 m^3 (A2) and 0.75 m^3 (B2) on sample plots in the half-tree length method. Within the same compartment average volume piece was larger on sample plots where the half-tree length method was performed (Figure 54).

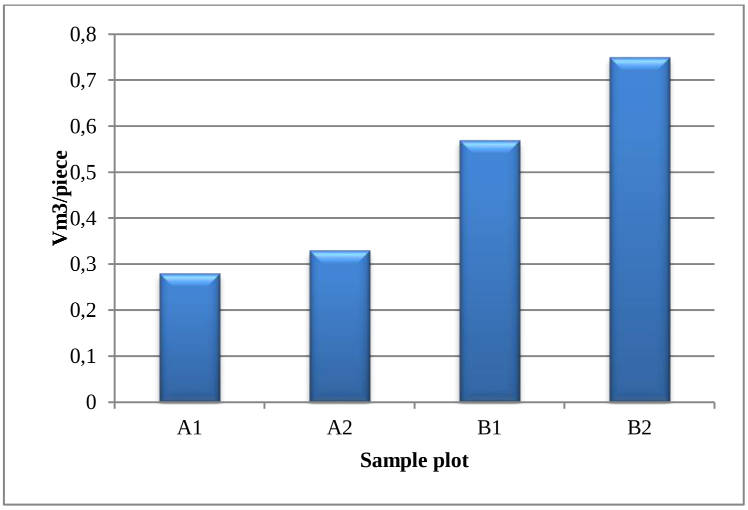


Figure 54: Average volume of piece

The average load volume in the assortment method was 2.80 m^3 (A1) and 4.98 m^3 (B1), and 3.56 m^3 (A2) and 6.62 m^3 (B2) in the half-tree length method (Figure 55).

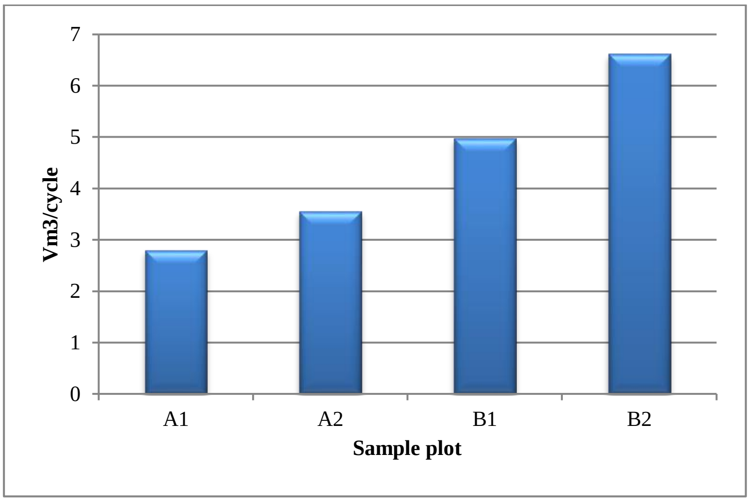


Figure 55: Average load volume

The average length of the piece in the assortment method was 5.38 m (A1) and 5.30 m (B1), and 8.97 m (A2) and 9.19 m (B2) in the half-tree length method. In the assortment method, length of pieces varies from 3.83 m (B1) to 7.66 m (B1). In the half-tree length method length of pieces varies from 6.12 m (A1) to 14.14 m (B2).

The length of pieces on sample plots in the half-tree length harvesting method was evidently larger and that was the main reason why other characteristics of load differed (Figure 56).

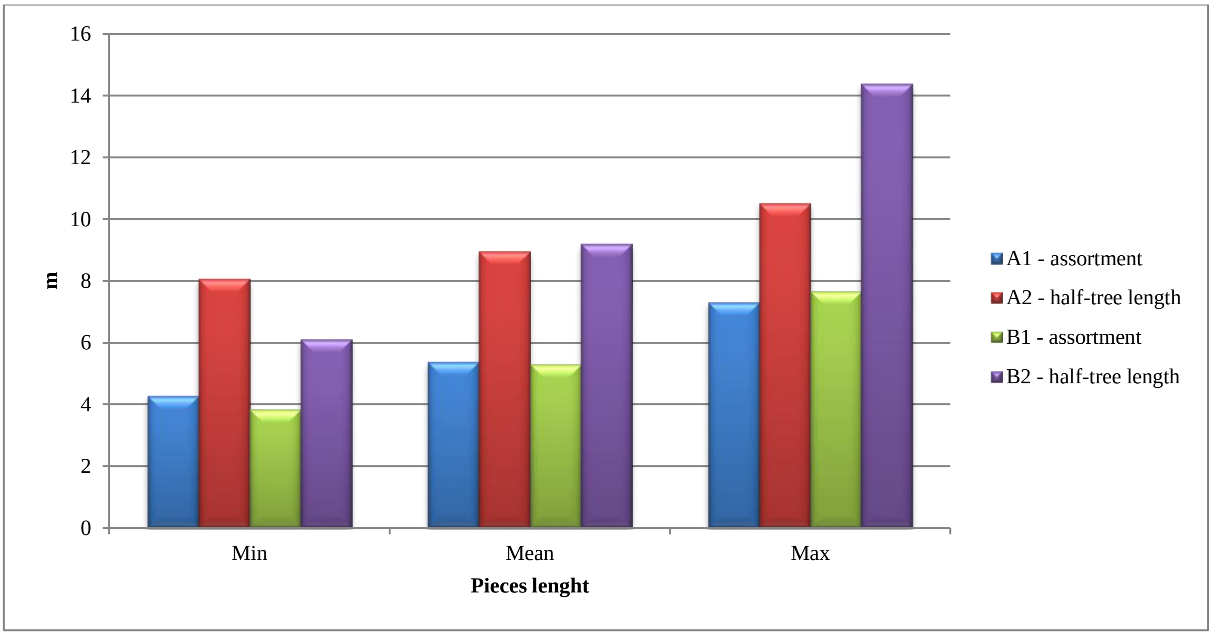


Figure 56: Average pieces length

The average skidding distance in the assortment method was 250.15 m and varied from 90 to 460 m. On sample plots where the half-tree length method was performed average skidding distance was 287.44 m and varied from 130 to 490 m (Figure 57).

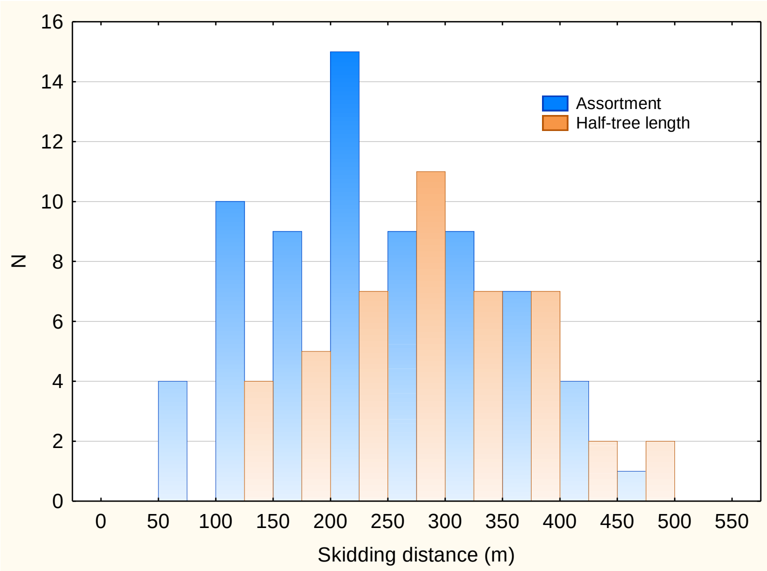


Figure 57: Skidding distance

The average winching distance from the stump to the skidding trail was 25.04 m in the assortment method and 27.4 m in the half-tree length method. The distribution of winching distances is presented in Figure 58.

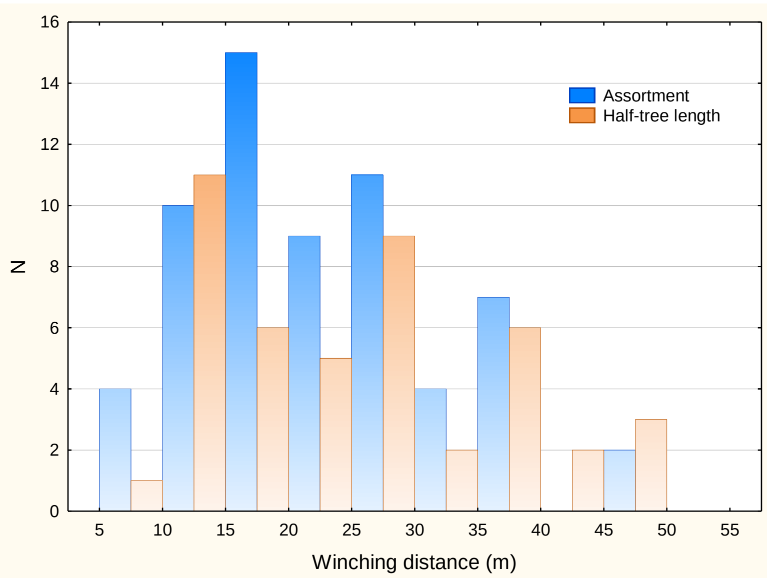


Figure 58: Winching distance distribution

5.2.2 Analysis of work operations

Total studied work time was 2132.75 min on sample plots in the assortment method and 1505.47 min on sample plots in the half-tree length method. Total productive time was 1638.28 min (assortment) and 1147.93 min (half-tree length) with share of allowance time 30.18 % and 31.15 %, respectively (Table 17).

Table 17: Descriptive analysis of skidding work time

Working method	Assortment	Half-tree length	Assortment	Half-tree length	Assortment	Half-tree length	Assortment	Half-tree length	Assortment	Half-tree length
Work operation	Average/cycle (min)		Std.Dev.		Sum (min)		min/cycle (min)		min /cycle (max)	
Unloaded drive	5.09	5.20	2.51	1.75	345.78	234.01	1.48	2.33	12.34	9.58
Pulling out of cable	1.61	1.48	0.80	0.59	104.58	66.52	0.37	0.33	5.53	2.87
Hooking	5.23	5.46	2.50	1.90	355.31	245.54	1.20	1.50	12.06	10.02
Winching	2.92	3.32	1.40	1.63	198.78	149.24	0.73	0.48	8.28	7.30
Forming of load	2.04	1.95	1.51	0.83	89.56	42.98	0.16	0.67	8.00	4.00
Loaded drive	4.72	5.53	1.97	1.59	321.22	248.94	0.31	1.85	9.16	8.87
Unhooking	2.34	2.29	0.92	0.67	156.94	103.05	0.90	1.00	6.00	4.22
Decking	0.98	1.34	0.51	0.53	61.83	57.65	0.25	0.55	2.88	2.57
Productive work time					**1638.28**	**1147.93**				
Allowance time (min)					494.47	357.54				
Allowance time %					30.18	31.15				
Total work time (min)					**2132.75**	**1505.47**				

Productive work time was divided into work operations. Each work operation was recorded and analyzed. The structure of work operations showed (Figure 59) that the most time consuming operations in both methods were Unloaded drive, Loaded drive and Hooking. An average cycle time for Unloaded drive was 5.09 and 5.20 min/cycle for the assortment and the half-tree length method, respectively. An average cycle time for Loaded drive was 4.72 min/cycle (assortment) and 5.53 min/cycle (half-tree length) and average time for Hooking was 5.23 min/cycle (assortment) and 5.46 min/cycle (half-tree length).

The shortest work operations were Pulling out of cable and Decking. Time of Pulling out of cable was 1.61 min/cycle (assortment) and 1.48 min/cycle (half-tree length) and of Decking 0.98 min/cycle (assortment) and 1.34 min/cycle (half-tree length).

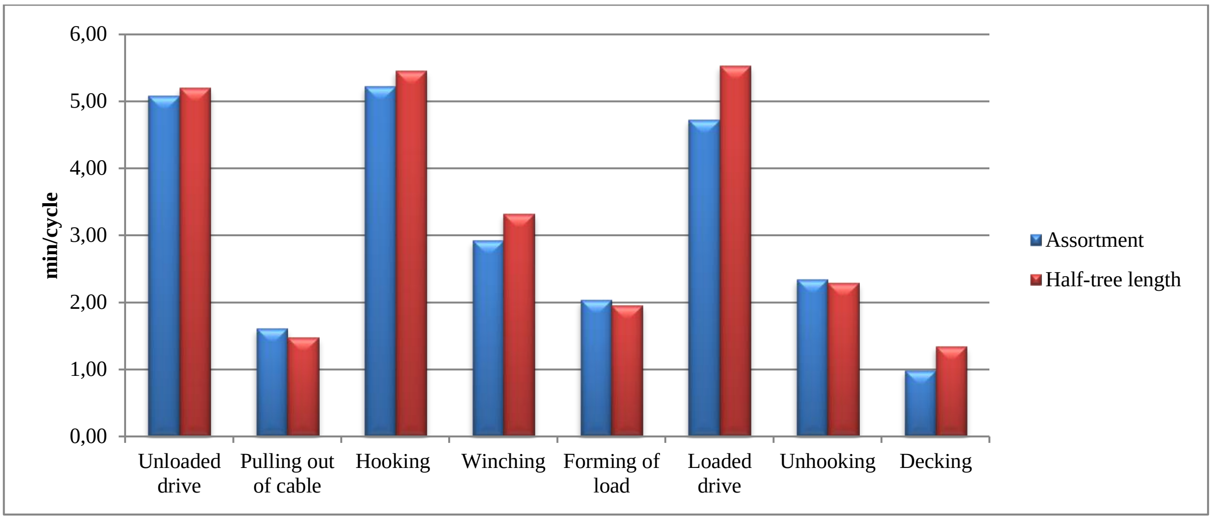
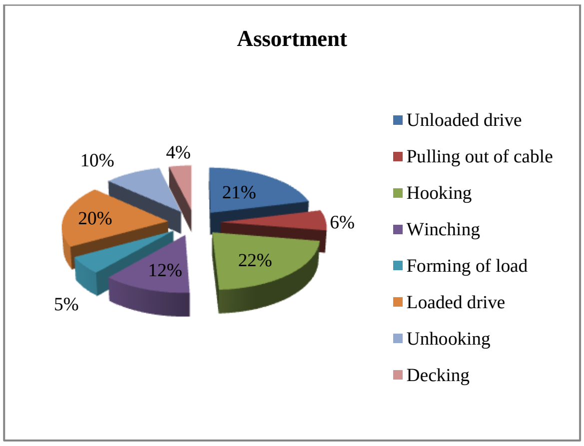


Figure 59: Average time per cycle

The structure of productive work time shows that relative share of working operations was very similar in both working methods (Figure 60 and 61). These results indicate that log length, which is longer in the half-tree length method, did not influence on the relative share of working operations. Skidding assitant did not use more time for Hooking or Unhooking, and skidder did not use more time for Loaded drive or Winching of longer pieces.



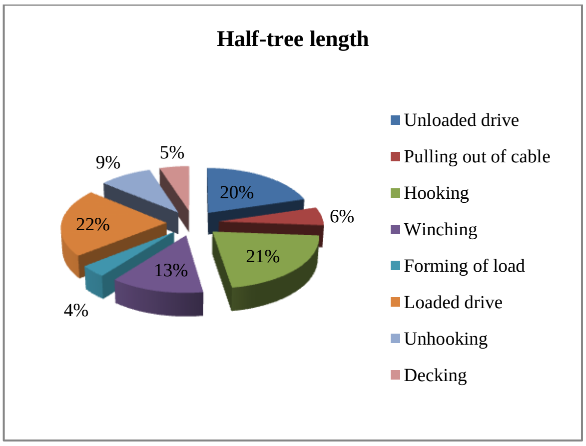


Figure 60 and 61: Relative share of work operations in productive work time

The structure of allowance time is presented in Table 18 and, as it can be seen, most time belongs to the Personal delays, 35% (assortment) and 33% (half-tree length), and then follows Preparatory-final time with 28% (assortment) and 29% (half-tree length). Coefficients of allowance time for skidding are 1.30 and 1.31.

Table 18: Structure of allowance time

	Assortment		Half-tree length	
	min	%	min	%
Preparatory-final time	173.4	28	119.3	29
Technical delays	66.93	13	59.37	17
Organizational delays	117.14	24	74.87	21
Personal delays	137.00	35	104.00	33
Total	494.47	100	305.54	100

5.2.3 Analysis of influencing factors on the skidding work operations

The examination of different factor influence on skidding work operations time was done with regression and correlation analysis. The influence strength is presented with R, with the level of significance $p \leq 0.05$.

Mathematical models which in the best way show the dependence between variables were chosen and represented with equations.
General form of models for skidding work operations is linear equation is (16):

$$y = a + bx \qquad \text{... (16)}$$

where:

- y - dependent variable (min),
- a - intercept,
- b - slope of the line.
- x - independent variable (DBH, load volume, etc.)

Models were used for discussion and for productivity calculation. At work operations where no significant dependences were evidenced, mean values were used for productivity calculations.

5.2.3.1 Assortment method

Unloaded drive showed very strong dependence on the driving distance with correlation coefficient R=0.82. This correlation was presented with linear equation (Table 19). Strong correlation was established in dependence of Hooking from load volume, R=0.58. Medium correlations were established in dependence of Pulling out of cable from pulling distance (R=0.48) and Loading stacking from load volume (R=0.44). Very strong correlation was obtained examining the influence of driving distance and load volume on Loaded driving (R=0.90). Weak correlations were established in dependence of Winching from winching distance (R=0.38), Unhooking from load volume (R=0.39), and Forming of load from load volume (R=0.36).

Table 19: Skidding time dependence analysis - assortment method

Work operation	N	Independent Variable	Parameters		F test	R	p	Std.err
			intercept	b_1				
Unloaded drive	65	x_1 - distance (m)	-0.1890	0.0212	134.62	0.82	0.000	1.449
Pulling out of cable	58	x_2 - distance(m)	0.3208	0.0470	17.17	0.48	0.000	0.728
Hooking	65	x_3 - load volume (m^3)	1.2243	1.0536	32.65	0.58	0.000	2.057
Winching	59	x_4 - distance (m)	1.5973	0.0564	10.38	0.38	0.002	1.294
Forming of load	42	x_5 - load volume (m^3)	0.5799	0.3672	6.15	0.36	0.017	1.431
Loaded drive	65	x_6 - distance (m) x_7 - load volume (m^3)	-0.1162	0.0171 0.1469	146.69	0.90	0.000 0.026	0.851
Unhooking	61	x_8 - load volume (m^3)	1.4811	0.2462	2.83	0.39	0.008	0.906
Decking	60	x_9 - load volume (m^3)	0.4632	0.1357	14.36	0.44	0.000	0.465

5.2.3.1.1 Unloaded drive

There was the examination of skidding distance influence on Unloaded drive. Results on the basis of 65 observations showed that correlation coefficient is R=0.82 on the significance level p≤0.05. F-test result is 134.62 and standard error is 1.45. R and Figure 62 show that very strong correlation was proved. The dependence was presented with linear function (17).

y_1= -0.189+0.0212x_1; where: y_1-unloaded drive (min/cycle), x_1-skidding distance (m) … (17)

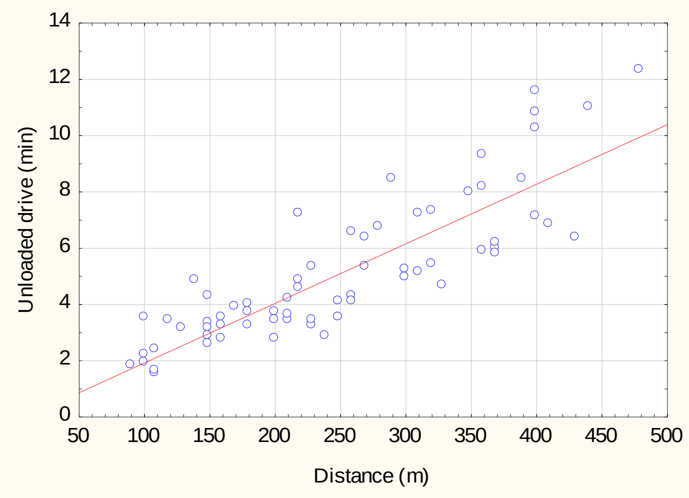


Figure 62: Unloaded drive in dependence from distance

5.2.3.1.2 Pulling out of cable

There was the examination of distance influence on Pulling out of cable. Results on the basis of 58 observations showed that correlation coefficient is R=0.48 on the significance level p≤0.05. F-test result is 17.17 and standard error is 0.73. R and Figure 63 show that medium correlation was proved. The dependence was presented with linear function (18).

y_2= 0.3208+0.047x_2; where: y_2-pulling out of cable (min/cycle), x_2-winching distance (m) … (18)

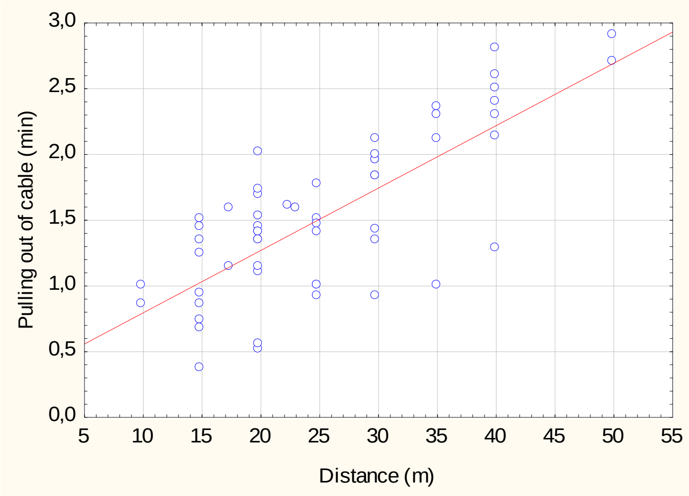


Figure 63: Pulling out of cable in dependence from distance

5.2.3.1.3 Hooking

There was the examination of load volume influence on Hooking. Results on the basis of 65 observations showed that correlation coefficient is R=0.58 on the significance level p≤0.05. F-test is 32.65 and standard error is 2.06. R and Figure 64 show that strong correlation was proved. The dependence was presented with linear function (19).

$y_3=1.2243+1.0536x_3$; where: y_3-hooking (min/cycle), x_3-load volume (m^3) … (19)

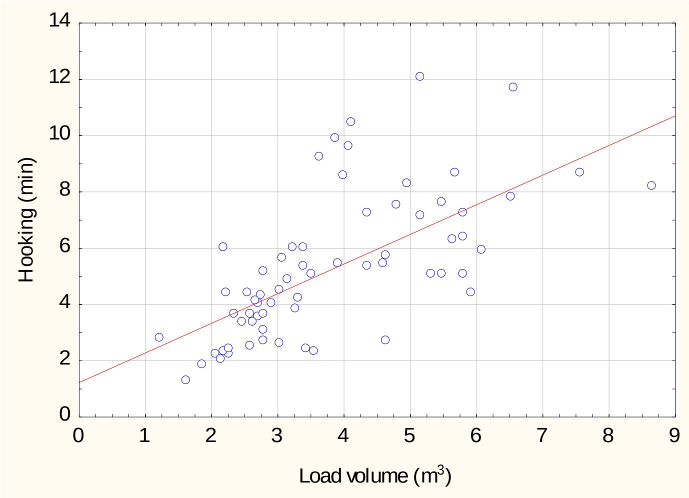


Figure 64: Hooking in dependence from load volume

5.2.3.1.4 Winching

There was the examination of winching distance influence on Winching. Results on the basis of 59 observations showed that correlation coefficient is R=0.38 on the significance level p≤0.05. F-test result is 10.38 and standard error is 1.29. R and Figure 65 show that weak correlation was proved. The dependence was presented with linear function (20).

$y_4=1.5973+0.0546x_4$; where: y_4-winching (min/cycle), x_4-winching distance (m) … (20)

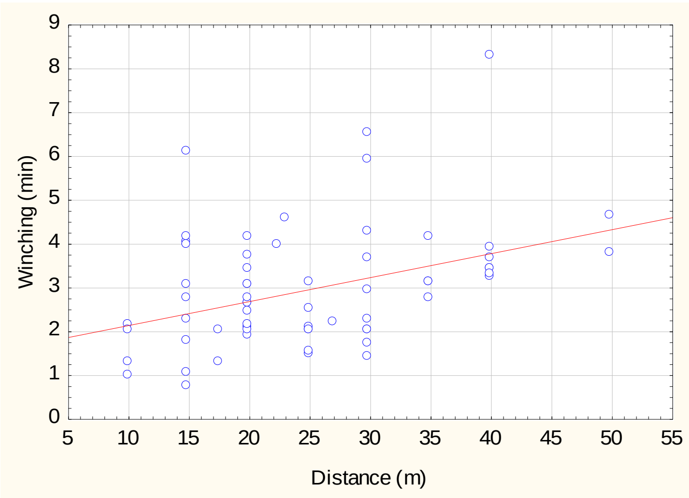


Figure 65: Winching in dependence from distance

5.2.3.1.5 Forming of load

There was the examination of load volume influence on Forming of load. Results on the basis of 42 observations showed that correlation coefficient is R=0.36 on the significance level p≤0.05. F-test result is 6.15 and standard error is 1.43. R and Figure 66 show that weak correlation was proved. The dependence was presented with linear function (21).

$y_5 = 0.5799 + 0.3672x_5$; where: y_5-forming of load (min/cycle), x_5-load volume (m^3) … (21)

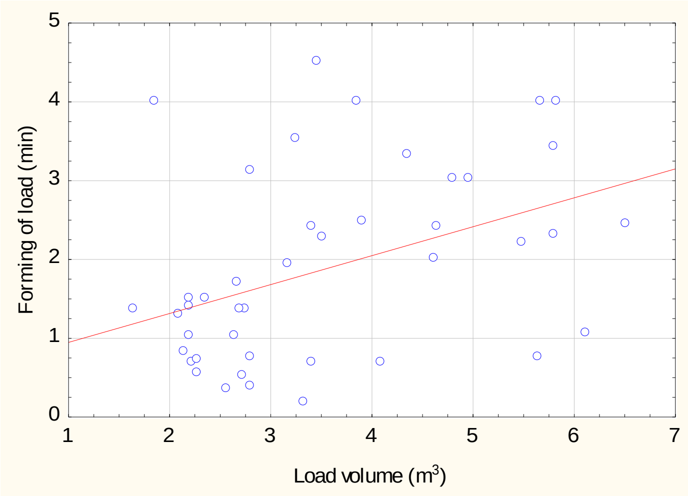


Figure 66: Forming of load in dependence from load volume

5.2.3.1.6 Loaded drive

There was the examination of distance and load volume influence with multiple regression on Loaded drive. Results on the basis of 65 observations showed that correlation coefficient is R=0.90 on the significance level p≤0.05. F-test result is 146.69 and standard error is 0.85. R and Figure 67 show that very strong correlation was proved. The dependence was presented with linear function (22).

y_6= -0.1162+0.0171x_6+0.1469x_7; where: y_6-loaded drive (min/cycle), x_6-skidding distance (m), x_7-load volume (m) … (22)

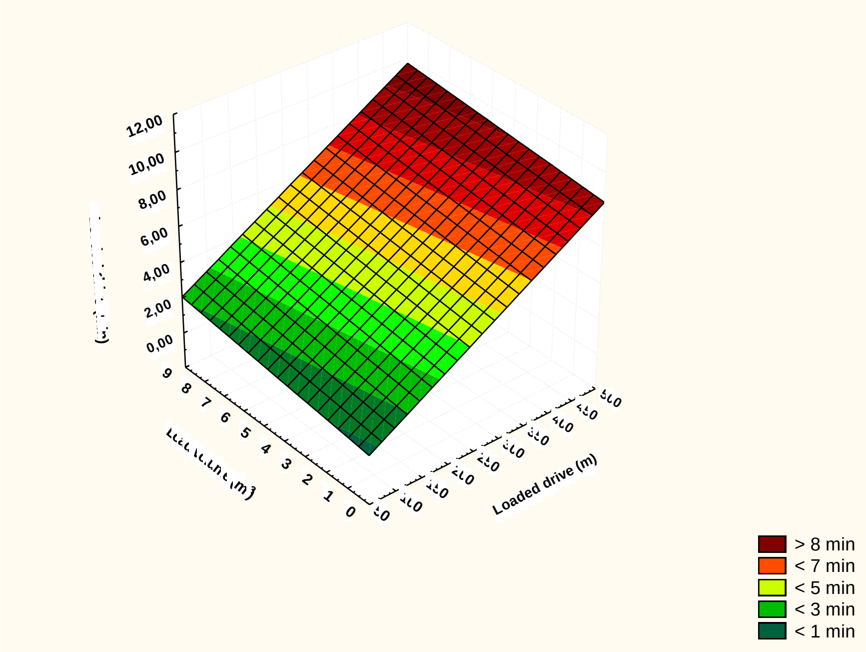


Figure 67: Loaded drive in dependence from distance and load volume

5.2.3.1.7 Unhooking

There was the examination of load volume influence on Unhooking. Results on the basis of 61 observations showed that correlation coefficient is R=0.39 on the significance level p≤0.05. F-test result is 2.83 and standard error is 0.91. R and Figure 68 show that weak correlation was proved. The dependence was presented with linear function (23).

y_7=1.4811+0.2462x_8; where: y_7-unhooking (min/cycle), x_8-load volume (m^3) … (23)

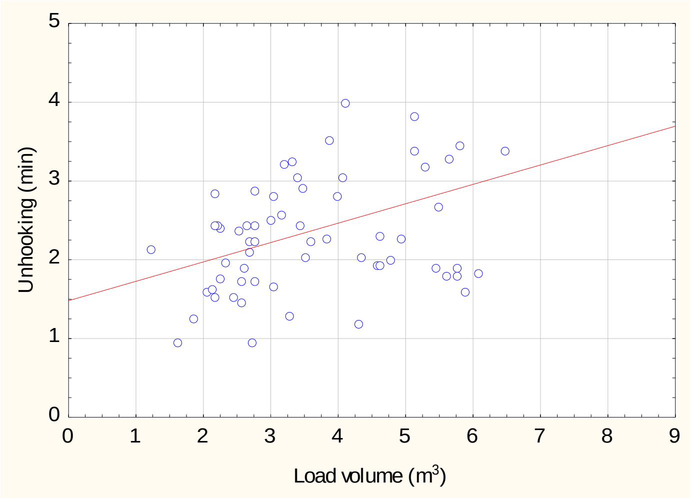


Figure 68: Unhooking in dependence from load volume

5.2.3.1.8 Decking

There was the examination of load volume influence on Decking. Results on the basis of 60 observations showed that correlation coefficient is R=0.44 on the significance level p≤0.05. F-test result is 14.36 and standard error is 0.47. R and Figure 69 show that medium correlation was proved. The dependence was presented with linear function (24).

y_8=0.4632+0.1357x_9; where: y_8-decking (min/cycle), x_9-load volume (m^3) … (24)

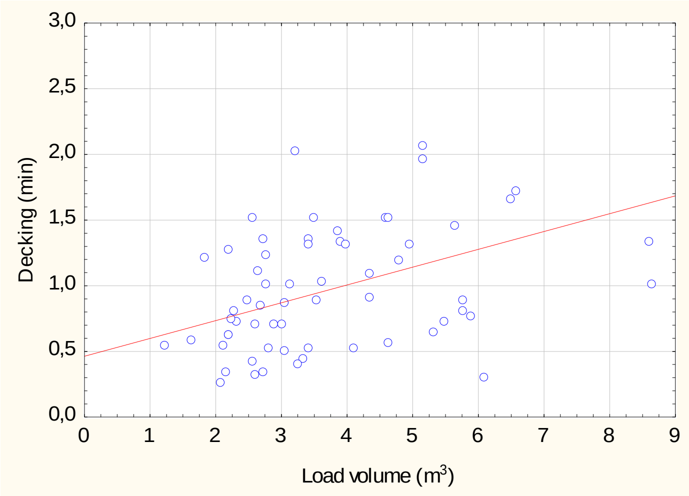


Figure 69: Decking in dependence from load volume

5.2.3.2 Half-tree length method

Unloaded drive showed very strong dependence on the driving distance with correlation coefficient R=0.87. This correlation was presented with linear equation (Table 20). Strong correlation was established in dependence of Decking from load volume, R=0.60 and in dependence of Winching from winching distance (R=0.64). Medium correlation was established in dependence of Pulling out of cable of pulling distance (R=0.49). Very strong correlation was obtained examining the influence of driving distance and load volume on Loaded driving (R=0.90). Weak correlations are established in dependence of Unhooking from load volume (R=0.38) and Hooking of load from load volume (R=0.37). Working operation Forming of load did not show significant dependence from any examined influencing factors. All correlations were with significance level of p≤0.05.

Table 20: Skidding time dependence analysis - half-tree length method

Work operation	N	Independent Variable	Parameters: intercept	Parameters: b_1	F test	R	p	Std.err
Unloaded drive	39	x_1 - distance (m)	0.4808	0.0169	119.14	0.87	0.000	0.869
Pulling out of cable	39	x_2 - distance(m)	0.8146	0.0246	11.77	0.49	0.001	0.522
Hooking	36	x_3 - load volume (m^3)	3.6482	0.4596	5.54	0.37	0.024	1.801
Winching	39	x_4 - distance (m)	0.9294	0.0918	26.29	0.64	0.000	1.305
Forming of load	19	x_5 - load volume (m^3)	no significance		-	-	-	-
Loaded drive	39	x_6 - distance (m) x_7 - load volume (m^3)	0.3261	0.0157 0.1487	74.08	0.90	0.000 0.002	0.683
Unhooking	30	x_8 - load volume (m^3)	1.4544	0.1417	4.78	0.38	0.037	0.613
Decking	38	x_9 - load volume (m^3)	0.5178	0.1556	20.69	0.60	0.000	0.404

5.2.3.2.1 Unloaded drive

There was the examination of driving distance influence on Unloaded drive. Results on the basis of 39 observations showed that correlation coefficient is R=0.87 on the significance level $p \leq 0.05$. F-test result is 119.14 and standard error is 0.87. R and Figure 70 show that very strong correlation was proved. The dependence was presented with linear function (25).

$y_1 = 0.4808+0.0169x_1$ where: y_1-unloaded drive (min/cycle), x_1-skidding distance (m) … (25)

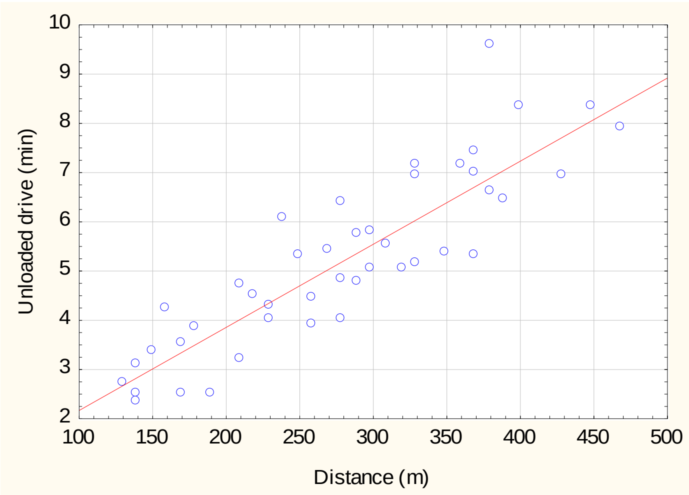


Figure 70: Unloaded drive in dependence from distance

5.2.3.2.2 Pulling out of cable

There was the examination of driving distance influence on Pulling out of cable. Results on the basis of 39 observations showed that correlation coefficient is R=0.49 on the significance level $p \leq 0.05$. F-test result is 11.77 and standard error is 0.52. R and Figure 71 show that medium correlation was proved. The dependence was presented with linear function (26).

y_2= 0.8146+0.0246x; where: y_2-pulling out of cable (min/cycle), x_2-winching distance (m^3) … (26)

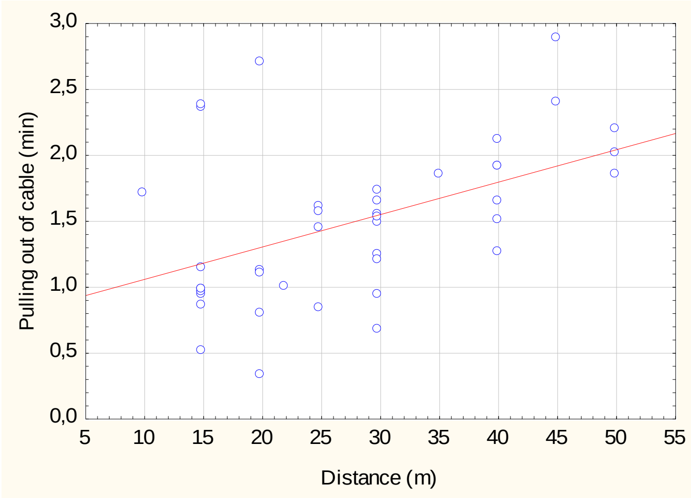


Figure 71: Pulling out of cable in dependence from distance

5.2.3.2.3 Hooking

There was the examination of load volume influence on Hooking. Results on the basis of 36 observations showed that correlation coefficient is R=0.37 on the significance level $p \leq 0.05$. F-test result is 5.54 and standard error is 1.80. R and Figure 72 show that weak correlation was proved. The dependence was presented with linear function (27).

y_3 = 3.6482+0.4596x_3; where: y_3-hooking (min/cycle), x_3-load volume (m^3) … (27)

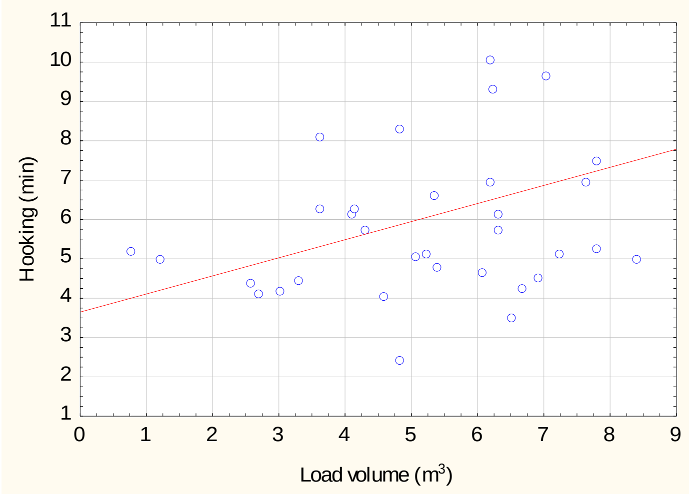


Figure 72: Hooking in dependence from load volume

5.2.3.2.4 Winching

There was the examination of winching distance influence on Winching. Results on the basis of 39 observations showed that correlation coefficient is R=0.64 on the significance level p≤0.05. F-test result is 26.29 and standard error is 1.31. R and Figure 73 show that strong correlation was proved. The dependence was presented with linear function (28).

y_4= 0.9294+0.0918x_4; where: y_4-winching (min/cycle), x_4-winching distance (m) … (28)

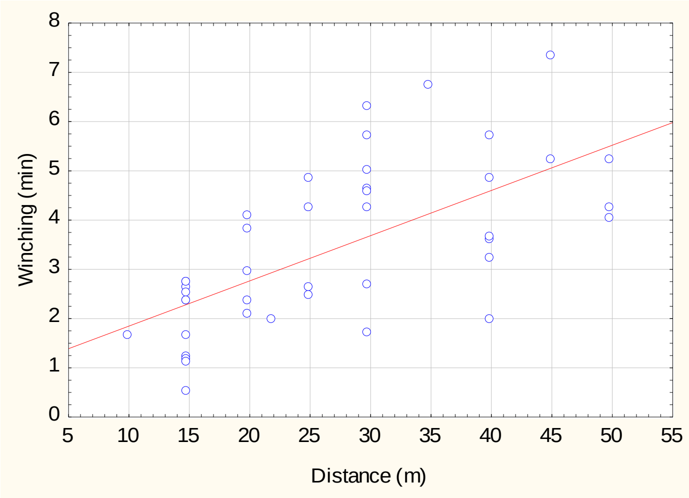


Figure 73: Winching in dependence from distance

5.2.3.2.5 Forming of load

There was the examination of load volume influence on Forming of load. Results on the basis of 19 observations showed that there was no correlation evidenced. The mean value per cycle was taken for the calculations.

5.2.3.2.6 Loaded drive

There was the examination of load volume and distance influence on Loaded drive with multiple regression. Results on the basis of 39 observations showed that correlation coefficient is R=0.90 on the significance level p≤0.05. F-test result is 74.08 and standard error is 0.68. R and Figure 74 show that very strong correlation was proved. The dependence was presented with linear function (29).

y_6=0.3261+0.0157x6+0.1487x_7 where:y_6-loaded drive (min/cycle), x_6-skidding distance (m), x_7-load volume (m) … (29)

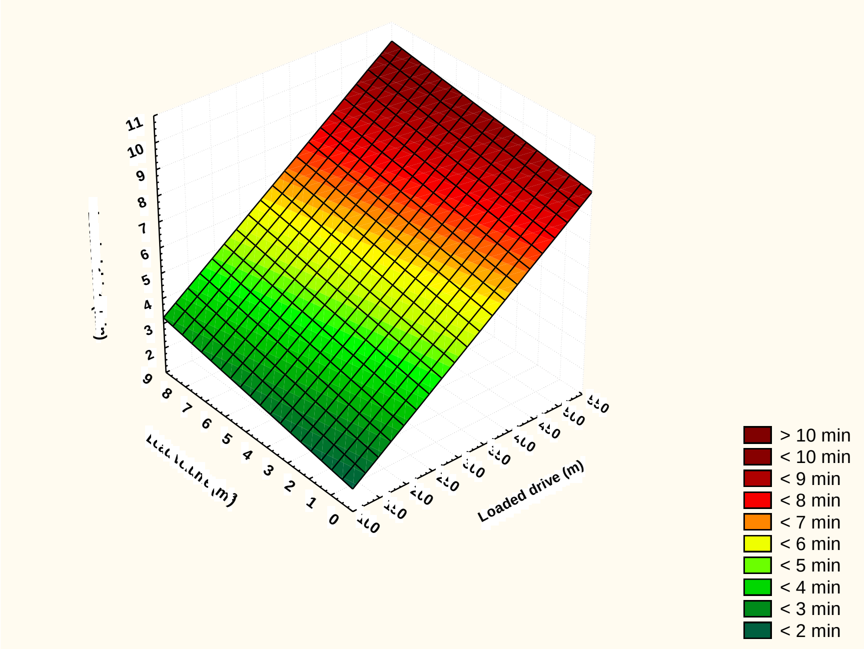


Figure 74: Loaded drive in dependence from distance and load volume

5.2.3.2.7 Unhooking

There was the examination of load volume influence on Unhooking. Results on the basis of 30 observations showed that correlation coefficient is R=0.38 on the significance level p≤0.05. F-test result is 4.78 and standard error is 0.61. R and Figure 75 show that weak correlation was proved. The dependence was presented with linear function (30).

y_7= 1.4544+0.1417x_8; where: y_7-unhooking (min/cycle), x_8-load volume (m^3) … (30)

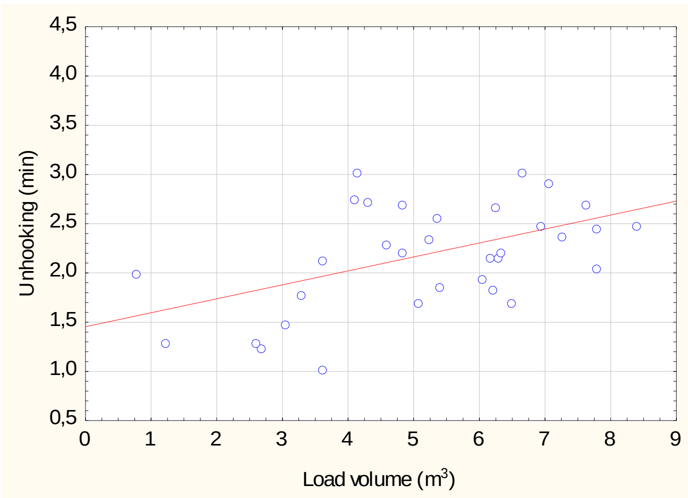


Figure 75: Unhooking in dependence from load volume

5.2.3.2.8 Decking

There was the examination of load volume influence on Decking. Results on the basis of 38 observations showed that correlation coefficient is R=0.60 on the significance level p≤0.05. F-test result is 20.69 and standard error is 0.40. R and Figure 76 show that strong correlation was proved. The dependence was presented with linear function (31).

y_8= 0.5178+0.1556x_9; where: y_8-decking (min/cycle), x_9-load volume (m^3) … (31)

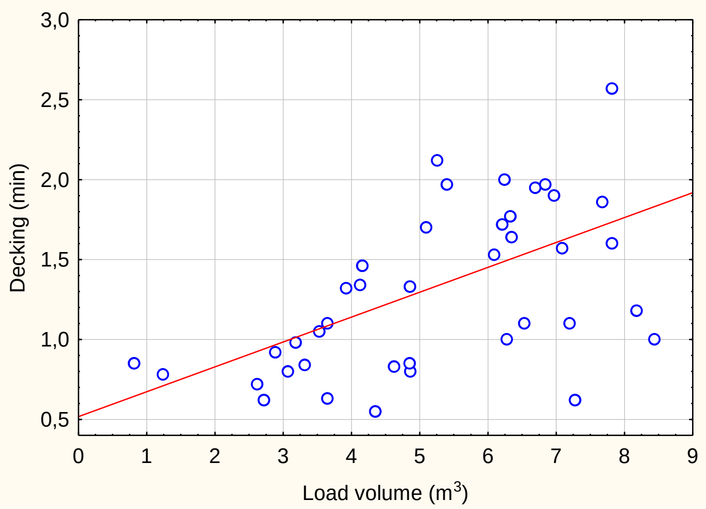


Figure 76: Decking in dependence from load volume

5.2.4 Productivity of skidding

Productivity was calculated when allowance time in a form of coefficient was added to the sum of duration of work operations for specific distances and load volumes. For comparison, productivity was presented for all four sample plots for distance of 250 m and average load volume founded on each sample plot (Table 21). Costs of the working day of skidder LKT 81T were calculated on the basis of official methodology which is in use in Public Company "Šume RS“, based on Myiata (1980).

Table 21: Productivity of skidding for distance 250 m and realized mean load volume

Sample plot	**A1**	**B1**	**A2**	**B2**
Method	Assortment (short log)		Half-tree length (long log)	
Distance	250 m	250 m	250 m	250 m
Load volume	2.80 m^3	4.98 m^3	3.56 m^3	6.62 m^3
Cycle time	29.80 min/cycle	35.61 min/cycle	31.72 min/cycle	35.63 min/cycle
Standard time	10.64 min/m^3	7.15 min/m^3	8.91 min/m^3	5.38 min/m^3
Productivity	42.29 m^3/day	62.93 m^3/day	50.50 m^3/day	83.64 m^3/day

Table 22: Standard time for skidding – the assortment method

min/m³														
		Load volume (m³)												
Skidding distance (m)	Winching distance (m)	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8
50	10	7.9	6.9	6.1	5.6	5.2	4.9	4.7	4.5	4.3	4.2	4.1	4.0	3.9
	30	9.3	7.9	7.0	6.4	5.9	5.5	5.2	5.0	4.8	4.6	4.5	4.3	4.2
	50	10.6	9.0	7.9	7.1	6.6	6.1	5.8	5.5	5.2	5.0	4.8	4.7	4.5
100	10	9.2	7.9	7.0	6.3	5.9	5.5	5.2	5.0	4.8	4.6	4.4	4.3	4.2
	30	10.5	8.9	7.8	7.1	6.5	6.1	5.7	5.4	5.2	5.0	4.8	4.7	4.5
	50	11.8	10.0	8.7	7.8	7.2	6.7	6.3	5.9	5.6	5.4	5.2	5.0	4.9
150	10	10.4	8.9	7.8	7.0	6.5	6.0	5.7	5.4	5.2	5.0	4.8	4.6	4.5
	30	11.8	9.9	8.7	7.8	7.1	6.6	6.2	5.9	5.6	5.4	5.2	5.0	4.8
	50	13.1	11.0	9.6	8.6	7.8	7.2	6.8	6.4	6.0	5.8	5.5	5.3	5.2
200	10	11.7	9.8	8.6	7.8	7.1	6.6	6.2	5.9	5.6	5.3	5.1	5.0	4.8
	30	13.0	10.9	9.5	8.5	7.8	7.2	6.7	6.3	6.0	5.8	5.5	5.3	5.2
	50	14.3	12.0	10.4	9.3	8.4	7.8	7.3	6.8	6.5	6.2	5.9	5.7	5.5
250	10	12.9	10.8	9.5	8.5	7.7	7.2	6.7	6.3	6.0	5.7	5.5	5.3	5.1
	30	14.2	11.9	10.3	9.2	8.4	7.7	7.2	6.8	6.4	6.1	5.9	5.7	5.5
	50	15.6	13.0	11.2	10.0	9.1	8.3	7.7	7.3	6.9	6.5	6.3	6.0	5.8
300	10	14.2	11.8	10.3	9.2	8.4	7.7	7.2	6.8	6.4	6.1	5.9	5.6	5.4
	30	15.5	12.9	11.2	9.9	9.0	8.3	7.7	7.2	6.9	6.5	6.2	6.0	5.8
	50	16.8	14.0	12.1	10.7	9.7	8.9	8.2	7.7	7.3	6.9	6.6	6.3	6.1
350	10	15.4	12.8	11.1	9.9	9.0	8.3	7.7	7.2	6.8	6.5	6.2	6.0	5.8
	30	16.7	13.9	12.0	10.7	9.6	8.8	8.2	7.7	7.3	6.9	6.6	6.3	6.1
	50	18.1	15.0	12.9	11.4	10.3	9.4	8.7	8.2	7.7	7.3	7.0	6.7	6.4
400	10	16.7	13.8	12.0	10.6	9.6	8.8	8.2	7.7	7.2	6.9	6.6	6.3	6.1
	30	18.0	14.9	12.8	11.4	10.3	9.4	8.7	8.2	7.7	7.3	7.0	6.7	6.4
	50	19.3	16.0	13.7	12.1	10.9	10.0	9.2	8.6	8.1	7.7	7.3	7.0	6.7
450	10	17.9	14.8	12.8	11.3	10.2	9.4	8.7	8.1	7.7	7.3	6.9	6.6	6.4
	30	19.2	15.9	13.7	12.1	10.9	10.0	9.2	8.6	8.1	7.7	7.3	7.0	6.7
	50	20.6	16.9	14.5	12.8	11.5	10.5	9.7	9.1	8.5	8.1	7.7	7.3	7.0
500	10	19.2	15.8	13.6	12.0	10.8	9.9	9.2	8.6	8.1	7.7	7.3	7.0	6.7
	30	20.5	16.9	14.5	12.8	11.5	10.5	9.7	9.1	8.5	8.1	7.7	7.3	7.0
	50	21.8	17.9	15.4	13.5	12.2	11.1	10.2	9.5	9.0	8.5	8.0	7.7	7.4
550	10	20.4	16.8	14.4	12.7	11.5	10.5	9.7	9.0	8.5	8.0	7.6	7.3	7.0
	30	21.7	17.9	15.3	13.5	12.1	11.1	10.2	9.5	8.9	8.4	8.0	7.7	7.3
	50	23.0	18.9	16.2	14.3	12.8	11.7	10.7	10.0	9.4	8.8	8.4	8.0	7.7
600	10	21.6	17.8	15.3	13.5	12.1	11.0	10.2	9.5	8.9	8.4	8.0	7.6	7.3
	30	23.0	18.9	16.2	14.2	12.8	11.6	10.7	10.0	9.3	8.8	8.4	8.0	7.6
	50	24.3	19.9	17.0	15.0	13.4	12.2	11.2	10.4	9.8	9.2	8.8	8.3	8.0
650	10	22.9	18.8	16.1	14.2	12.7	11.6	10.7	9.9	9.3	8.8	8.4	8.0	7.6
	30	24.2	19.9	17.0	14.9	13.4	12.2	11.2	10.4	9.8	9.2	8.7	8.3	8.0
	50	25.5	20.9	17.9	15.7	14.0	12.8	11.7	10.9	10.2	9.6	9.1	8.7	8.3
700	10	24.1	19.8	16.9	14.9	13.3	12.1	11.2	10.4	9.7	9.2	8.7	8.3	7.9
	30	25.5	20.9	17.8	15.6	14.0	12.7	11.7	10.9	10.2	9.6	9.1	8.7	8.3
	50	26.8	21.9	18.7	16.4	14.7	13.3	12.2	11.4	10.6	10.0	9.5	9.0	8.6
750	10	25.4	20.8	17.8	15.6	14.0	12.7	11.7	10.8	10.2	9.6	9.1	8.6	8.3
	30	26.7	21.9	18.7	16.3	14.6	13.3	12.2	11.3	10.6	10.0	9.4	9.0	8.6
	50	28.0	22.9	19.5	17.1	15.3	13.9	12.7	11.8	11.0	10.4	9.8	9.3	8.9

Table 23: Standard time for skidding – the half-tree length method

		min/m³												
		Load volume (m^3)												
Skidding distance (m)	Winching distance (m)	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8
50	10	9.7	8.0	6.8	6.0	5.4	5.0	4.6	4.3	4.0	3.8	3.6	3.4	3.3
	30	11.2	9.2	7.9	6.9	6.2	5.6	5.2	4.8	4.5	4.3	4.0	3.9	3.7
	50	12.7	10.4	8.9	7.8	6.9	6.3	5.8	5.4	5.0	4.7	4.5	4.3	4.1
100	10	10.7	8.8	7.5	6.6	6.0	5.4	5.0	4.7	4.4	4.1	3.9	3.7	3.6
	30	12.3	10.0	8.6	7.5	6.7	6.1	5.6	5.2	4.9	4.6	4.3	4.1	4.0
	50	13.8	11.3	9.6	8.4	7.5	6.8	6.2	5.8	5.4	5.1	4.8	4.5	4.3
150	10	11.8	9.7	8.3	7.2	6.5	5.9	5.4	5.0	4.7	4.5	4.2	4.0	3.8
	30	13.3	10.9	9.3	8.1	7.3	6.6	6.0	5.6	5.2	4.9	4.7	4.4	4.2
	50	14.8	12.1	10.3	9.0	8.0	7.3	6.7	6.2	5.7	5.4	5.1	4.8	4.6
200	10	12.9	10.5	9.0	7.9	7.0	6.4	5.9	5.4	5.1	4.8	4.5	4.3	4.1
	30	14.4	11.7	10.0	8.7	7.8	7.1	6.5	6.0	5.6	5.2	5.0	4.7	4.5
	50	15.9	13.0	11.0	9.6	8.6	7.7	7.1	6.5	6.1	5.7	5.4	5.1	4.9
250	10	13.9	11.4	9.7	8.5	7.6	6.9	6.3	5.8	5.4	5.1	4.8	4.6	4.4
	30	15.5	12.6	10.7	9.3	8.3	7.5	6.9	6.4	5.9	5.6	5.3	5.0	4.8
	50	17.0	13.8	11.7	10.2	9.1	8.2	7.5	6.9	6.5	6.0	5.7	5.4	5.1
300	10	15.0	12.2	10.4	9.1	8.1	7.3	6.7	6.2	5.8	5.4	5.1	4.9	4.6
	30	16.5	13.5	11.4	10.0	8.9	8.0	7.3	6.8	6.3	5.9	5.6	5.3	5.0
	50	18.1	14.7	12.4	10.8	9.6	8.7	7.9	7.3	6.8	6.4	6.0	5.7	5.4
350	10	16.1	13.1	11.1	9.7	8.6	7.8	7.1	6.6	6.1	5.8	5.4	5.2	4.9
	30	17.6	14.3	12.1	10.6	9.4	8.5	7.8	7.2	6.7	6.2	5.9	5.6	5.3
	50	19.1	15.5	13.1	11.4	10.2	9.2	8.4	7.7	7.2	6.7	6.3	6.0	5.7
400	10	17.1	13.9	11.8	10.3	9.2	8.3	7.6	7.0	6.5	6.1	5.7	5.4	5.2
	30	18.7	15.2	12.8	11.2	9.9	9.0	8.2	7.5	7.0	6.6	6.2	5.8	5.6
	50	20.2	16.4	13.9	12.0	10.7	9.6	8.8	8.1	7.5	7.0	6.6	6.3	5.9
450	10	18.2	14.8	12.5	10.9	9.7	8.8	8.0	7.4	6.9	6.4	6.1	5.7	5.4
	30	19.7	16.0	13.6	11.8	10.5	9.4	8.6	7.9	7.4	6.9	6.5	6.1	5.8
	50	21.3	17.2	14.6	12.7	11.2	10.1	9.2	8.5	7.9	7.4	6.9	6.5	6.2
500	10	19.3	15.7	13.2	11.5	10.2	9.2	8.4	7.8	7.2	6.8	6.4	6.0	5.7
	30	20.8	16.9	14.3	12.4	11.0	9.9	9.0	8.3	7.7	7.2	6.8	6.4	6.1
	50	22.3	18.1	15.3	13.3	11.8	10.6	9.6	8.9	8.2	7.7	7.2	6.8	6.5
550	10	20.3	16.5	14.0	12.1	10.8	9.7	8.9	8.2	7.6	7.1	6.7	6.3	6.0
	30	21.9	17.7	15.0	13.0	11.5	10.4	9.5	8.7	8.1	7.6	7.1	6.7	6.4
	50	23.4	19.0	16.0	13.9	12.3	11.1	10.1	9.3	8.6	8.0	7.5	7.1	6.7
600	10	21.4	17.4	14.7	12.7	11.3	10.2	9.3	8.5	7.9	7.4	7.0	6.6	6.2
	30	22.9	18.6	15.7	13.6	12.1	10.9	9.9	9.1	8.4	7.9	7.4	7.0	6.6
	50	24.5	19.8	16.7	14.5	12.8	11.5	10.5	9.7	8.9	8.4	7.8	7.4	7.0
650	10	22.5	18.2	15.4	13.4	11.8	10.7	9.7	8.9	8.3	7.7	7.3	6.9	6.5
	30	24.0	19.4	16.4	14.2	12.6	11.3	10.3	9.5	8.8	8.2	7.7	7.3	6.9
	50	25.5	20.7	17.4	15.1	13.4	12.0	10.9	10.0	9.3	8.7	8.1	7.7	7.3
700	10	23.6	19.1	16.1	14.0	12.4	11.1	10.1	9.3	8.6	8.1	7.6	7.2	6.8
	30	25.1	20.3	17.1	14.8	13.1	11.8	10.7	9.9	9.2	8.5	8.0	7.6	7.2
	50	26.6	21.5	18.1	15.7	13.9	12.5	11.4	10.4	9.7	9.0	8.4	8.0	7.5
750	10	24.6	19.9	16.8	14.6	12.9	11.6	10.6	9.7	9.0	8.4	7.9	7.4	7.0
	30	26.1	21.2	17.8	15.5	13.7	12.3	11.2	10.3	9.5	8.9	8.3	7.8	7.4
	50	27.7	22.4	18.8	16.3	14.4	13.0	11.8	10.8	10.0	9.3	8.8	8.3	7.8

Table 24: Daily skidding productivity – the assortment method

		m^3/day												
		Load volume (m^3)												
Skidding distance (m)	Winching distance (m)	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8
50	10	56.7	65.6	73.3	80.0	85.9	91.2	95.8	100.0	103.8	107.2	110.3	113.1	115.8
	30	48.6	56.9	64.1	70.6	76.3	81.5	86.1	90.3	94.2	97.7	100.9	103.9	106.7
	50	42.5	50.2	57.0	63.1	68.6	73.6	78.2	82.4	86.2	89.8	93.1	96.1	98.9
100	10	49.0	57.3	64.6	71.0	76.8	82.0	86.6	90.8	94.7	98.2	101.4	104.4	107.2
	30	42.8	50.5	57.3	63.5	69.0	74.0	78.6	82.8	86.6	90.2	93.5	96.5	99.3
	50	38.0	45.1	51.5	57.4	62.7	67.5	72.0	76.1	79.9	83.4	86.7	89.7	92.6
150	10	43.2	50.8	57.7	63.9	69.4	74.4	79.0	83.2	87.1	90.6	93.9	96.9	99.8
	30	38.3	45.4	51.8	57.7	63.0	67.8	72.3	76.4	80.2	83.8	87.0	90.1	93.0
	50	34.4	41.0	47.1	52.6	57.6	62.3	66.6	70.7	74.4	77.9	81.1	84.2	87.0
200	10	38.5	45.7	52.1	58.0	63.3	68.2	72.7	76.8	80.6	84.1	87.4	90.5	93.3
	30	34.6	41.3	47.3	52.8	57.9	62.6	66.9	71.0	74.7	78.2	81.4	84.5	87.3
	50	31.4	37.6	43.3	48.5	53.4	57.9	62.1	66.0	69.6	73.0	76.2	79.2	82.1
250	10	34.8	41.5	47.6	53.1	58.2	62.9	67.3	71.3	75.0	78.5	81.7	84.8	87.7
	30	31.6	37.8	43.5	48.8	53.6	58.1	62.3	66.2	69.9	73.3	76.5	79.5	82.3
	50	28.9	34.7	40.1	45.1	49.7	54.0	58.1	61.8	65.4	68.7	71.9	74.8	77.7
300	10	31.8	38.0	43.7	49.0	53.9	58.4	62.6	66.5	70.2	73.6	76.8	79.8	82.6
	30	29.1	34.9	40.3	45.3	49.9	54.3	58.3	62.1	65.6	69.0	72.1	75.1	77.9
	50	26.8	32.2	37.3	42.1	46.5	50.7	54.6	58.2	61.7	64.9	68.0	70.9	73.7
350	10	29.2	35.0	40.5	45.5	50.1	54.5	58.5	62.3	65.9	69.2	72.4	75.4	78.2
	30	26.9	32.4	37.5	42.2	46.7	50.9	54.8	58.4	61.9	65.2	68.2	71.2	73.9
	50	24.9	30.1	34.9	39.4	43.7	47.7	51.4	55.0	58.4	61.5	64.5	67.4	70.1
400	10	27.0	32.5	37.6	42.4	46.9	51.1	55.0	58.6	62.1	65.4	68.5	71.4	74.2
	30	25.0	30.2	35.1	39.6	43.9	47.9	51.6	55.2	58.5	61.7	64.7	67.6	70.3
	50	23.3	28.2	32.8	37.1	41.2	45.0	48.7	52.1	55.4	58.5	61.4	64.2	66.9
450	10	25.1	30.3	35.2	39.8	44.0	48.0	51.8	55.4	58.7	61.9	64.9	67.8	70.5
	30	23.4	28.3	32.9	37.3	41.3	45.2	48.8	52.3	55.5	58.6	61.6	64.4	67.1
	50	21.9	26.5	30.9	35.1	39.0	42.7	46.2	49.5	52.7	55.7	58.6	61.3	63.9
500	10	23.5	28.4	33.1	37.4	41.5	45.4	49.0	52.4	55.7	58.8	61.8	64.6	67.2
	30	22.0	26.6	31.0	35.2	39.1	42.8	46.3	49.7	52.8	55.8	58.7	61.5	64.1
	50	20.6	25.1	29.3	33.2	37.0	40.5	43.9	47.2	50.2	53.2	56.0	58.6	61.2
550	10	22.1	26.7	31.2	35.3	39.2	43.0	46.5	49.8	53.0	56.0	58.9	61.6	64.3
	30	20.7	25.2	29.4	33.3	37.1	40.7	44.1	47.3	50.4	53.3	56.1	58.8	61.4
	50	19.5	23.8	27.8	31.6	35.2	38.6	41.9	45.0	48.0	50.9	53.6	56.2	58.7
600	10	20.8	25.2	29.5	33.4	37.2	40.8	44.2	47.4	50.5	53.5	56.3	58.9	61.5
	30	19.6	23.8	27.8	31.7	35.3	38.7	42.0	45.1	48.1	51.0	53.7	56.3	58.9
	50	18.5	22.6	26.4	30.1	33.5	36.9	40.0	43.1	46.0	48.7	51.4	54.0	56.4
650	10	19.7	23.9	27.9	31.8	35.4	38.8	42.1	45.3	48.3	51.1	53.9	56.5	59.0
	30	18.6	22.6	26.5	30.2	33.6	37.0	40.1	43.2	46.1	48.9	51.5	54.1	56.6
	50	17.6	21.5	25.2	28.7	32.1	35.3	38.3	41.3	44.1	46.8	49.4	51.9	54.3
700	10	18.6	22.7	26.6	30.2	33.7	37.1	40.3	43.3	46.2	49.0	51.7	54.2	56.7
	30	17.7	21.6	25.3	28.8	32.1	35.4	38.4	41.4	44.2	46.9	49.5	52.0	54.4
	50	16.8	20.5	24.1	27.5	30.7	33.8	36.8	39.6	42.4	45.0	47.5	50.0	52.3
750	10	17.7	21.6	25.3	28.9	32.2	35.5	38.5	41.5	44.3	47.0	49.6	52.1	54.5
	30	16.8	20.6	24.1	27.5	30.8	33.9	36.9	39.7	42.5	45.1	47.6	50.1	52.4
	50	16.1	19.6	23.0	26.3	29.4	32.4	35.3	38.1	40.8	43.3	45.8	48.2	50.5

Table 25: Daily skidding productivity – the half-tree length method

		m^3/day												
		Load volume (m^3)												
Skidding distance (m)	Winching distance (m)	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8
50	10	46.6	56.5	65.8	74.7	83.0	90.9	98.4	105.5	112.2	118.6	124.7	130.6	136.2
	30	40.2	49.0	57.3	65.2	72.7	79.9	86.8	93.3	99.6	105.6	111.3	116.8	122.1
	50	35.4	43.2	50.7	57.9	64.8	71.3	77.6	83.7	89.5	95.1	100.5	105.6	110.6
100	10	42.0	51.0	59.6	67.8	75.5	82.9	89.9	96.6	103.0	109.2	115.0	120.6	126.0
	30	36.7	44.8	52.5	59.9	67.0	73.7	80.2	86.4	92.3	98.0	103.5	108.7	113.8
	50	32.7	40.0	47.0	53.7	60.1	66.3	72.3	78.0	83.6	88.9	94.0	99.0	103.8
150	10	38.2	46.5	54.5	62.1	69.3	76.2	82.9	89.2	95.3	101.1	106.7	112.0	117.2
	30	33.8	41.3	48.5	55.4	62.0	68.4	74.5	80.4	86.0	91.4	96.7	101.7	106.6
	50	30.3	37.1	43.7	50.0	56.1	62.0	67.7	73.1	78.4	83.5	88.4	93.2	97.8
200	10	35.0	42.7	50.2	57.3	64.1	70.6	76.8	82.8	88.6	94.1	99.5	104.6	109.6
	30	31.3	38.3	45.0	51.5	57.8	63.8	69.6	75.1	80.5	85.7	90.7	95.6	100.3
	50	28.3	34.7	40.9	46.9	52.6	58.2	63.6	68.8	73.8	78.7	83.4	88.0	92.4
250	10	32.3	39.5	46.5	53.1	59.5	65.7	71.6	77.3	82.8	88.1	93.2	98.1	102.9
	30	29.1	35.7	42.0	48.2	54.1	59.8	65.3	70.6	75.7	80.7	85.5	90.1	94.6
	50	26.5	32.5	38.4	44.1	49.5	54.8	59.9	64.9	69.7	74.4	78.9	83.3	87.6
300	10	30.0	36.8	43.3	49.6	55.6	61.4	67.0	72.5	77.7	82.8	87.6	92.4	97.0
	30	27.2	33.4	39.4	45.2	50.8	56.2	61.4	66.5	71.4	76.2	80.8	85.3	89.6
	50	24.9	30.7	36.2	41.6	46.8	51.8	56.7	61.5	66.1	70.6	74.9	79.1	83.3
350	10	28.0	34.4	40.5	46.4	52.2	57.7	63.0	68.2	73.2	78.0	82.7	87.3	91.7
	30	25.6	31.4	37.1	42.6	47.9	53.1	58.1	62.9	67.6	72.2	76.6	80.9	85.1
	50	23.5	29.0	34.2	39.3	44.3	49.1	53.8	58.4	62.8	67.1	71.3	75.4	79.3
400	10	26.3	32.3	38.1	43.7	49.1	54.4	59.5	64.4	69.2	73.8	78.3	82.7	86.9
	30	24.1	29.7	35.0	40.3	45.3	50.2	55.0	59.7	64.2	68.5	72.8	76.9	81.0
	50	22.3	27.5	32.5	37.4	42.1	46.7	51.2	55.6	59.8	64.0	68.0	71.9	75.8
450	10	24.7	30.4	35.9	41.2	46.4	51.4	56.3	61.0	65.6	70.0	74.4	78.6	82.7
	30	22.8	28.1	33.2	38.2	43.0	47.7	52.3	56.7	61.1	65.3	69.4	73.4	77.3
	50	21.2	26.1	30.9	35.6	40.1	44.5	48.8	53.0	57.1	61.1	65.0	68.8	72.5
500	10	23.3	28.7	34.0	39.0	44.0	48.8	53.4	57.9	62.3	66.6	70.8	74.9	78.8
	30	21.6	26.7	31.5	36.3	40.9	45.4	49.8	54.1	58.2	62.3	66.3	70.1	73.9
	50	20.2	24.9	29.4	33.9	38.3	42.5	46.7	50.7	54.6	58.5	62.3	65.9	69.5
550	10	22.1	27.2	32.2	37.1	41.8	46.4	50.8	55.2	59.4	63.5	67.6	71.5	75.3
	30	20.6	25.4	30.0	34.6	39.0	43.3	47.6	51.7	55.7	59.6	63.4	67.1	70.8
	50	19.2	23.7	28.1	32.4	36.6	40.7	44.7	48.6	52.4	56.1	59.7	63.3	66.8
600	10	21.0	25.9	30.7	35.3	39.8	44.2	48.5	52.7	56.7	60.7	64.6	68.4	72.1
	30	19.6	24.2	28.7	33.0	37.3	41.5	45.5	49.5	53.3	57.1	60.8	64.4	67.9
	50	18.4	22.7	26.9	31.1	35.1	39.0	42.9	46.6	50.3	53.9	57.4	60.8	64.2
650	10	20.0	24.7	29.2	33.7	38.0	42.2	46.4	50.4	54.3	58.1	61.9	65.5	69.1
	30	18.7	23.1	27.4	31.6	35.7	39.7	43.6	47.4	51.2	54.8	58.4	61.9	65.3
	50	17.6	21.8	25.8	29.8	33.7	37.5	41.2	44.8	48.4	51.8	55.3	58.6	61.9
700	10	19.1	23.6	28.0	32.2	36.4	40.4	44.4	48.3	52.1	55.8	59.4	62.9	66.4
	30	17.9	22.2	26.3	30.3	34.3	38.1	41.9	45.6	49.2	52.7	56.2	59.5	62.8
	50	16.9	20.9	24.8	28.6	32.4	36.0	39.6	43.1	46.6	50.0	53.3	56.5	59.7
750	10	18.3	22.6	26.8	30.9	34.9	38.8	42.6	46.3	50.0	53.6	57.1	60.5	63.9
	30	17.2	21.3	25.2	29.1	32.9	36.6	40.3	43.8	47.3	50.7	54.1	57.4	60.6
	50	16.3	20.1	23.9	27.6	31.2	34.7	38.2	41.6	44.9	48.2	51.4	54.5	57.6

5.3 CARRYING OUT OF STACKED WOOD

Carrying out of stacked wood with animals (horses) is a traditional way practiced in local forestry, particularly in mountainous conditions. In the past state forest companies used to have their own horse logging sections but now they hire private companies over public bids (Figure 77).

For horse logging there are officially used standard times tables and on their bases forest managers predict expected daily efficiency. Inputs are stand and terrain conditions, cutting intensity and mean carrying distance.

For compartments 98 and 65 where investigated samples were placed, expected daily productivity for one horse was 4.89 m^3/day or 0.61 m^3/h.

Figure 77: Horse logging

5.4 PROCESSING AT THE LANDING SITE

Processing at the landing site was investigated in the half-tree length harvesting method. After preliminary time study, it was decided not to go into detail of time study because the work was very inconsistent with frequently interruptions and especially because, in productive work, it was very hard to distinguish precise border between work operations. Cleaning, bucking, removing of knots and other operations constantly overlapped and joined into Work on the landing. Processing was done by a cutter and an assistant, a group of two workers. The idea was that in the half-tree length harvesting method the same working group should be engaged on the all landing sites in one compartment.

So, productive time and delays were measured. Delays were divided as necessary and not necessary. Dimensions of wood were measured and productivity was calculated in relation to the piece diameter.

Result showed that share of delays is 59% and productive time 41% (Figure 78). The explanation for relative dominant share of delays is in the fact that workers who performed processing were interrupted by trucks which were constantly arriving for shipping.

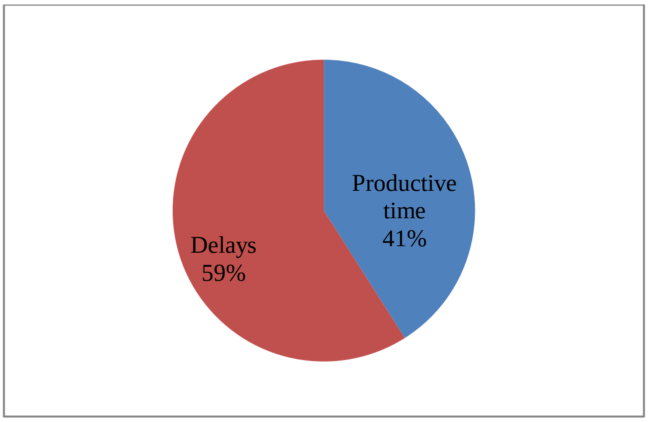


Figure 78: Structure of work time for working group in processing at landing site

Productivity was calculated for a productive working hour and a day (Table 26). As it can be seen, productivity is increasing with an average log diameter increase.

Table 26: Productivity of processing at the landing site

Diameter (cm)	min/m^3	m^3/day	m^3/hour
10	5.1	88.24	11.03
20	4.6	97.83	12.23
30	3.6	125.00	15.63
40	2.3	195.65	24.46
50	1.6	281.25	35.16

Workers who worked on processing at the landing site had the same cost structure as cutters, so cost calculation for cutters can be used for calculation of units cost of processing.

Residue which occurs at the landing site after processing was chipped together with the fuelwood. The residue amount was 2 m^3 on 100 m^3 of roundwood. Those were parts of wood (removed knots and similar) remained after bucking of assortments according to dimensions prescribed by JUS standard (JUS D.B4.028; JUS D.B5.023; JUS D.B5.020)

5.5 CHIPPING

Chipping was done at the landing site. The subject of chipping was long fuelwood, which was skidded by a skidder and stacked fuelwood carried out by animals.

5.5.1 Chipping with the JENZ HEM 700

Wood chips was thrown directly on the truck with the container for transport. The container volume was 30 loose m^3. Calculated conversion coefficient was 2.7 i.e., 1 m^3 of wood was equal to 2.7 loose m^3 of wood chips. Water content of chips was 33%.

Productivity of chipper was calculated on the basis of productive machine hour. Calculated productivity was 51 m^3/h of roundwood with average diameter of 18.6 cm and average length of pieces 6.6 m. Expressed in chips amount productivity was 137.7 loose m^3/h.

When chipping of stacked fuelwood productivity was 36 m^3/h, so 29.5% lower, the reason was the fact that crane could not achieve full efficiency when manipulating with the stacked wood, especially when stacked wood was not piled. This was highly dependable of the operator skills.

Measured fuel consumption was 56 l/h.

5.5.2 Chipping with the Pezzolato PTH 1300/1500

Chipper Pezzolato PTH 1300/1500 belongs to the group of big capacity chippers. It has own motor and needs truck for transport and loading of raw material. Because of its capacity and dimensions, this chipper is suitable for big central landing sites. The chipper was fed by the crane mounted on the truck, the same as previous.

Produced wood chips was piled on the ground. For that reason there was no opportunity for estimation of conversion factors from solid wood volume into loose volume. Granulation (dimension) of chips was the same as in chipping with the JENZ HEM 700, so presumption was that the same conversion factor can be used, 2.7.

Average water content of chips was 35%.

Productivity of chipper was calculated on the basis of productive machine hour too. Calculated productivity was 60 m^3/h of roundwood with average diameter of 20.5 cm and average length of pieces 7.6 m. Productivity of chips was 162.0 loose m^3/h of chips.

Fuel consumption was 72 l/h.

5.6 CALCULATIONS AND UNIT COSTS

5.6.1 Cost calculations

Cost calculation for a chainsaw, a skidder and animals was done on the basis of methodology explained in earlier chapters. The chainsaw lifetime is a 2.5 years. This is based on official calculations of Public Company "Šume RS" (Table 27). Expected lifetime for skidder is 5 years and for animals 9 years. It is expected that the chainsaw and animals achieve 1680 working hours per year and the skidder 1640 working hours per year. Remained value was calculated as 10% of purchase price. Data about purchase price, material costs and other were taken from of Public Company "Šume RS".

Table 27: Cost calculation for chainsaw, skidder and animal

	Husqvarna 372 XP	**LKT 81T**	**Animals**
Lifetime (year)	2.5	5	9
Working hours per year	1680	1640	1680
Purchase price (€)	649.09	105052.56	1278.25
Remained value (€)	64.91	10505.26	127.82
Investment (€/year)	31.81	4412.21	49.71
Material costs (€/year)	1425.91	50842.62	1184.32
Gross wages (€/year)	9788.12	10450.20	4894.06
Other costs (€/year)	5214.03	4922.18	2567.29
Total costs (€/year)	16459.87	70627.21	8695.38
Total costs (€/h)	**9.80**	**43.07**	**5.18**

Cost calculation for chippers and trucks were done on the basis of combination of collected data from chipper owners and from other sources like other studies and manufacturer's data.

Although Jenz HEM 700 and Pezzolato PTH 1300/1500 were included in time study, Jenz HEM 561 DQ was also included in cost calculation. The idea was to cover wider range of chippers according to size. The data for this chipper were taken from other sources (Spinelli et al., 2007; Vusić, 2013).

The chipper and truck lifetime is 8 years. Yearly working hours for chippers are 1600 hours. This was based on the information from chipper owners. There are no official calculation for chippers in Public Company "Šume RS". Remained value was calculated as 10% of purchase value.

Table 28: Cost calculation for chippers and truck

	Jenz HEM 700	Jenz HEM 561 DQ	Pezzolato PTH 1300/1500	Mercedes ACTROS 2654
Lifetime (year)	8	8	8	8
Working hours per year	1600	1600	1600	1640
Purchase price (€)	350000.00	265356.00	500000.00	98280.00
Remained value (€)	35000.00	26535.60	50000.00	9828.00
Depreciation(€/year)	43750.00	33169.50	62500.00	12285.00
Investment (€/year)	13781.25	10448.39	19687.50	3869.78
Insurance(€/year)	0.00	0.00	0.00	1730.32
Fixed costs(€/year)	57531.25	43617.89	82187.50	17885.10
Cost of spare parts and maintenance (€/year)	21875.00	16584.75	31250.00	6142.50
Cost of additional wear parts(€/year)	448.50	448.50	448.50	2691.00
Fuel costs(€/year)	112404.13	84303.10	149872.18	25203.11
Lubricant costs(€/year)	11240.41	8430.31	14987.22	2520.31
Variable costs(€/year)	145968.04	109766.66	196557.89	33161.49
Fixed costs (€/year)	**57531.25**	**43617.89**	**82187.50**	**17885.10**
Variable costs (€/year)	**145968.04**	**109766.66**	**196557.89**	**33161.49**
Workers costs(€/year)	**10226.00**	**10226.00**	**10226.00**	**10226.00**
Total costs (€/year)	**213725.29**	**163610.55**	**288971.39**	**61272.59**

5.6.2 Unit costs

Unit costs of production were calculated by dividing the total costs by the average productivity per hour. Total cost is a sum of machine (horse) and labor costs. Machine or horse costs were obtained by totaling fixed costs and variable costs.

Cutting

Unit costs for cutting, for both methods, were calculated for DBH classes of 5 cm and presented in €/m^3 (Table 29).

Table 29: Unit costs of cutting by harvesting methods

DBH (cm)	Assortment	Half-tree length
	€/m^3	
15	10.85	5.49
20	8.03	4.09
25	5.68	3.19
30	4.16	2.63
35	3.43	2.20
40	3.05	2.07
45	2.82	1.92
50	2.77	1.83
55	2.46	1.66
60	2.18	1.59
65	2.04	1.50
70	1.85	1.39

Figure 79 shows that unit costs in the assortment method were higher than in the half-tree length method for all DBH classes. As DBH class ascends, difference between costs decreases.

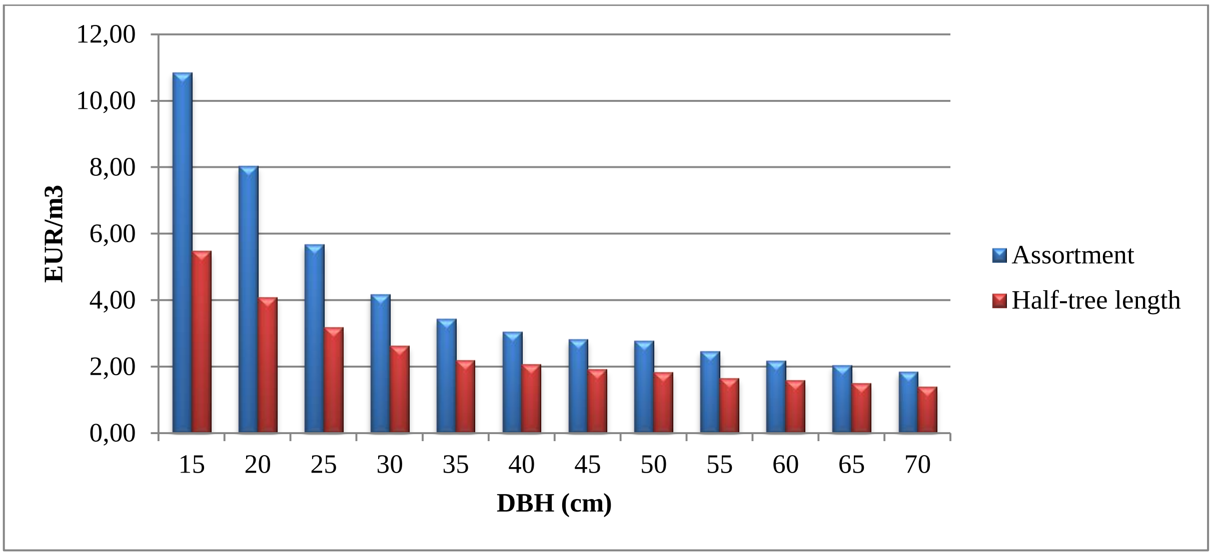


Figure 79: Comparison of cutting unit costs by methods

Processing at the landing site

Unit cost of processing at the landing site was calculated on the basis of measured productivity and the cost structure of workers which was the same as the cost of cutting groups (Table 30).

Table 30: Unit costs of processing at the landing site

Diameter (cm)	€/m^3
10	0.89
20	0.80
30	0.63
40	0.40
50	0.28

Horse logging

Calculated cost of horse logging was 5.15 €/h, so unit cost for carrying out of stacked wood for invstigated stand conditions was 8.44 €/ m^3.

Skidding

Unit costs for skidding were calculated in dependence of skidding distance, winching distance and load volume (Tables 31 and 32).

Table 31: Unit costs for skidding – the assortment method

€/m³														
		Load volume (m³)												
Skidding distance (m)	Winching distance (m)	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8
50	10	5.7	4.9	4.4	4.0	3.8	3.5	3.4	3.2	3.1	3.0	2.9	2.9	2.8
	30	6.6	5.7	5.0	4.6	4.2	4.0	3.8	3.6	3.4	3.3	3.2	3.1	3.0
	50	7.6	6.4	5.7	5.1	4.7	4.4	4.1	3.9	3.7	3.6	3.5	3.4	3.3
100	10	6.6	5.6	5.0	4.5	4.2	3.9	3.7	3.6	3.4	3.3	3.2	3.1	3.0
	30	7.5	6.4	5.6	5.1	4.7	4.4	4.1	3.9	3.7	3.6	3.5	3.3	3.3
	50	8.5	7.2	6.3	5.6	5.2	4.8	4.5	4.2	4.0	3.9	3.7	3.6	3.5
150	10	7.5	6.4	5.6	5.1	4.7	4.3	4.1	3.9	3.7	3.6	3.4	3.3	3.2
	30	8.4	7.1	6.2	5.6	5.1	4.8	4.5	4.2	4.0	3.9	3.7	3.6	3.5
	50	9.4	7.9	6.9	6.1	5.6	5.2	4.8	4.6	4.3	4.1	4.0	3.8	3.7
200	10	8.4	7.1	6.2	5.6	5.1	4.7	4.4	4.2	4.0	3.8	3.7	3.6	3.5
	30	9.3	7.8	6.8	6.1	5.6	5.2	4.8	4.6	4.3	4.1	4.0	3.8	3.7
	50	10.3	8.6	7.5	6.7	6.1	5.6	5.2	4.9	4.6	4.4	4.2	4.1	3.9
250	10	9.3	7.8	6.8	6.1	5.5	5.1	4.8	4.5	4.3	4.1	4.0	3.8	3.7
	30	10.2	8.5	7.4	6.6	6.0	5.6	5.2	4.9	4.6	4.4	4.2	4.1	3.9
	50	11.2	9.3	8.1	7.2	6.5	6.0	5.6	5.2	4.9	4.7	4.5	4.3	4.2
300	10	10.2	8.5	7.4	6.6	6.0	5.5	5.2	4.9	4.6	4.4	4.2	4.0	3.9
	30	11.1	9.3	8.0	7.1	6.5	6.0	5.5	5.2	4.9	4.7	4.5	4.3	4.1
	50	12.1	10.0	8.7	7.7	6.9	6.4	5.9	5.5	5.2	5.0	4.7	4.6	4.4
350	10	11.1	9.2	8.0	7.1	6.4	5.9	5.5	5.2	4.9	4.7	4.5	4.3	4.1
	30	12.0	10.0	8.6	7.6	6.9	6.4	5.9	5.5	5.2	5.0	4.7	4.5	4.4
	50	13.0	10.7	9.3	8.2	7.4	6.8	6.3	5.9	5.5	5.3	5.0	4.8	4.6
400	10	12.0	9.9	8.6	7.6	6.9	6.3	5.9	5.5	5.2	4.9	4.7	4.5	4.4
	30	12.9	10.7	9.2	8.2	7.4	6.7	6.3	5.9	5.5	5.2	5.0	4.8	4.6
	50	13.9	11.5	9.8	8.7	7.8	7.2	6.6	6.2	5.8	5.5	5.3	5.0	4.8
450	10	12.9	10.6	9.2	8.1	7.3	6.7	6.2	5.8	5.5	5.2	5.0	4.8	4.6
	30	13.8	11.4	9.8	8.7	7.8	7.1	6.6	6.2	5.8	5.5	5.2	5.0	4.8
	50	14.8	12.2	10.4	9.2	8.3	7.6	7.0	6.5	6.1	5.8	5.5	5.3	5.1
500	10	13.7	11.4	9.8	8.6	7.8	7.1	6.6	6.2	5.8	5.5	5.2	5.0	4.8
	30	14.7	12.1	10.4	9.2	8.3	7.5	7.0	6.5	6.1	5.8	5.5	5.3	5.0
	50	15.6	12.9	11.0	9.7	8.7	8.0	7.4	6.8	6.4	6.1	5.8	5.5	5.3
550	10	14.6	12.1	10.4	9.1	8.2	7.5	7.0	6.5	6.1	5.8	5.5	5.2	5.0
	30	15.6	12.8	11.0	9.7	8.7	7.9	7.3	6.8	6.4	6.1	5.8	5.5	5.3
	50	16.5	13.6	11.6	10.2	9.2	8.4	7.7	7.2	6.7	6.4	6.0	5.7	5.5
600	10	15.5	12.8	11.0	9.7	8.7	7.9	7.3	6.8	6.4	6.0	5.7	5.5	5.3
	30	16.5	13.6	11.6	10.2	9.2	8.3	7.7	7.2	6.7	6.3	6.0	5.7	5.5
	50	17.4	14.3	12.2	10.7	9.6	8.8	8.1	7.5	7.0	6.6	6.3	6.0	5.7
650	10	16.4	13.5	11.6	10.2	9.1	8.3	7.7	7.1	6.7	6.3	6.0	5.7	5.5
	30	17.4	14.3	12.2	10.7	9.6	8.7	8.0	7.5	7.0	6.6	6.3	6.0	5.7
	50	18.3	15.0	12.8	11.3	10.1	9.2	8.4	7.8	7.3	6.9	6.5	6.2	5.9
700	10	17.3	14.2	12.2	10.7	9.6	8.7	8.0	7.5	7.0	6.6	6.3	6.0	5.7
	30	18.3	15.0	12.8	11.2	10.1	9.1	8.4	7.8	7.3	6.9	6.5	6.2	5.9
	50	19.2	15.7	13.4	11.8	10.5	9.6	8.8	8.2	7.6	7.2	6.8	6.5	6.2
750	10	18.2	14.9	12.8	11.2	10.0	9.1	8.4	7.8	7.3	6.9	6.5	6.2	5.9
	30	19.2	15.7	13.4	11.7	10.5	9.5	8.8	8.1	7.6	7.2	6.8	6.4	6.2
	50	20.1	16.5	14.0	12.3	11.0	10.0	9.1	8.5	7.9	7.5	7.1	6.7	6.4

Table 32: Unit costs for skidding – the half-tree length method

		€/m³												
		Load volume (m³)												
Skidding distance (m)	Winching distance (m)	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8
50	10	6.9	5.7	4.9	4.3	3.9	3.6	3.3	3.1	2.9	2.7	2.6	2.5	2.4
	30	8.0	6.6	5.6	5.0	4.4	4.0	3.7	3.5	3.2	3.1	2.9	2.8	2.6
	50	9.1	7.5	6.4	5.6	5.0	4.5	4.2	3.9	3.6	3.4	3.2	3.1	2.9
100	10	7.7	6.3	5.4	4.8	4.3	3.9	3.6	3.3	3.1	3.0	2.8	2.7	2.6
	30	8.8	7.2	6.1	5.4	4.8	4.4	4.0	3.7	3.5	3.3	3.1	3.0	2.8
	50	9.9	8.1	6.9	6.0	5.4	4.9	4.5	4.1	3.9	3.6	3.4	3.3	3.1
150	10	8.5	6.9	5.9	5.2	4.7	4.2	3.9	3.6	3.4	3.2	3.0	2.9	2.8
	30	9.6	7.8	6.7	5.8	5.2	4.7	4.3	4.0	3.8	3.5	3.3	3.2	3.0
	50	10.7	8.7	7.4	6.5	5.8	5.2	4.8	4.4	4.1	3.9	3.7	3.5	3.3
200	10	9.2	7.6	6.4	5.6	5.0	4.6	4.2	3.9	3.6	3.4	3.2	3.1	2.9
	30	10.3	8.4	7.2	6.3	5.6	5.1	4.6	4.3	4.0	3.8	3.6	3.4	3.2
	50	11.4	9.3	7.9	6.9	6.1	5.6	5.1	4.7	4.4	4.1	3.9	3.7	3.5
250	10	10.0	8.2	7.0	6.1	5.4	4.9	4.5	4.2	3.9	3.7	3.5	3.3	3.1
	30	11.1	9.0	7.7	6.7	6.0	5.4	5.0	4.6	4.3	4.0	3.8	3.6	3.4
	50	12.2	9.9	8.4	7.3	6.5	5.9	5.4	5.0	4.6	4.3	4.1	3.9	3.7
300	10	10.8	8.8	7.5	6.5	5.8	5.3	4.8	4.5	4.2	3.9	3.7	3.5	3.3
	30	11.9	9.7	8.2	7.1	6.4	5.7	5.3	4.9	4.5	4.2	4.0	3.8	3.6
	50	13.0	10.5	8.9	7.8	6.9	6.2	5.7	5.3	4.9	4.6	4.3	4.1	3.9
350	10	11.5	9.4	8.0	7.0	6.2	5.6	5.1	4.7	4.4	4.1	3.9	3.7	3.5
	30	12.6	10.3	8.7	7.6	6.7	6.1	5.6	5.1	4.8	4.5	4.2	4.0	3.8
	50	13.7	11.2	9.4	8.2	7.3	6.6	6.0	5.5	5.1	4.8	4.5	4.3	4.1
400	10	12.3	10.0	8.5	7.4	6.6	5.9	5.4	5.0	4.7	4.4	4.1	3.9	3.7
	30	13.4	10.9	9.2	8.0	7.1	6.4	5.9	5.4	5.0	4.7	4.4	4.2	4.0
	50	14.5	11.8	9.9	8.6	7.7	6.9	6.3	5.8	5.4	5.1	4.8	4.5	4.3
450	10	13.1	10.6	9.0	7.8	7.0	6.3	5.7	5.3	4.9	4.6	4.3	4.1	3.9
	30	14.2	11.5	9.7	8.5	7.5	6.8	6.2	5.7	5.3	4.9	4.7	4.4	4.2
	50	15.3	12.4	10.5	9.1	8.1	7.3	6.6	6.1	5.7	5.3	5.0	4.7	4.5
500	10	13.8	11.2	9.5	8.3	7.3	6.6	6.0	5.6	5.2	4.8	4.6	4.3	4.1
	30	14.9	12.1	10.2	8.9	7.9	7.1	6.5	6.0	5.5	5.2	4.9	4.6	4.4
	50	16.0	13.0	11.0	9.5	8.4	7.6	6.9	6.4	5.9	5.5	5.2	4.9	4.6
550	10	14.6	11.9	10.0	8.7	7.7	7.0	6.4	5.9	5.4	5.1	4.8	4.5	4.3
	30	15.7	12.7	10.8	9.3	8.3	7.5	6.8	6.3	5.8	5.4	5.1	4.8	4.6
	50	16.8	13.6	11.5	10.0	8.8	7.9	7.2	6.7	6.2	5.8	5.4	5.1	4.8
600	10	15.4	12.5	10.5	9.1	8.1	7.3	6.7	6.1	5.7	5.3	5.0	4.7	4.5
	30	16.5	13.3	11.3	9.8	8.7	7.8	7.1	6.5	6.1	5.7	5.3	5.0	4.8
	50	17.6	14.2	12.0	10.4	9.2	8.3	7.5	6.9	6.4	6.0	5.6	5.3	5.0
650	10	16.1	13.1	11.0	9.6	8.5	7.6	7.0	6.4	5.9	5.6	5.2	4.9	4.7
	30	17.2	14.0	11.8	10.2	9.0	8.1	7.4	6.8	6.3	5.9	5.5	5.2	4.9
	50	18.3	14.8	12.5	10.8	9.6	8.6	7.8	7.2	6.7	6.2	5.8	5.5	5.2
700	10	16.9	13.7	11.6	10.0	8.9	8.0	7.3	6.7	6.2	5.8	5.4	5.1	4.9
	30	18.0	14.6	12.3	10.7	9.4	8.5	7.7	7.1	6.6	6.1	5.8	5.4	5.1
	50	19.1	15.4	13.0	11.3	10.0	9.0	8.2	7.5	6.9	6.5	6.1	5.7	5.4
750	10	17.7	14.3	12.1	10.5	9.3	8.3	7.6	7.0	6.5	6.0	5.7	5.3	5.1
	30	18.8	15.2	12.8	11.1	9.8	8.8	8.0	7.4	6.8	6.4	6.0	5.6	5.3
	50	19.9	16.1	13.5	11.7	10.4	9.3	8.5	7.8	7.2	6.7	6.3	5.9	5.6

Chipping

Unit costs of chipping were calculated on the basis of raw material input and chipper output (Table 33). Roundwood (m^3) was taken as an input and chips volume (loose m^3) as an output. In chipping of stacked wood unit costs were about 30% higher.

Table 33: Unit costs of chipping based on the estimated productivity

	Jenz HEM 700	Jenz HEM 561 DQ	Pezzolato PTH 1300/1500	Mercedes ACTROS 2654
m³/h (roundwood)	51.00	31.00	60.00	-
Loose m³/h (woodchips)	137.70	83.70	162.00	.
€/h	133.58	102.26	180.61	37.36
€/m³ (roundwood)	2.62	3.30	3.01	-
€/ loose m³ (woodchips)	0.97	1.22	1.11	-

Unit costs were expressed for factory projected chippers productivity also, in order to compare obtained unit costs with costs when chippers are working under full capacity (Table 34).

Table 34: Unit costs of chipping based on the factory predicted productivity

	Jenz HEM 700	Jenz HEM 561 DQ	Pezzolato PTH 1300/1500	Mercedes ACTROS 2654
m³/h (roundwood)	60.00	45.00	100.00	-
loose m³/h (woodchips)	162.00	121.50	270.00	
€/h	133.58	102.26	180.61	37.36
€/m³ (roundwood)	2.23	2.27	1.81	-
€/ loose m³ (woodchips)	0.82	0.84	0.67	

5.7 WOOD BIOMASS UTILIZATION

The term of utilization of wood stands for quantitative and qualitative utilization of wood volume from each tree in relation to the total tree biomass. Tables for biomass estimation were used as a base for this comparison (Drinić et al., 1980). They are in official use in forestry of Republic of Srpska. In those tables for each tree species and for each DBH and stand quality, there is predicted total tree biomass volume and gross wood volume. The term gross wood stands for wood of tree stem and branches above 7 cm. The difference between total biomass and gross wood are branches thinner than 7cm, twigs, leaves and stump.

5.7.1 Quantitative wood biomass utilization

Quantitative utilization was compared on the basis of total amount of wood obtained from trees in each harvesting method. Figure 80 shows that up to 50 cm DBH quantitatively utilization was similar and above 50 cm difference occurs in favor of the assortment method. This result was probable a consequence of situation that in the half-tree length method cutters did not literally produce stacked wood from each branch as in the assortment method. They were more focused on the bucking of stem on the transport lengths and had intention that have as less as possible stacked wood. Some thin branches stayed non-bucked.

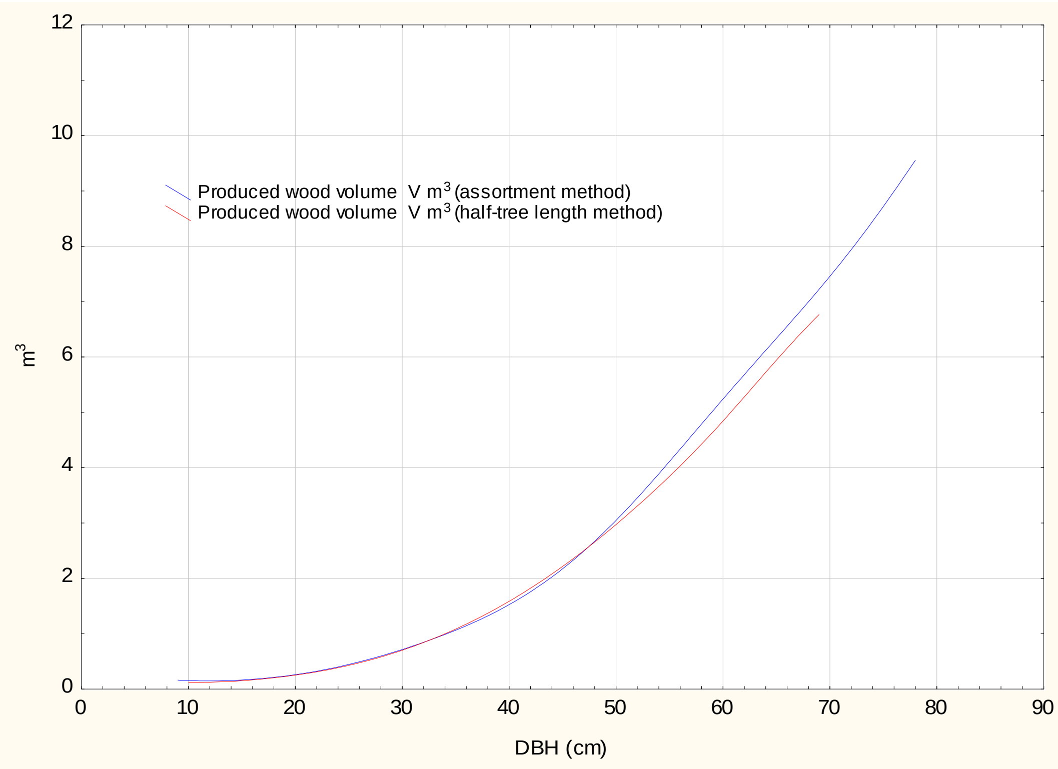


Figure 80: Utilization of wood by harvesting method

Relation between estimated wood biomass (Drinić et al., 1980) and obtained biomass after harvesting was presented in the Figure 81. As shown, by approximately 50 cm DBH utilization of wood in both harvesting methods was equal to gross wood estimation. After 50 cm there was a difference in favor of both harvesting methods related to gross wood estimation. The difference was more significant in favor of the assortment than the half-tree length method. In both harvesting methods utilization was below estimated total biomass volume, what was expected.

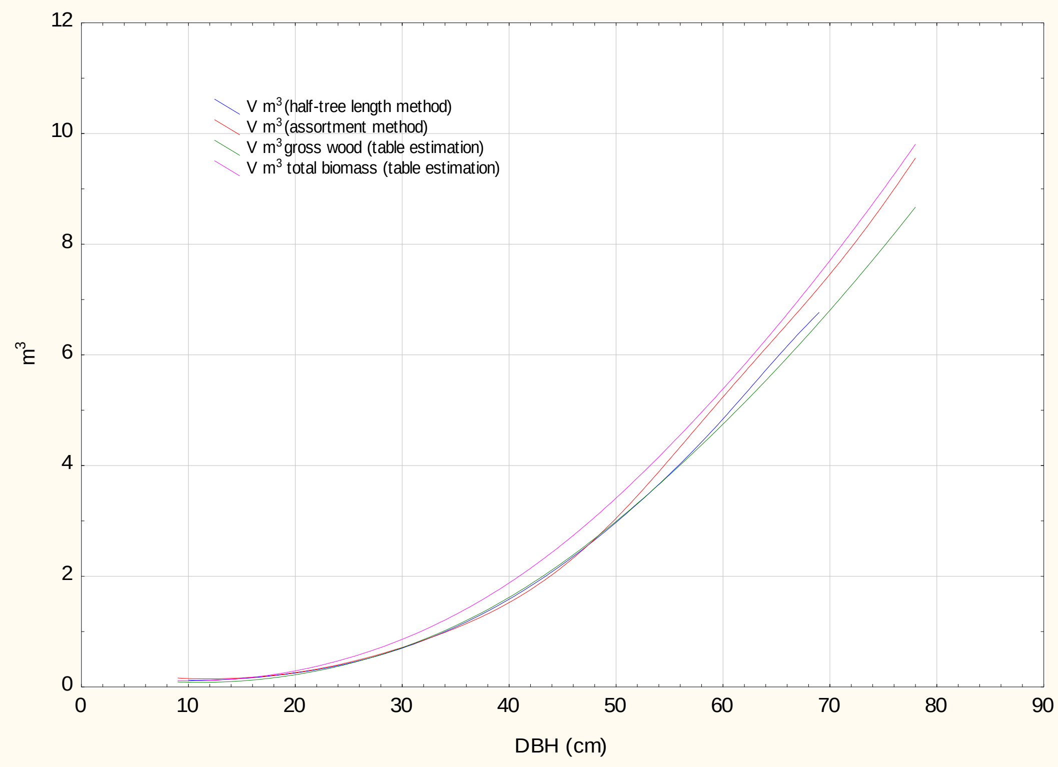


Figure 81: Utilization of wood biomass related to estimation

Relative utilization of wood biomass in relation to the total wood biomass volume predicted from estimation tables is presented in Table 35.

Table 35: Relative utilization of wood biomass in relation to the estimated total wood biomass

	Total wood biomass		
DBH (cm)	Assortment	Half-tree length	Table estimation
10	74.69%	53.42%	100.00%
20	88.59%	87.64%	100.00%
30	86.92%	81.71%	100.00%
40	78.09%	84.23%	100.00%
50	86.88%	86.79%	100.00%
60	99.17%	89.37%	100.00%
70	95.44%	92.39%	100.00%

Relative utilization of woody biomass in relation to the gross wood biomass volume predicted from estimation tables is presented in Table 36.

Table 36: Relative utilization of wood biomass in relation to estimated gross wood biomass

	Gross wood biomass		
DBH (cm)	Assortment method	Half-tree length method	Table estimation
10	132.87%	95.03%	100.00%
20	116.94%	115.68%	100.00%
30	105.49%	99.17%	100.00%
40	90.56%	97.69%	100.00%
50	99.00%	98.90%	100.00%
60	112.45%	101.33%	100.00%
70	108.07%	104.61%	100.00%

5.7.2 Qualitative wood biomass utilization

The analysis of qualitative utilization was done on the basis of mutual comparison of relative share of wood classes obtained in both harvesting methods and on the basis of comparison with estimated value from assortment tables (Drinić et al., 1980). Quality classes were compared by diameter classes which have been used in local forestry organizations. Drinić et al. (1980) prepared tables for calculation of expected assortment structure for each tree species. Inputs in tables are tree species, DBH and technical category of tree. Output is expected relative assortment structure according to JUS (JUS D.B4.020; JUS D.B4.028; JUS D.B5.020; JUS D.B5.023; JUS D.B4.022). Those tables are used by forest managers to predict assortment structure for each compartment in purpose of planning and controlling of production process. Realized assortment structure should not differ from estimated in case that assortment tables are used in a proper way and input data are correct.

Codes for wood classes are:

- ✓ F – veneer logs;
- ✓ L – peeling logs;
- ✓ I – sawlogs 1. class
- ✓ II – sawlogs 2. class
- ✓ III – sawlogs 3. class
- ✓ O – fuelwood

Fuelwood occurs in two forms, as a roundwood fuelwood and as a stacked fuelwood.

5.7.2.1 Qualitative wood biomass utilization on the sample plot A1- the assortment method

As presented in the Table 37, the assortment structure obtained on the sample plot A1 differs from estimation for compartment 98 where sample plot was placed. F logs were predicted but were not found. There was less fuelwood than predicted, 53.43% contrary to 76.94%. The share of L logs and sawlogs of I, II and III class was higher than predicted. In general, assortment structure was better than was predicted on the basis of assortment table.

Table 37: Assortment structure on the sample plot A1 – the assortment method

	Classes	**F**	**L**	**I**	**II**	**III**	**O**
	Estimated assortment structure from assortment table						
	Total	**0.55%**	**1.09%**	**2.82%**	**7.65%**	**10.95%**	**76.94%**
	Obtained assortment structure						
	Total	**0.00%**	**3.63%**	**12.23%**	**13.41%**	**17.29%**	**53.43%**
DBH classes (cm)	10 - 15	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	15 - 20	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
	20 - 30	0.00%	0.00%	0.00%	5.26%	14.99%	79.74%
	30 - 50	0.00%	4.77%	16.08%	16.18%	18.59%	44.38%
	50 - 80	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	> 80	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

When looking at the structure of fuelwood on the sample plot A1 (Table 38) it was shown that roundwood fuelwood was prevailing (72.62 %) in relation to stacked fuelwood (27.38 %). In the lower DBH class (15-20 cm) the share of stacked wood was higher (44.43 %).

Table 38: Structure of fuelwood on the sample plot A1– the assortment method

		Roundwood fuelwood	**Stacked fuelwood**
	Total	**72.62%**	**27.38%**
DBH classes (cm)	10 - 15	0.00%	0.00%
	15 - 20	55.57%	44.43%
	20 - 30	80.36%	19.64%
	30 - 50	70.24%	29.76%
	50 - 80	0.00%	0.00%
	> 80	0.00%	0.00%

5.7.2.2 Qualitative wood biomass utilization on the sample plot A2 – the half-tree length method

As presented in the Table 39, the assortment structure obtained on the sample plot A2 where the half-tree length method was performed also differs from estimation for compartment 98 where the sample plot was placed. F and L logs were predicted but were not found. There was less fuelwood than predicted, 58.38% contrary to 76.94%. The share of sawlogs of I, II and III class was higher than predicted.

Table 39: Assortment structure on the sample plot A2– the half tree length method

	Classes	**F**	**L**	**I**	**II**	**III**	**O**
	Estimated assortment structure from assortment table						
	Total	**0.55%**	**1.09%**	**2.82%**	**7.65%**	**10.95%**	**76.94%**
	Obtained assortment structure						
	Total	**0.00%**	**0.00%**	**14.43%**	**9.74%**	**17.45%**	**58.38%**
DBH classes (cm)	10 - 15	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
	15 - 20	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
	20 - 30	0.00%	0.00%	0.98%	1.85%	17.41%	79.76%
	30 - 50	0.00%	0.00%	25.75%	16.51%	19.28%	38.46%
	50 - 80	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	> 80	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

The structure of fuelwood on the sample plot A2 (Table 40) shows that almost all fuelwood was in the form of roundwood, 96.56% contrary to 3.44% in form of stacked wood. Only in higher DBH class (30-50 cm) there was a considerable amount of stacked wood (8.50%). This is understandable on the basis of methodology of performed harvesting method.

Table 40: The structure of fuelwood on the sample plot A2– the half tree length method

		Roundwood fuelwood	**Stacked fuelwood**
	Total	**96.56%**	**3.44%**
DBH classes (cm)	10 - 15	100.00%	0.00%
	15 - 20	100.00%	0.00%
	20 - 30	99.28%	0.72%
	30 - 50	91.50%	8.50%
	50 - 80	0.00%	0.00%
	> 80	0.00%	0.00%

5.7.2.3 Qualitative wood biomass utilization on the sample plot B1- the assortment method

When looking at the assortment structure obtained on the sample plot B1 and relation on the prediction from assortment table for compartment 65 it was shown that share of fuelwood was the same as predicted (56.37% and 56.17%) and was decreasing with the increasing of DBH. The share of F logs was significantly higher, 4.7% toward 1.18%. L logs were not found although there was a prediction for 2.68%. The share of sawlogs of I class was higher and share of sawlogs of II and III class was less than predicted (Table 41).

Table 41: Assortment structure on the sample plot B1–the assortment method

	Classes	F	L	I	II	III	O
	Estimated assortment structure from assortment table						
	Total	**1.18%**	**2.68%**	**6.88%**	**14.48%**	**18.41%**	**56.37%**
	Obtained assortment structure						
	Total	**4.70%**	**0.00%**	**18.38%**	**9.59%**	**11.16%**	**56.17%**
DBH classes (cm)	10 - 15	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	15 - 20	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	20 - 30	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
	30 - 50	0.00%	0.00%	2.94%	12.42%	17.56%	67.08%
	50 - 80	5.49%	0.00%	21.07%	9.52%	10.66%	53.27%
	> 80	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

The structure of fuelwood on the sample plot B1 (Table 42) shows that relative share of roundwood fuelwood was higher than stacked wood (68.35% contrary to 31.47%). With the increase of DBH share of roundwood fuelwood is decreasing.

Table 42: The structure of fuelwood on the sample plot B1– the assortment method

		Roundwood fuelwood	Stacked fuelwood
	Total	68.53%	31.47%
DBH classes (cm)	10 - 15	0.00%	0.00%
	15 - 20	0.00%	0.00%
	20 - 30	87.01%	12.99%
	30 - 50	75.31%	24.69%
	50 - 80	66.24%	33.76%
	> 80	0.00%	0.00%

5.7.2.4 Qualitative wood biomass utilization on the sample plot B2 – the half-tree length method

The assortment structure obtained on the sample plot B2 where the half-tree length harvesting method was performed and the prediction from assortment tables for compartment 65 differs significantly. It was shown that obtained share of fuelwood was lower than predicted (44.26% contra 56.37%). Relative share of all other classes, except sawlogs of III class, was higher than predicted. It can be said that obtained assortment structure was much better than the estimated one from assortment tables for a respective compartment i.e. stand conditions (Table 43).

Table 43: The assortment structure on the sample plot B2- the half-tree length method

	Classes	F	L	I	II	III	O
	Estimated assortment structure from assortment table						
	Total	**1.18%**	**2.68%**	**6.88%**	**14.48%**	**18.41%**	**56.37%**
	Obtained assortment structure						
	Total	**2.69%**	**4.18%**	**28.42%**	**15.43%**	**5.02%**	**44.26%**
DBH classes (cm)	10 - 15	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	15 - 20	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
	20 - 30	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
	30 - 50	0.00%	0.00%	30.09%	20.93%	5.55%	43.43%
	50 - 80	3.32%	5.15%	28.44%	14.44%	4.97%	43.68%
	> 80	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

The structure of fuelwood on the sample plot B2 (Table 44) shows that relative share of roundwood fuelwood was higher than stacked wood (80.01 % contrary to 19.99 %). With the increase of DBH share of roundwood, fuelwood is decreasing. Up to the DBH 30-50 cm there was no stacked wood at whole.

Table 44: The structure of fuelwood on the sample plot B2– the half-tree length method

		Roundwood fuelwood	Stacked fuelwood
	Total	80.01%	19.99%
DBH classes (cm)	10 - 15	0.00%	0.00%
	15 - 20	100.00%	0.00%
	20 - 30	100.00%	0.00%
	30 - 50	84.50%	15.50%
	50 - 80	78.40%	21.60%
	> 80	0.00%	0.00%

5.7.2.5 Qualitative wood biomass utilization in the assortment method in general

In general, in the assortment method for both sample plots in average relative share of fuelwood was less than predicted (Table 45). Share of F logs was higher and L logs smaller. The structure of sawlogs shows that obtained share of sawlogs II and III class was slightly lower than predicted and share of sawlogs of I class was significantly higher (16.09% contrary to 5.50 %).

Table 45: The assortment structure in the assortment method

	Classes	F	L	I	II	III	O
	Estimated assortment structure from assortment table						
	Total	**0.97%**	**2.14%**	**5.50%**	**12.15%**	**15.87%**	**63.37%**
	Obtained assortment structure						
	Total	**2.95%**	**1.35%**	**16.09%**	**11.02%**	**13.45%**	**55.15%**
DBH classes (cm)	10 - 15	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	15 - 20	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
	20 - 30	0.00%	0.00%	0.00%	4.31%	12.27%	83.42%
	30 - 50	0.00%	3.80%	13.41%	15.41%	18.38%	49.00%
	50 - 80	5.49%	0.00%	21.07%	9.52%	10.66%	53.27%
	> 80	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

The share of stacked fuelwood was about 30% (Table 46) and after 20 cm DBH was increasing constantly in relation to roundwood fuelwood.

Table 46: The structure of fuelwood in the assortment method

		Roundwood fuelwood	Stacked fuelwood
	Total	70.01%	29.99%
DBH classes (cm)	10 - 15	0.00%	0.00%
	15 - 20	55.57%	44.43%
	20 - 30	81.81%	18.19%
	30 - 50	71.65%	28.35%
	50 - 80	66.24%	33.76%
	> 80	0.00%	0.00%

5.7.2.6 Qualitative wood biomass utilization in the half-tree length method in general

In the half-tree length harvesting method assortment structure differs from predicted, the share of fuelwood was lower than predicted (63.37% contrary to 49.45%) and the share of all other classes except sawlogs of III class was higher (Table 47). The difference was particularly notable at sawlogs of I class.

Table 47: The assortment structure in the half-tree length method

	Classes	F	L	I	II	III	O
	Estimated assortment structure from assortment table						
	Total	**0.97%**	**2.14%**	**5.50%**	**12.15%**	**15.87%**	**63.37%**
	Obtained assortment structure						
	Total	**1.70%**	**2.64%**	**23.27%**	**13.34%**	**9.59%**	**49.45%**
DBH classes (cm)	10 - 15	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
	15 - 20	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
	20 - 30	0.00%	0.00%	0.94%	1.78%	16.73%	80.54%
	30 - 50	0.00%	0.00%	27.31%	18.10%	14.35%	40.24%
	50 - 80	3.32%	5.15%	28.44%	14.44%	4.97%	43.67%
	> 80	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

For the half-tree length harvesting method in the whole relative share of fuelwood shows that roundwood fuelwood was very dominant over stacked fuelwood (87.20% contrary to 12.80%) (Table 48). This was expected because one of the presumptions of the half-tree length harvesting method was that production of stacked wood should be as less possible in favor of roundwood fuelwood.

Table 48: The structure of fuelwood in the half-tree length method

		Roundwood fuelwood	Stacked fuelwood
	Total	87.20%	12.80%
DBH classes (cm)	10 - 15	100.00%	0.00%
	15 - 20	100.00%	0.00%
	20 - 30	99.32%	0.68%
	30 - 50	88.79%	11.21%
	50 - 80	78.41%	21.59%
	> 80	0.00%	0.00%

5.7.2.7 Comparison of the assortment structure between harvesting methods

Comparison of the assortment structure was done between harvesting methods in the same compartment and in the whole.

As shown in Figure 82, for the compartment 98, the most significant difference was at L logs where in the half-tree length method these logs were not found at all. With both harvesting methods applied, the share of sawlogs was larger than predicted, and the share of fuelwood was fewer.

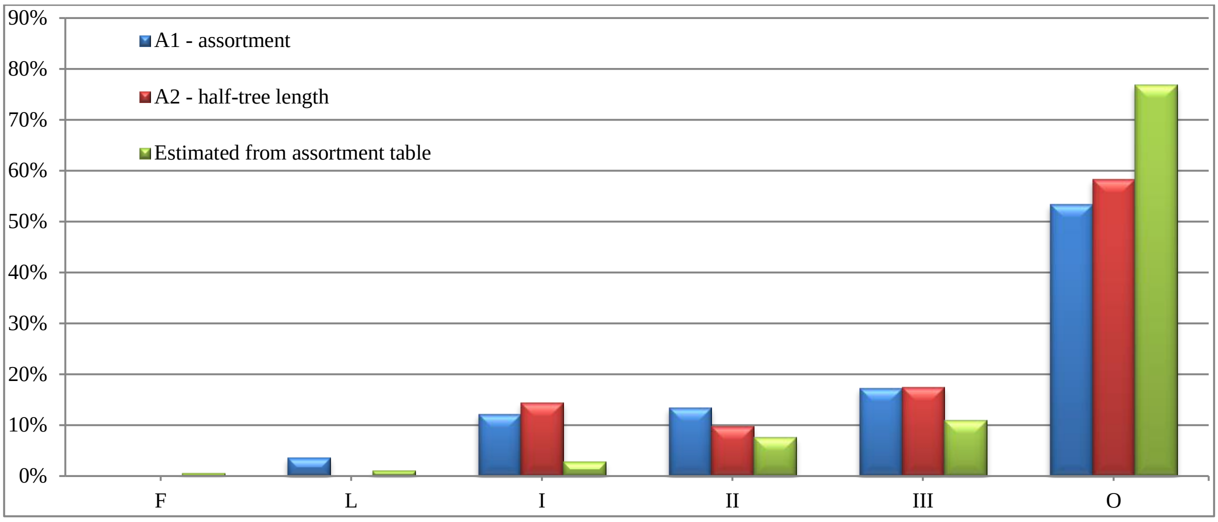


Figure 82: The assortment structure in the compartment 98 (sample plots A1 and A2)

When looking at the structure of fuelwood in the compartment 98, the share of stacked fuelwood was significantly fewer in the half-tree length harvesting method (Figure 83).

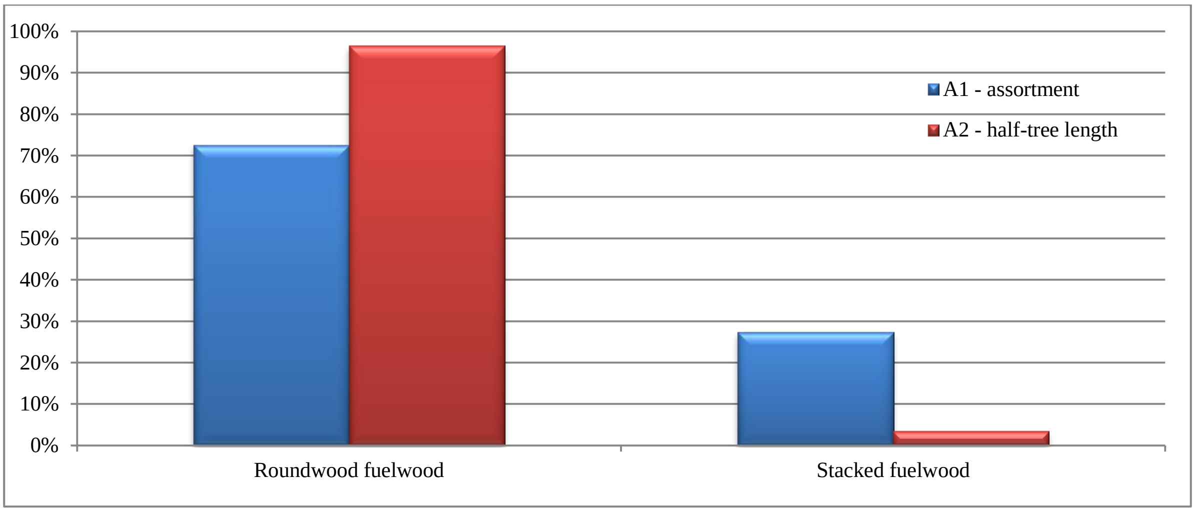


Figure 83: The structure of fuelwood in the compartment 98 (sample plots A1 and A2)

In the compartment 65 relation of predicted and estimated structure shows that relative share of high value logs (L, I and II) obtained was higher than predicted. The half-tree length harvesting method gave better structure in L, I and II class than the assortment method, except F logs where better results were obtained in the assortment method (Figure 84).

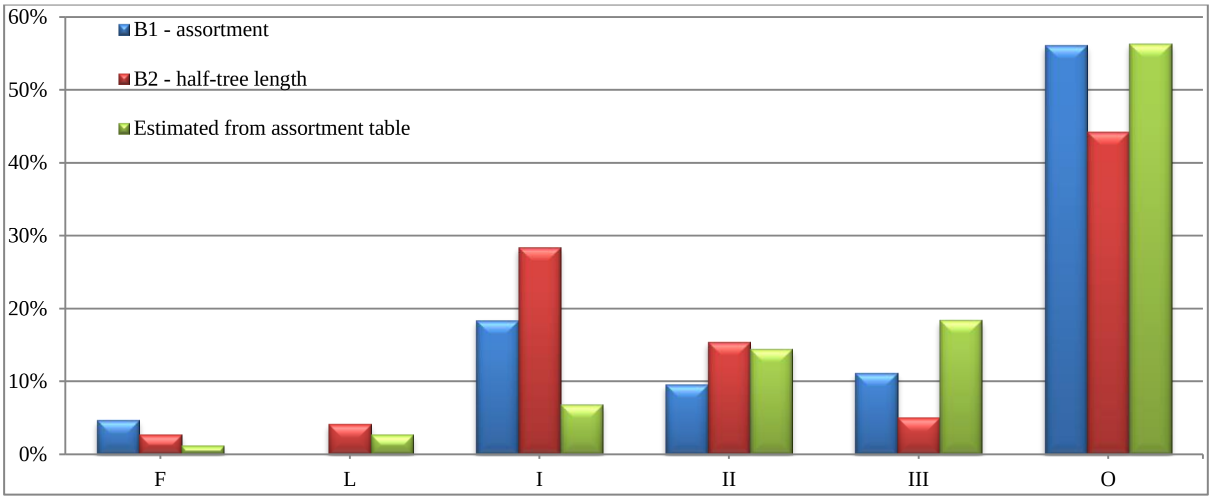


Figure 84: The assortment structure in compartment 65 (sample plots B1 and B2)

When looking at the structure of fuelwood in the compartment 65 share of stacked fuelwood was significantly fewer in the half-tree length harvesting method (Figure 85).

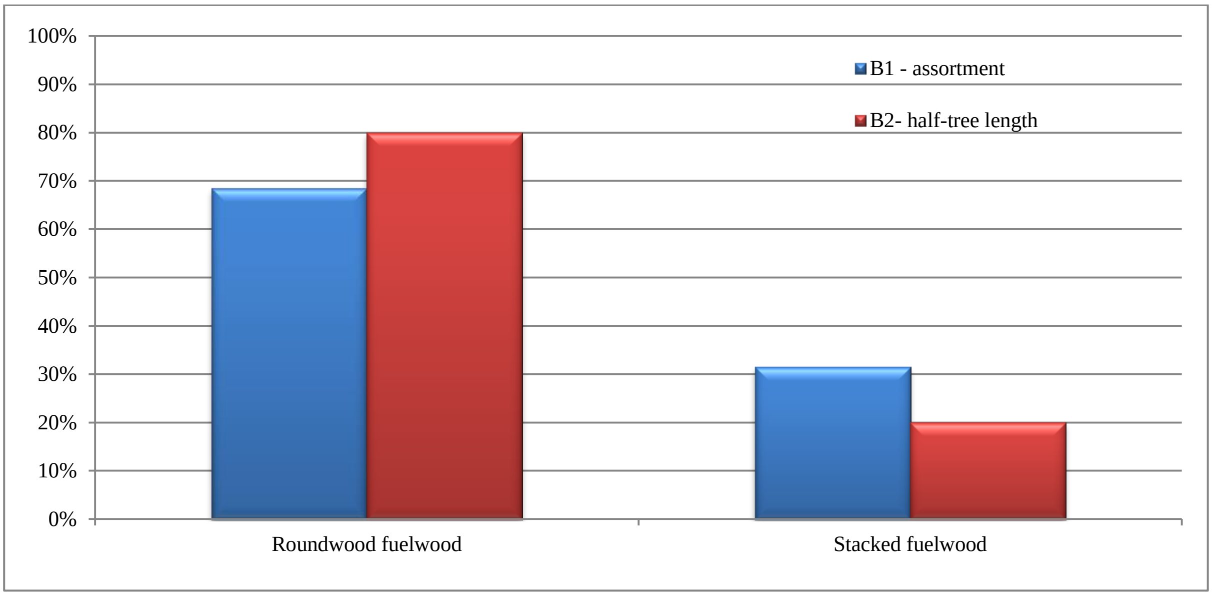


Figure 85: The structure of fuelwood in the compartment 65 (sample plots B1 and B2)

Comparing of the assortment structure summary obtained on the all sample plots in both harvesting methods with the predicted structure in general, it was shown that obtained share of higher value logs was higher, than predicted and the share of fuelwood was less. Looking at the relation between harvesting methods it was shown that the half-tree length method gives better assortment structure in high value logs, except F logs (Figure 86).

These results represent a significant problem for forest managers because it is shown that predictions for assortment structure were false. Reasons for that could be inproper evaluation of tree categories during marking of trees for cutting, inaccurate forest inventoriy or some other.

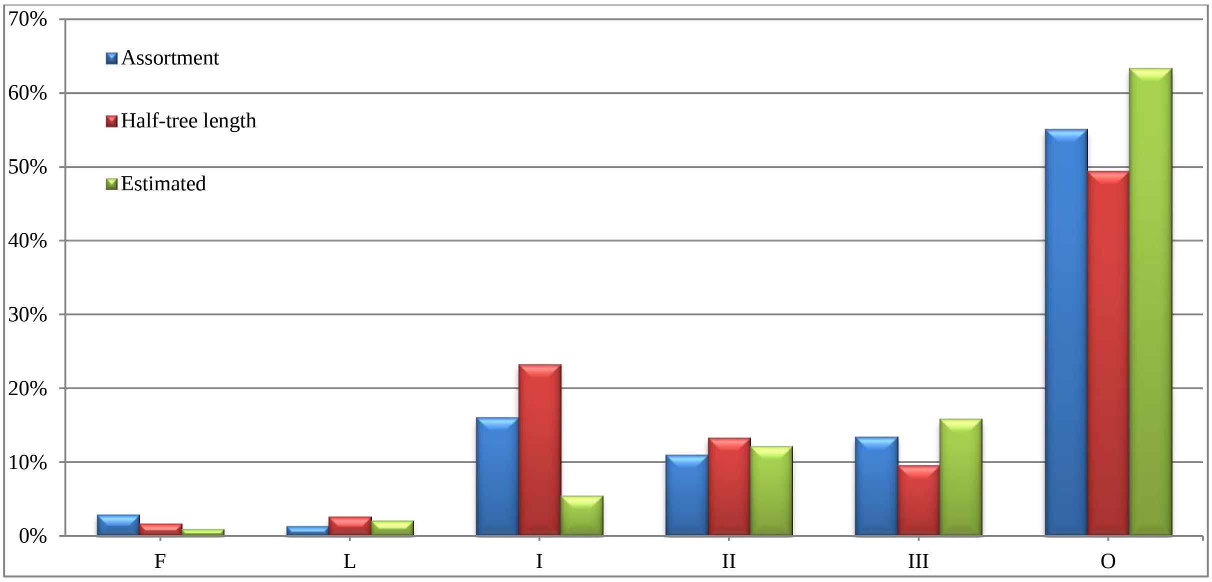


Figure 86: Assortment structure by harvesting methods

In the half-tree length method there is presumption that from the same stand gets better assortment structure. Main reason for that is because final processing is done at the forest landing site where wood is concentrate and it can be chosen bests workers, who proved to be specialists for JUS.

Looking at the structure of the fuelwood obtained in the whole experiment it was shown that there was a notable difference in sense that the half-tree length harvesting method produced smaller amount of stacked wood which had an important consequence on transport and costs of process in the whole (Figure 87).

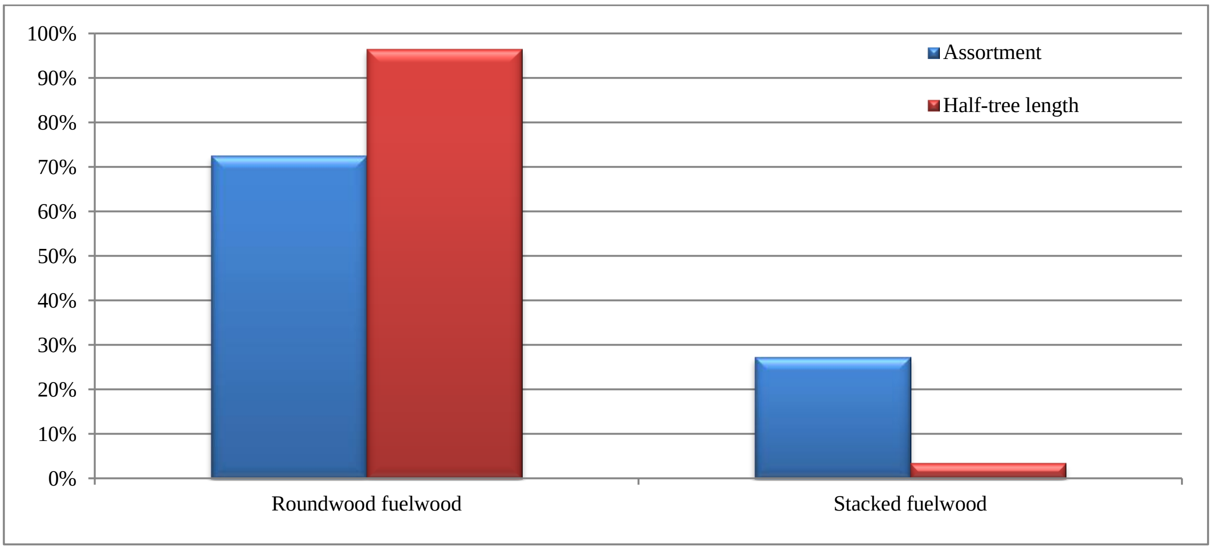


Figure 87: Structure of fuelwood by harvesting method

5.7.2.8 The value of wood

The value of wood was calculated on the basis of the assortment structure and prices of wood that were valid in Republic of Srpska at the moment of calculation (June, 2013) (Table 49). Value was calculated in purpose of comparing how applied harvesting method influences values of produced wood.

Table 49: Prices of wood

Class	Prices of wood(€/m³)
F	140.51
L	94.36
I	60.68
II	46.67
III	35.56
O	30.26

The value of wood was calculated as a weighted value based on the amount and the value of each class (Table 50). It is obvious that in both harvesting methods obtained average value of wood was higher than predicted. On the sample plot A1 (assortment method) higher value was obtained than on the A2 (half-tree length method), 39.42 €/m³ contrary to 37.17 €/m³. On the sample plot B2 (half-tree length method), higher average value was obtained than on the B1 (assortment method), 47.35 €/m³ contrary to 43.20 €/m³. Results for sample plots B1 and B2 confirm research hypothesis that in half-tree length method qualitative utilization of wood biomass is better, but for sample plots A1 and A2 where average wood value is similar (considering that DBH on A1 is 3 cm larger than on A2), this research hypothesis is not confirmed. Table 50: Average prices of wood obtained

Sample plot	Harvesting method	Obtained wood value (€/m³)	Predicted wood value (€/m³)
A1	Assortment	39.42	34.26
A2	Half-tree length	37.17	34.26
B1	Assortment	43.20	38.72
B2	Half-tree length	47.35	38.72
A1 and B1	Assortment	41.79	37.20
A2 and B2	Half-tree length	43.60	37.20

The value of wood by DBH classes is presented in the Table 51. In upper DBH classes difference is more notable in favor of the half-tree length method.

Table 51: The value of wood by DBH classes

		Assortment method	**Half-tree length method**
		Value (€/m³)	Value (€/m³)
DBH classes (cm)	10 - 15	0.00	30.26
	15 - 20	30.26	30.26
	20 - 30	31.61	31.72
	30 - 50	40.27	42.30
	50 - 80	44.84	48.50
	> 80	0.00	0.00

When processing at the landing site there is presumption that workers who work at wood classification easier detect errors which can influence on the wood classes. Obviously it came to the fore more at the thicker logs in this case.

5.8 DAMAGES

Damages were measured on the sample plots after felling and skidding was done, as described in methodology.

5.8.1 Damages on the sample plot A1 – the assortment method

On the sample plot A1 77 damages were evidenced on the 55 trees in total. The number of damages per tree varied from 1 to 3. From 55 damaged trees, 35 had 1 damage, 18 had 2 damages per tree and 2 trees had 3 damages. The average width of damage was 21.84 cm and varied from 2 cm to 100 cm. Damages were below 20 cm wide mostly.

Average height of damages was 8.06 cm and varied from 1 cm to 32 cm. The damage height was below 10 cm mostly.

The average damage surface was 184.69 cm^2 and varied from 3 to 1200 cm^2. In most cases the surface was below 200 cm^2.

Height on the standing tree where damages were evidenced was 38.69 cm and varied from 5 cm to 330 cm. Damages occurred mostly below height of 50 cm on the tree.

Measuring the distance from the skidding trail where damage occurred showed that the average distance was 19.17 m and varied from 0 to 50 m. It is obvious that damages are slightly more frequently closer to the skidding trail, what was expected because more wood is bunched closer to skidding trail.

When looking at the distance from the landing site or the beginning of skidding trail it was shown that damages were more or less evenly distributed.

The distribution of DBH of damaged trees showed that damages mostly occur on the trees from 5 cm to 30 cm.

5.8.2 Damages on the sample A2 – the half-tree length method

On the sample plot A2 79 damages were evidenced on the 53 trees in total. Number of damages per trees varied from 1 to 4, 37 trees had 1 damage per tree, 5 had 2 damages per tree, 4 trees had 3 damages and 3 trees had 4 damages.

The average damage width was 25.70 cm and varied from 2 cm to 90 cm. Mostly damages were below 40 cm wide.

The average damage height was 8.91 cm and varied from 2 cm to 40 cm. The damage height was below 10 cm mostly.

The average damage surface was 277.25 cm^2 and varied from 4 to 1950 cm^2. In most cases the surface was below 200 cm^2.

The average height on the standing tree where damages were evidenced was 38.01 cm and varied from 5 cm to 150 cm. Damages occurred mostly below height of 40 cm on the tree.

Measuring the distance from skidding trail where damage occurred showed that the average distance was 13.46 m and varied from 0 to 45 m. It is shown that damages were more frequently closer to the skidding trail; mostly they were on the edge trees, what was expected.

When looking at the distance from landing site or beginning of the skidding trail it was evidenced that damages mostly occurred at the middle of length of the skidding trail.

The distribution of DBH of damaged trees showed that damages mostly occurred on the trees from 15 cm to 30 cm.

5.8.3 Damages on the sample plot B1 – the assortment method

On the sample plot B1 52 damages were evidenced on 39 trees in total. From total number of damaged trees, 28 had 1 damage per tree, 9 had 2 per tree and 1 tree had 1 damage.

The average damage width was 31.44 cm and varied from 4 cm to 130 cm. Mostly damages were below 40 cm wide.

The average damage height was 12.17 cm and varied from 2 cm to 45 cm. The height of damages was from 5 to 15 cm mostly.

The average damage surface was 407.52 cm^2 and varied from 8 to 2470 cm^2. In most cases the surface was up to 600 cm^2.

The average height on the standing tree where damages were evidenced was 40.37 cm and varied from 5 cm to 200 cm. Damages occurred mostly below height of 60 cm on the tree.

Measuring the distance from skidding trail where damage occurred showed that average distance was 16.92 m and varied from 0 to 45 m. It is shown that damages were more frequently closer to the skidding trail; mostly they were on the edge trees.

When looking at the distance from landing site or beginning of the skidding trail it was evidenced that damages mostly occurred at the middle of length of the skidding trail.

Distribution of DBH of damaged trees showed that damages mostly occurred on the trees from 15 cm to 30 cm.

5.8.4 Damages on the sample plot B2 – the half-tree length method

On the sample plot B2 58 damages were evidenced on 40 trees in total. Number of damages per tree varied from 1 to 4, 30 trees had 1 damage per tree, 2 had 2 damages per tree, 4 trees had 3 damages and 3 trees had 4 damages.

The average damage width was 31.22 cm and varied from 3 cm to 105 cm. Mostly damages were below 50 cm wide.

The average damage height was 13.83 cm and varied from 3 cm to 54 cm. The damage height was from 5 to 15 cm mostly.

The average damage surface was 495.84 cm^2 and varied from 18 to 3403 cm^2. In most cases surface was up to 500 cm^2.

The average height on the standing tree where damages were evidenced was 45.52 cm and varied from 5 cm to 130 cm. Damages occurred mostly below height of 40 cm on the tree.

Measuring the distance from skidding trail where damage occurred, showed that the average distance was 8.76 m and varied from 0 to 42 m. It is shown that damages were more frequently closer to the skidding trail; mostly they were on the edge trees, what was expected.

When looking at the distance from landing site or beginning of the skidding trail it was evidenced that damages mostly occurred at the middle of length of the skidding trail.

Distribution of DBH of damaged trees showed that damages mostly occurred on the trees from 30 cm to 40 cm.

5.8.5 Comparison of sample plots by damages

The number of damages per sample plot and per hectare is presented in the Figure 88. It is noticeable that the number of damages and the number of damages per tree was higher on the sample plots A1 and A2 than on the B1 and B2. It is understandable when considering that the average DBH on sample plots A1 and A2 was smaller and the number of trees per hectare was higher.

The number of damaged trees per ha was similar regardless harvesting method, 15.4 trees/ha on A1 (assortment method) and 15.8 trees/ha on A2 (half-tree length method), or 10.4 trees/ha on B1 (assortment method) and 11.6 trees/ha on B2 (half-tree length method).

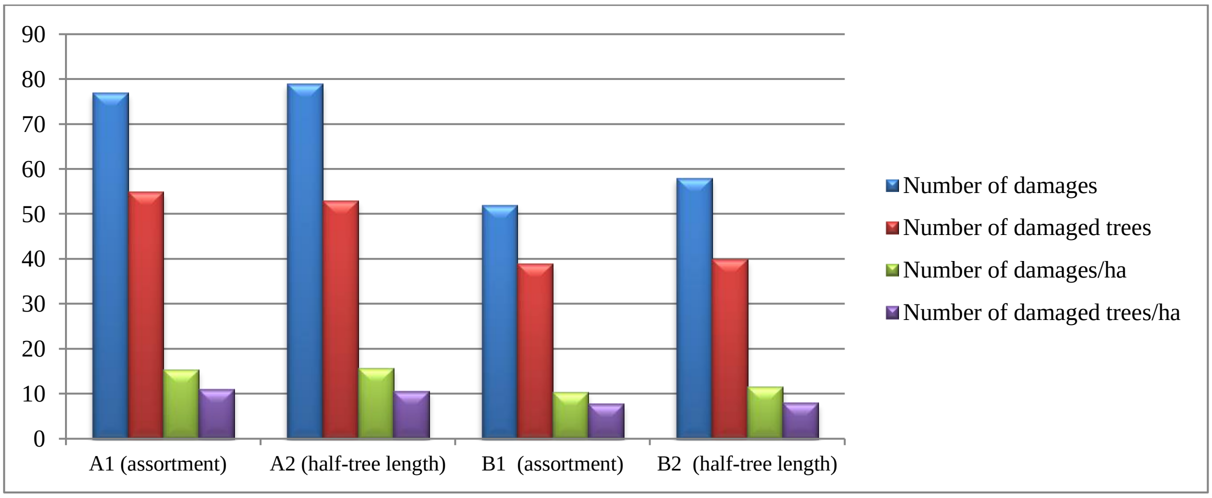


Figure 88: Number of damaged trees

Comparing of dimension of damages by sample plots (Figure 89) it was shown that in general damages on the sample plots B1 (assortment method) and B2 (half-tree length method) which have larger average DBH were larger, by width and height.

Within the same harvesting method, the average width of damage was 43.9% larger on the sample plot B1 (assortment method) than on A1 (assortment method) and 21.5% on B2 (half-tree length method) than A2 (half-tree length method). With the height of damages situation was similar. On the sample plot B1 (assortment method) the average height of damages was 50.9% larger than on the sample plot A1 (assortment method) and 55.2% on B2 (half-tree length method) than A2 (half-tree length method).

When comparing damages between the assortment and the half-tree length harvesting method it was shown that the damage width was 17.6% larger on A2 (half-tree length method) than on A1 (assortment method) sample plot. On sample plots B1 and B2 (half-tree length method) the average damage width was similar.

The average damage height was 10.5% larger on the sample plot A2 (half-tree length method), than on A1 (assortment method) and 13.4% on B2 (half-tree length method) than on B1 (assortment method).

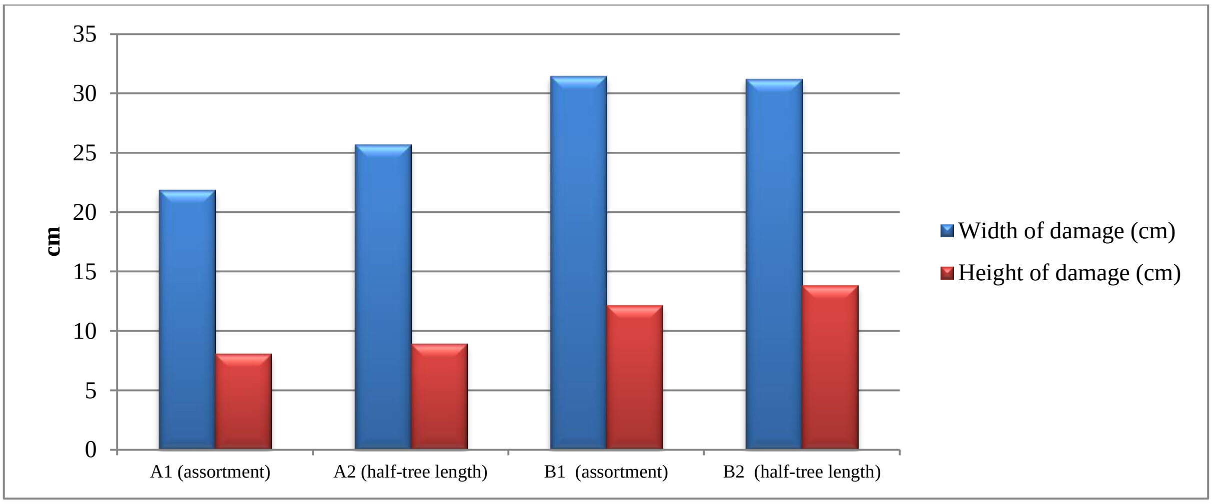


Figure 89: Average sizes of damage by sample plots

When looking at the average surface per sample plots it was concluded that damage surface in general was larger on sample plots with larger average stand DBH for 120% (B1 contrary to A1) and 78.8% (B2 contrary to A2) (Figure 90).

Within the same harvesting method the average damage surface was larger on sample plots with the half-tree length harvesting method, 50% were larger damages on sample plot A2 (half-tree length method) than A1(assortment method) and 21.7% on B2 (half-tree length method) than B1 (assortment method).

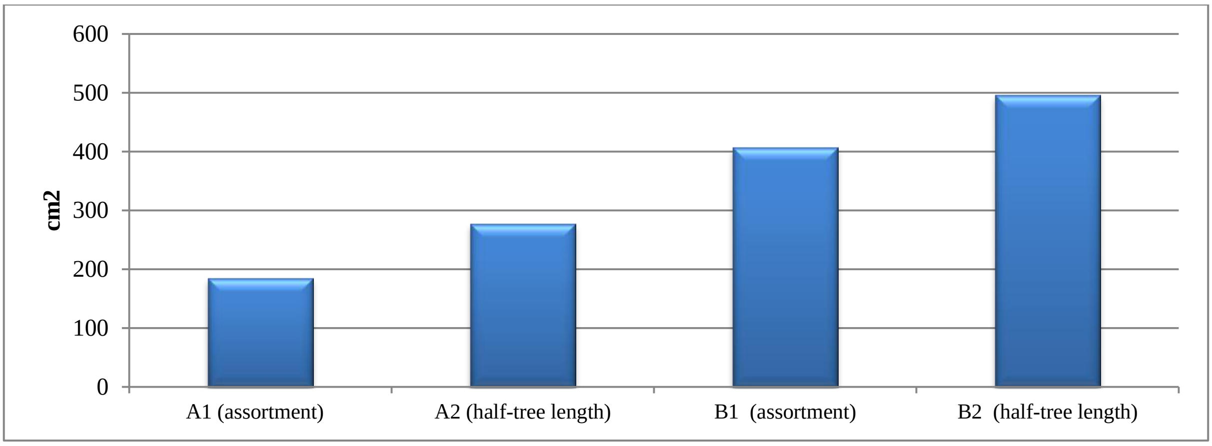


Figure 90: Average injury surface of damage by sample plots

The tree damages were slightly higher on sample plots with higher DBH, approximately 45.52 cm on B2 (half-tree length method) and 40.37 cm on B1 (assortment) (Figure 91). Generally, it was shown that only on the sample plot B2 (half-tree length method) the damage height on the tree differs from others.

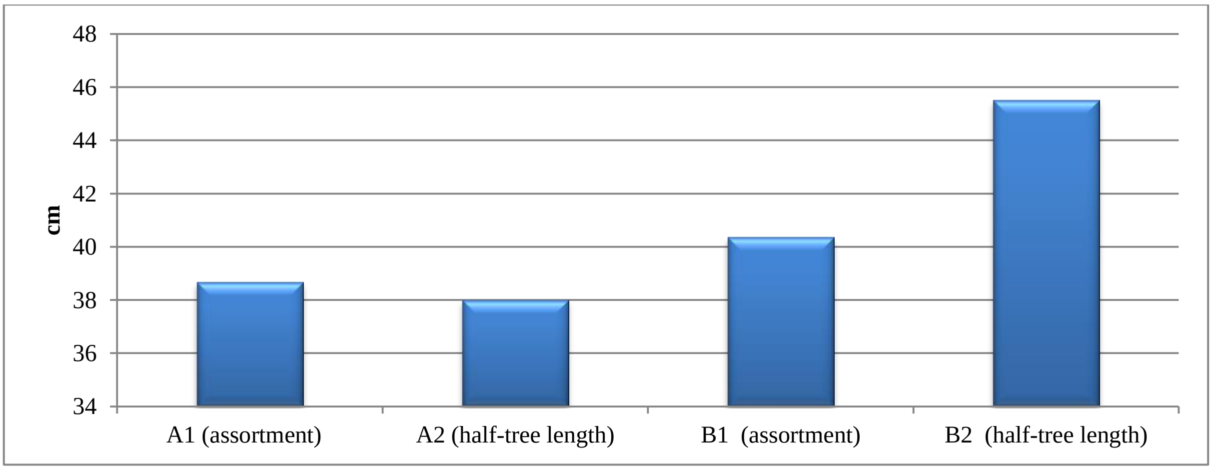


Figure 91: Average height of damages on the tree

The average tree distance of where damages occurred from skidding trail on all sample plots was below 20 m. On sample plots where the half-tree length harvesting method was performed average distances were smaller, 13.46 m (B2) and 8.74 m (A2), contrary to 19.17 m (A1) and 16.92 m (B1) (Figure 92).

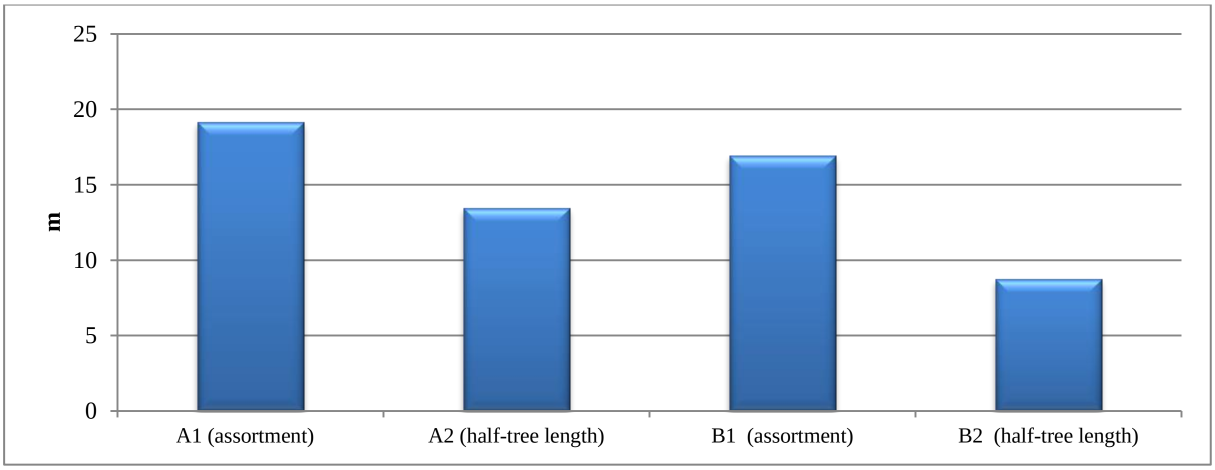


Figure 92: Average distance of damages from skidding trail

The average distance from landing site or beginning of skidding trail which leads from landing site is presented in the Figure 93.

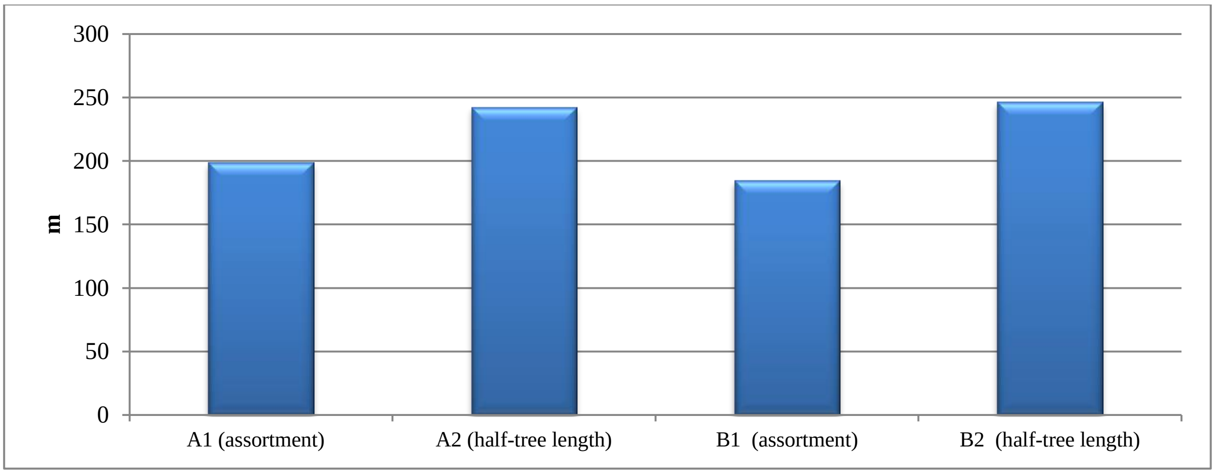


Figure 93: Average distance of damages from landing site

Average DBH of damaged trees is presented in the Figure 94. In the half-tree length harvesting method, DBH of damaged trees was slightly higher than in the assortment method, 24.62 cm contrary to 21.49 cm, and 39.80 cm contrary to 32.63 cm.

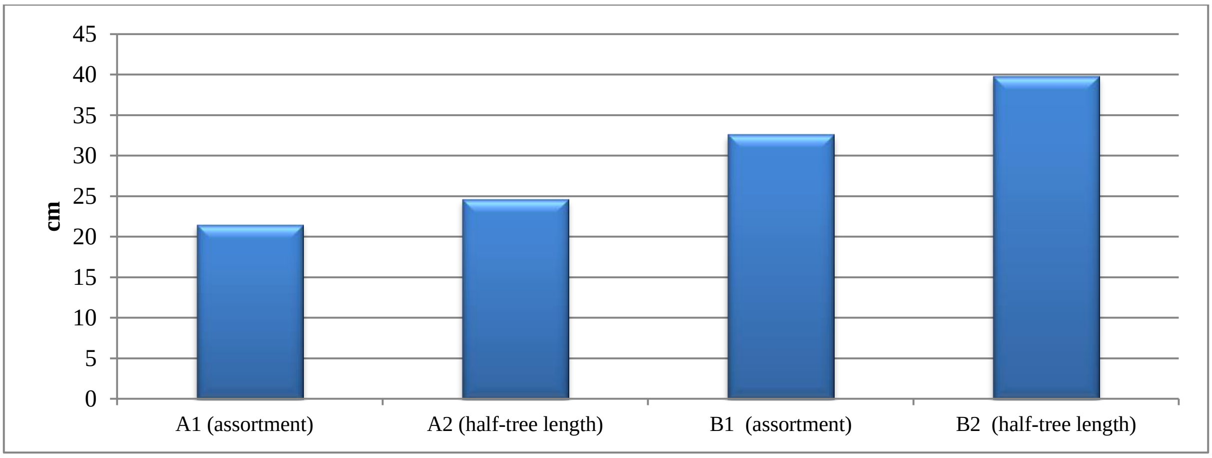


Figure 94: DBH of damaged trees

6 DISCUSSION

6.1 RESULTS DISCUSSION

Felling

The share of stacked wood was significantly lower at the half-tree length method than in the assortment, 1.95% (A2 - the half tree length method) contra 15.53% (A1 - the assortment method) and 8.12% (B2 - the half tree length method) contra 17.13% (B1 - the assortment method).

Obtained results were expected if considering the description of harvesting methods. In the assortment method, stacked wood was made from branches and from thinner parts of the stem, while in the half-tree length method it was made only form branches.

The decision where a point on the stem is where producing of roundwood stops and producing of stacked wood starts was based on the decision of forest technician. There are recommendations, regarding bucking, in operation plans which are prepared for each specific compartment and they should be followed. Bucking optimization requires simultaneous consideration of stem dimensions, quality, log length and prices (Wang et al., 2007).

The difference in the amount of stacked wood within the same harvesting method was higher on sample plots with smaller average tree diameter, within the same harvesting method. The reason could be that thicker trees had relatively bigger amount of branches above 7 cm diameter, from which stacked wood was produced.

The average number of assortments per tree obtained was smaller in the half-tree length method, 1.81 pieces per tree (A2 - half tree length method) contrary to 2.23 pieces per tree (A1 - assortment method) and 4.77 (B2 - half tree length method) contrary to 6.23 (B1-assortment method). The difference was slightly bigger on sample plots with larger DBH, 19% (A2 contra A1) and 23% (B2 contra B1).

The diameter of assortments was lower in the half-tree length method than in the assortment one, 20.01 cm (A2 - half tree length method) contrary to 25.73 cm (A1- assortment method) and 26.90 cm (B2 - half tree length method) contrary to 34.83 cm (B1 - assortment method).

The reason for such difference was the fact that in the half tree length method logs were relatively longer and was stretching into thinner part of the stem, into a part which in the assortment method was bucked in to the stacked wood. Here, the emphasis is in the fact that firewood is a part of the same log as technical wood (combined log), what makes skidding of lower value wood cost competitive (Košir, 2009; Bajić et al., 2007).

The average length of assortments was smaller in the assortment method, 5.16 m (A1-assortment method) contrary to 8.83 m (A2 - half tree length method) and 4.95 m (B1-assortment method) contrary to 8.66 m (B2 - half tree length method).

The length of logs in the assortment method mostly depends from dimension and quality. Those are main inputs for wood classification. In the half-tree length method, the length was dominantly linked to skidding options. In this case density of remaining trees was limiting factor in most cases. Mousavi (2009) in his research found maximum log length in short-log method of 5.6 m, and in long-log method minimum length was 7.80 m. These results are in compliance with this research.

As a consequence of length and diameter, volume of assortments was bigger in the half-tree length method 19% (A2 contra A1) on sample plots with smaller DBH and 27% (B2 contra B1) on plots with larger DBH.

Relative structure of productive work time showed that work operations Production of fuelwood and Stacking of fuelwood consumed relatively less time in the half-tree length method than in the assortment one, 9.22 % and 21.1% and in the half-tree length and 17.75% and 29.56% in the assortment method, respectively.

Work operation Delimbing consumed relative larger share of time in the half-tree length method, 33.73% contrary to 20.86% in the assortment method. This could be explained by the fact that in upper parts of stem in the assortment method Delimbing can overlap with the Production of fuelwood and it is hard to define the border between those two operations during the time study because of inconsistent work of cutter.

The structure of allowance time was similar in both methods, coefficient of allowance times were 1.30 for the assortment and 1.31 for the half-tree length method. Zečić and Marenče (2005) found allowance time for cutters 1.55 and 1.70 for two groups. Ghaffarian et al. (2013) found total delays time of 19% of total work time.

Regression and correlation analysis showed that in both methods operation Moving did not show dependence from the distance, what was contrary from some other studies, like Kluender and Stokes (1996). Trees marked for felling were equally distributed in the stand and that could be reason for that. The reason could also be the workers discipline.

Preparing of work place did not show significant dependence from any examined factor as well. Other work operations showed more or less strong significant dependence from DBH. Lortz et al. (2007) concluded that DBH has strongest impact on felling productivity also.

Productivity was constantly increasing with increasing of DBH and it was higher in the half-tree length method than in the assortment one. These results are in compliance with some other authors who performed studies where compared different felling and processing methods (Nagdhi, 2005; Adebayo et al., 2007; Mousavi, 2009).

Reason because half-tree length was more productive was in the fact that some working operations were avoided or minimized in half-tree length method, like Production of fuelwood and Stacking of fuelwood. Also work operation Processing was mostly transferred to the landing site where could be done in more productive way.

Skidding

Number of pieces in load was similar in both methods, 9.94 (A1) and 9.00 (B1) in the assortment method and 11.09 (A2) and 9.57 (B2) in the half-tree length method.

The possible reason for that would be that number of pieces was rather a result of skidder hooking capacity, than the volume or length of pieces. So, the skidder always worked below its optimum capacity. This is interesting for forest managers because it was shown that the assortment method in beech forests do not allow optimal using of capacity of LKT 81T skidder.

The average piece volume was notably bigger at the half-tree length method, 0.28 m^3 (A1) contrary to 0.33 m^3 (A2) and 0.57 m^3 (B1) contrary to 0.75 m^3 (B2). The difference was more noticeable on sample plots with bigger average piece.

As a consequence of the previous, the average load volume in the assortment method was 2.80 m^3 (A1) and 4.98 m^3 (B1), and 3.56 m^3 (A2) and 6.62 m^3 (B2) in the half-tree length method. The average load was 22% and 25% larger at the half tree length method under the same conditions. Mousavi, (2009) in his study evidenced similar load volume for short-log and long-log. His definition of short-log and long-log are comparable with assortment and half-tree length method.

The average length of pieces in the assortment method was 5.38 m (A1) and 5.30 m (B1), and 8.97 m (A2) and 9.19 m (B2) in the half-tree length method. The average length of pieces was 40% and 42% larger in the half-tree length method.

Looking at duration of individual work operations it can be seen that Unloaded drive, Loaded drive and Hooking were most time consuming operations.

Relative share of each individual operation in productive work time was very similar at both methods.

Multiple linear regression analysis showed that work operations depended mainly of distance and load volume at both methods. Loaded drive depended from distance and load volume. Strength of correlation relationship was similar at both methods.

These findings were in compliance with other researches. Wang et al. (2004) found that load volume and skidding distance have main influence on cycle time. Some other researchers reported that skidding distance, log volume, winching distance and trail slope have strong impact on productivity (Ghaffaryan et al., 2013; Sabo and Poršinsky, 2005; Zečić et al., 2005).

Only Forming of load at the half-tree length method did not show a significant difference from any examined variable. The reason may be a consequence of the small sample because this operation did not appear at each work cycle.

Coefficients of allowance time for skidding are 1.30 and 1.31. Zečić and Marenče established allowance time coefficients for two skidders, 1.29 and 1.24. Horvat et al. (2007) for Ecotrac

120V found allowance time coefficients 1.34 for hilly mountain site and 1.18 for mountainous site.

Skidding costs were 17% and 40% lower in the half-tree length method when all other conditions were identical. The difference in cost was higher when average piece volume was higher. Mousavi (2009) concluded similar in comparing of skidding of long-log and short-log.

Processing at the landing site

Processing at the landing site was investigated in the half-tree length harvesting method. The result showed that the share of delays was 59% and productive time 41%.

The explanation for relative dominant share of delays is the fact that workers who performed processing also were interrupted by trucks which were constantly arriving for shipping. Also, workers often needed help of the crane to retrieve each piece.

Residue which occurred at the landing site after processing was chipped together with the fuelwood. The amount of residue was 2 m^3 on 100 m^3 of roundwood. Those were parts of wood which remained after processing at the landing site. Positive thing is that residue was relative well concentrated and suitably for chipping.

Chipping

Chipping was done at the forest landing site with the mobile chippers JENZ HEM 700 and Pezzolato PTH 1300/1500. Both chippers were fed with the crane Palfinger Epsilon 120 Z plus mounted on the truck Mercedes Benc Actros 2654.

Conversion coefficient from solid wood volume into loose chips volume was calculated and it was 2.7. In opposite way, from loose to solid m^3 conversion factor was 0.37.

When chipping of stacked instead of roundwood fuelwood productivity was 29.5% lower. The reason for that was that crane could not achieve full efficiency when manipulating with the stacked wood, especially when stacked wood was not piled. This was highly dependable of the operator skills.

Both investigated chippers achieved less productivity than was predicted by manufacturer. At the landing site manipulating with the chippers crane and feeding did not go smoothly because of limited space.

Cost calculation of chippers showed that bigger chippers had lower unit costs, but because of inability to achieve full capacity at forest landing site and because of their dimensions which hinder the manipulation, it can be recommended using of chippers of smaller capacity like Jenz HEM 561 DQ or even smaller.

When it comes to transportation it is noticeable that there should be enough chips containers if we want that chippers work under full capacity. Spinelli et al. (2007) also found that chipping at the landing site is technically very effective method but requires close coordination of the transportation fleet.

Wood biomass utilization

Quantitative utilization was compared on the basis of total wood obtained from trees in each harvesting method and showed that up to 50 cm DBH quantitatively utilization was similar and above 50 cm difference occurred in favor of the assortment method. Main reason for that was that trees above 50 cm DBH had a large amount of branches which were not in the whole cut in the stacked wood.

While performing the half-tree length method, there was attention from side of forest technician and cutters that the amount of stacked wood produced would be as less as possible.

Relation between estimated wood biomass utilization and obtained after harvesting showed that by the approximately 50 cm DBH utilization of wood in both harvesting methods was equal to estimation for gross wood, what is expected because gross wood assumed wood of stem and branches over 7 cm diameter. .

After 50 cm there was a difference in favor of both harvesting methods related to gross wood estimation. These results showed that assortment tables which are in use for beech did not give precise estimations or that forest managers did not follow exact procedure for prediction. In both cases this is not acceptable in terms of planning of business efficiency of forest companies. The difference was more significant in favor of the assortment than the half-tree length method.

In both harvesting methods, utilization was below total estimated biomass value, what was expected.

Quality classes were compared by diameter classes which were used in local forestry organizations. Comparison of the assortment structure was done between harvesting methods in the same compartment and in the whole.

In the compartment 65 the most significant difference was at L logs, where in the assortment method, these logs were not found at all. In both harvesting methods applied, share of sawlogs was larger than predicted and the share of fuelwood was fewer.

The half-tree length harvesting method in general gave better structure in L, I and II class than the assortment method, except F logs where better results were obtained in the assortment method.

Comparing of summary, the assortment structure obtained on the all sample plots in both harvesting methods applied with the predicted structure, speaking in general, obtained share of higher value logs was higher than predicted and the share of fuelwood was less. Relation between harvesting methods shows that the half-tree length method gives “better” assortment structure in high value logs, except F logs. The reason could be the fact that wood processing in the half-tree length method was done at the landing site where there were better conditions for processing in term of visibility, technical performance and that job was done by a man who was a specialist for bucking.

The value of wood was calculated as a weighted value based on the amount and the value of each class of wood. It was shown that in both harvesting methods obtained average value of wood was higher than predicted. On the sample plot A1 (assortment method) higher value was obtained than on the A2 (half-tree length method), 39.42 €/m³ contrary to 37.17 €/m³. On the sample plot B2 (half-tree length method) higher average value was obtained than on the B1 (assortment method), 47.35 €/m³ contrary to 43.20 €/m³.

Damages

The number of damages and the number of damages per tree was higher on the sample plot A1 (assortment method) and A2 (half-tree length method) than on the B1 (assortment method) and B2 (half-tree length method). It was understandable when considering that average DBH on sample plots A1 and A2 was smaller and the number of trees per hectare was higher.

The number of damaged trees per ha was similar regardless the harvesting method, 15.4 trees/ha on A1 (assortment method) and 15.8 trees/ha on A2 (half-tree length method), or 10.4 trees/ha on B1 (assortment method) and 11.6 trees/ha on B2 (half-tree length method).

Within the same harvesting method, the average width of damage was 43.9% larger on the sample plot B1 (assortment method) than on A1 (assortment method) and 21.5% on B2 (half-tree length method) than A2 (half-tree length method). With the damage height, situation was similar. On sample plot B1 (assortment method) the average damage height was 50.9% larger than on sample plot A1 (assortment method) and 55.2% on B2 (half-tree length method) than A2 (half-tree length method).

When comparing damages between the assortment and the half-tree length harvesting method it was shown that damage width was 17.6% larger on A2 (half-tree length method) than on A1 (assortment method) sample plot. On sample plots B1 (assortment method) and B2 (half-tree length method) the average damage width was similar.

The average damage height was 10.5% larger on the sample plot A2 (half-tree length method) than on A1 (assortment method) and 13.4% on B2 (half-tree length method), than on B1 (assortment method).

Within the same stand conditions, the average damage surface is larger on sample plots with the half-tree length harvesting method, 50% are larger damages on the sample plot A2 than A1 and 21.7% on B2 than B1.

Difference in damage size is a consequence of longer pieces in the load in the half-tree length method, which hider manipulation of load with the skidder. Usually distance between skidding trails is 100 m. If the distance is reduces and cutters pay more attention to directed felling there are preconditions that damages in half-tree length reduce.

Comparison of system costs

In order to compare the harvesting system productivity and costs where all workers and production phases were included the simulation for 100 m^3 of produced wood was done. It was taken two different average DBH (30 and 50 cm), 250 m skidding distance and the average load volume that was obtained in experiment for given stand condition (Table 52).

Table 52: Comparison of system costs

			A1	A2	B1	B2
	Method	**Unit**	**Assortment**	**Half-tree length**	**Assortment**	**Half-tree length**
Wood characteristics	DBH	cm	30	30	50	50
	Roundwood	m^3	72.6	96.6	68.5	80
	Stacked wood	m^3	27.4	3.4	31.5	20
	Total wood	**m^3**	**100**	**100**	**100**	**100**
	Load volume	m^3	2.80	3.56	4.98	6.62
	Residue at the landing site	m^3		2		2
Chainsaw cost	Felling costs	€/m^3	4.16	2.63	2.77	1.83
	Processing at the landing site	€/m^3		0.80		0.63
	Total costs	**€**	**416**	**264.6**	**277**	**184.26**
Transport cost	Skidding costs	€/m^3	7.65	6.41	5.14	3.86
	Skidding costs (total)	€	555.39	619.21	357.23	308.8
	Carrying out with horses	€/m^3	8.44	8.44	8.44	8.44
	Carrying out with horses (total)	€	231.26	27.7	265.86	168.8
	Total costs	**€**	**786.65**	**646.91**	**623.09**	**477.6**
Total cost system costs		**€**	**1202.65**	**911.51**	**900.09**	**661.86**
Wood value		**€/m^3**	**39.42**	**37.17**	**43.20**	**47.35**
Total wood value		**€**	**3942**	**3717**	**4320**	**4735**
Total profit		**€**	**2739.35**	**2805.49**	**3419.91**	**4073.14**
Profit/m^3		**€/m^3**	**27.39**	**28.06**	**34.20**	**40.73**

Profit per m^3 of wood was higher on sample plots where the half-tree length method was performed. The difference was more emphasized on sample plots with higher DBH.

If discussing the competitiveness of fuelwood chipping at the landing site, several important facts must be taken into account.

Selling price of the fuelwood at the landing site was 30.26 €/m^3. At the moment of investigating (2013 year) the average price of wood chips was about 19 €/loose m^3. If it was established that from 1 m^3 of roundwood it was possible to get 2.7 loose m^3 of chips and that chipping cost with chipper Jenz HEM 700 was 2.62 €/m^3 of roundwood fuelwood it was obvious that from 1 m^3 of roundwood fuelwood with value of 30.26 €, 2.7 loose m^3 of chips with value of 48.68 € can be produced. The value was increased for 18.42 €. Of course this is only theoretically.

First of all it was very hard to achieve full capacity of chipper when chipping at the forest landing site; especially during chipping with large chippers. The reason was that chipper often should change the place from one to another landing site, waiting for containers, trucks, etc. This was increasing delays time and costs consequently. For calculating the utilization rate of each chipper in given conditions, long observations are necessary.

With choosing the chipper with optimal capacity, work could be more or less optimized. Level of optimization, besides chipper characteristic, depends on availability of wood amount at one place and frequency and distance of chipper moving. In this experiment the investigation was done on chippers who only were available at the labor market in the area.

The chipper must be engaged with enough number of special trucks with containers for chips transport. Transport should be done at the same time as chipping. Transport costs of chips are very uncertain and depend of many factors, like transport distance, road condition, wood chips price, etc.

Chipping and using chips is relatively new on the BIH market and this investigation only opens this problem for discussion and for further investigations.

6.2 HYPOTHESIS ANSWERS

1. It is proven that half-tree length harvesting method is more productive and cost effective than assortment harvesting method in studied conditions.

2. It is not proven that in half-tree length method is better quantitative wood biomass utilization, moreover, assortment method gave better utilization over 50 cm DBH. Qualitative biomass utilization is better in half-tree length method in compartment 65, but in compartment 98 was similar.

3. It is proven that during processing assortments at the forest road a wood residue remains in amount of 2% of total volume of processed wood which can be used for chipping.

4. Within the same stand conditions, in this study is shown that average damage surface is larger on sample plots with the half-tree length harvesting method. In order to keep damages at same level as in assortment method it can be recommended devoting more attention about felling direction and design of skidding trails.

5. In the half-tree length harvesting method there is greater possibility for rational utilization of wood residue than in the assortment method, when processing logs in assortment method residue left dispersed in the forest, in half-tree length method residue left at the forest landing site, where is more concentrate.

6. Chipping of fuelwood and wood residue at the forest landing site give added value to fuelwood and with optimal chipping and transport organization could be more profitable for forestry organizations than selling of fuelwood

6.3 SYNTHESIS AND RECOMMENDATIONS

This investigation showed, with no doubt, that there is a plenty of space for improvement of harvesting methods and forestry practice in state forests in Republic of Srpska.

Although it is well known that cutter achieve bigger productivity when is working alone, because of ergonomic reasons and rules, in local forestry such kind organization is not suitable. Typical work organization in state forest is that cutters are working in group of two. Two cutters + chainsaw, while one cutting, other assisting. In the assortment method where significantly amount of stacked wood is produced there is justification for such organization. In the half-tree length method where amount of stacked wood is fewer, assistant has no enough job and major part of time is unemployed.

Perhaps forest practitioners should consider using of complex working brigades where cutting and skidding would be done simultaneously, and cutter assistant at the same time could be choker-setter also. Another possibility is that working group consists from 3 workers + 2 chainsaws. One worker should have enough time for assisting of two cutters. Stand conditions are very important when thinking about work organization. In this study is shown that in stand with smaller DBH (30 cm) in the half-tree length method amount of stacked wood is very small, but in stand with DBH about 50 cm is still significant. All this organisational proposals should be investigated.

In Public Forest Company “Šume RS” which managed all state forests in Republic of Srpska, which is about 80% of total forest area in the entity, for skidding are used skidders of similar size and capacity (LKT 81T, mostly). These results showed that skidder works under its capacity in the assortment method. From economical point this is unacceptable. They should have skidders of various sizes and choose the optimal for stand conditions based on terrain and stand conditions. Load size should be most considered.

State-of-art intentions in using of wood as a green energy are coming with delays in Republic of Srpska, but in recent years are coming however. There are several plants for pellets and briquette production. Pellet plants export their products, in Italy and other EU countries. As a raw material they use sawmill residue mostly. As the sawmill residue has limiting potential and pellet production has intention for expansion, it will be need for other raw material sources. Some pellet plants managers are already buying the lower quality wood (fuelwood and pulpwood).

So far, fuelwood is used mostly for household heating of local people and one amount of fuelwood is exported also. Local people still use traditional furnaces where energy efficiency is very low. They can allow to have such low efficiently because fuelwood is still relatively cheaper that other energy sources.

As demand for fuelwood form side of pellet plants would arise, competitiveness between local people and pellet plants will arise also. This could influence on the price of fuelwood and local people will have to transfer toward more efficient technology of heating, like using of district heating on wood chips, small pellet furnace, etc. Wood chips which is producing now is used for industrial purpose and for heating of several municipalities which have small, experimental biomass heating systems.

Using of biomass of branches, twigs and other parts of tree which left in the forest after felling is still not practiced. There is no adequate machinery and technical solutions for that. This should be subject of further investigations also.

Forest managers must follow wood and wood energy market and adjusting harvesting technology in order to be most economical viable and to meet market needs.

Purchase and including of mobile chippers and container transportations trucks in production chain is opportunity and investigations in this area should be encouraged.

7 CONCLUSION

Many researchers showed in their studies that cutting and skidding of long wood (half-tree and tree length method) is more productive than short wood (assortment method). There are few reasons why the assortment method is still dominant in forestry of Republic of Srpska. One of the most important is that in local forestry regulations assortments are not allowed to be moved away from felling site unless they are marked (deboned).

This is a matter of regulation and could be changed. Also, stacked wood that remains in forest in the assortment method is usually carried out with horses what is problem for forest managers because there is no enough animal labor market. It becomes increasingly difficult for forest managers to find animals on the labor market, so often stacked wood remains unused in the forest. This is unacceptable from the point of tendency of increasing forest biomass utilization.

Secondary forest road network still has no satisfactory density and often is not optimally projected. This is a limiting possibility for manipulation of longer pieces of wood. Also, there is a presumption that skidding of long wood makes more damage in stand. This is partially true, but we think that that proper work with well skilled workers could keep damages under acceptable level, which is according to local regulations 3 or 5% (depending of stand type) of the number of trees in the stand.

Considering the constant need for increasing the work productivity and efficiency, it is necessary to improve whole harvesting system towards practicing the half-tree length harvesting method or even tree length method and as a result, wood skidding with as much as possible length of pieces.

The investigation of chipping of "lower value wood" in this experiment shows that there is a presumption for expanding of this method in beech forest utilization but it should be further examined, especially in terms of optimization of chipper capacity, position of landing sites, wood chips transport and harvesting timing.

8 SUMMARY

Aim of this research is to compare the productivity, costs, biomass utilization and stand damages of two methods:

1. Felling the tree, processing at the stump, and extraction the assortments to the landing site.
2. Felling the tree, partially processing at the stump and skidding to the landing site where processing is finishing and fuelwood is chipping.

First harvesting method was defined as the assortment method and second as the half-tree length method. Idea of the research was to identify advantages and disadvantages of introducing the half-tree length method in beech forest utilization.

Investigation was conducted in the northern part of the Republic of Srpska in the area of municipality Ribnik. It was taken two compartments with beech forests. When choosing compartments it was intent that stands conditions and forest infrastructure characteristics would be averages that are prevalent in beech forests in Republic of Srpska. In each compartment 2 sample plots i.e. work fields were chosen, (A1, A2, B1 and B2).

On sample plots A1 and B1 the assortment harvesting method was performed, where cutters cut trees with chainsaw and tree processing was done at the site. Working group consisted of two cutters. Technical and fuelwood roundwood assortments were made and staked wood (traditional 1m length fuelwood) was produced and piled. Fuelwood was made from thinner part of stem and branches. Assortments were skidded on the forest landing site with the skidder LKT 81T.

On the sample plots A2 and B2 the half-tree-length harvesting method was performed where cutting trees, delimbing and partially bucking were done at the site. Stem stayed whole or cut on the transport lengths to allow easier skidding. Stacked wood was made only from branches. After that, a part of the stem was skidded on the landing site where processing was finished. Stacked wood was carried out with animals.

After harvesting and skidding, damages were evidenced on all sample plots on the standing trees. Measuring was done on all damaged trees above 7 cm DBH. Total survey was done and different parameters were measured.

In the study 318 trees were felled of which 163 in the assortment method (sample plots A1 and B1) and 155 in the half-tree length method (A2 and B2). Average diameter of felled trees on sample plot A1 is 30.01 cm and varies from 9 to 54 cm, on sample plot B1 49.24 cm an varies from 23 to 78 cm. On sample plots A2 and B2 average tree diameter is 27.22 cm and 50.67 cm respectively and varies from 10 to 49 cm on A2 and 18 to 69 cm on B2.
The share of stacked wood was significantly lower at the half-tree length method than in the assortment - 1.95 % (A2 – the half tree length method) contra 15.53% (A1- the assortment method) and 8.12 % (B2- the half tree length method) contra 17.13 % (B1- the assortment method). These results were expected if considering the description of working methods. In the assortment method, stacked wood was made from branches and from thinner parts of the stem, while in the half-tree length method it was made only from branches. The decision, where on the stem, producing of roundwood stops and producing of stacked wood starts was based on the recommendations from operation plan for specific compartment.

The difference in the amount of stacked wood within the same harvesting method was higher on sample plots with smaller average tree diameter, within the same harvesting method. The reason could be that thicker trees have relatively bigger amount of branches above 7 cm diameter from which stacked wood was produced.

As a consequence of length and diameter, volume of assortments was bigger in the half-tree length method 19% (A2 contra A1) on sample plots with smaller DBH and 27% (B2 contra B1) on plots with larger DBH.

Relative structure of productive work time showed that work operations Production of fuelwood and Stacking of fuelwood consumed relatively less time in the half-tree length method than in the assortment one, 9.22% and 21.1% and in the half-tree length and 17.75% and 29.56% in the assortment method, respectively. Delimbing time takes relative larger share in the half-tree length method, 33.73% contrary to 20.86% in the assortment method. This could be explained by the fact that in upper parts of stem in the assortment method Delimbing can overlap with the Production of fuelwood and it is hard to define the border between those two operations during the time study.

The structure of allowance times was similar in both methods; coefficient of allowance times was 1.30 for the assortment and 1.31 for the half-tree length method.

Productivity was constantly increasing with increasing of DBH and it was higher in the half-tree length method than in the assortment one. Reason because half-tree length was more productive was in the fact that some working operations were avoided or minimized in half-tree length method, like production and stacking of fuelwood. Bucking was mostly transferred to the landing site where could be done in more productive way.

Total number of studied skidding cycles was 113. From total number, 68 cycles were the assortment method, 34 cycles on the sample plot A1 and 34 on the sample plot B1. On the plots where the half-tree length harvesting method was performed, A2 and B2, 45 cycles were studied, 22 on A2 and 23 on B2 sample plot.

Number of pieces in load was similar in both methods, 9.94 (A1) and 9.00 (B1) in the assortment method and 11.09 (A2) and 9.57 (B2) in the half-tree length method. The possible conclusion would be that number of pieces was rather a result of skidder hooking capacity, than the volume or length of pieces. So, the skidder always worked below its optimum capacity. The average piece volume was notably bigger at the half-tree length method, 0.28 m^3 (A1) contrary to 0.33 m^3 (A2) and 0.57 m^3 (B1) contrary to 0.75 m^3 (B2). The difference was more noticeable on sample plots with bigger average piece. As a consequence of the previous, the average load volume in the assortment method was 2.80 m^3 (A1) and 4.98 m^3 (B1), and 3.56 m^3 (A2) and 6.62 m^3 (B2) in the half-tree length method. The average load was 22% and 25% bigger at the half tree length method under the same conditions.

The average length of pieces in the assortment method was 5.38 m (A1) and 5.30 m (B1), and 8.97 m (A2) and 9.19 m (B2) in the half-tree length method. The average length of pieces was 40% and 42% larger in the half-tree length method.

Costs were lower in the half-tree length method when all other conditions were identical. The difference in cost was higher when average piece volume was higher.

Processing at the landing site was investigated in the half-tree length harvesting method. After preliminary time study, it was decided not to go into detail of time study because the work was very inconsistent with frequently interruptions and especially because, in productive work, it was very hard to distinguish precise border between work operations. Cleaning, bucking, removing of knots and other operations constantly overlapped and joined into work on the landing.

The result showed that the share of delays when working on landing site was 59% and productive time 41%. The explanation for relative dominant share of delays was the fact that workers who performed processing also were interrupted by trucks which were constantly arriving for shipping. Residue which occurred at the landing site after processing was chipped together with the fuelwood. The amount of residue was not significant, 2 m^3 on 100 m^3 of roundwood. Those were parts of wood which remained after bucking of assortments according to dimensions prescribed by JUS, removed knots and similar.

Chipping was done at the landing site. Subject of chipping was fuelwood and residue which left after processing. Chipping was done with the mobile wood chippers JENZ HEM 700 and Pezzolato PTH 1300/1500. Both chippers were fed with the crane Palfinger Epsilon 120 Z plus mounted on the truck Mercedes Benz Actros 2654. Conversion coefficient from solid wood volume into loose chips volume was calculated and it was 2.7. When chipping of stacked fuelwood was measured productivity was 29.5% lower. The reason was the fact that crane could not achieve full efficiency when manipulating with the stacked wood, especially when stacked wood was not piled. This was highly dependable of the operator skills. Both investigated chippers achieved less productivity than predicted by manufacturer. The main reason was the fact that at the landing site manipulating with the chippers crane and feeding did not go smoothly because of limited space. Cost calculation of chippers showed that bigger chippers had lower unit costs, but because of inability to achieve full capacity at forest landing site and because of their dimensions which hinder the manipulation, it can be recommended using of chippers of smaller capacity like Jenz HEM 561 DQ or even smaller.

Quantitative utilization was compared on the basis of total wood obtained from trees in each harvesting method and it is showed that up to 50 cm DBH quantitatively utilization was similar and above 50 cm difference occurs in favor of the assortment method. Main reason for that was that trees above 50 cm DBH had a large amount of branches which were not in the whole cut in the stacked wood. While performing the half-tree length method, there was intent that the amount of produced stacked wood would be as less as possible.

Relation between estimated wood biomass utilization and obtained after harvesting showed that by the approximately 50 cm DBH utilization of wood in both harvesting methods was equal to estimation for gross wood. After 50 cm there was a difference in favor of both harvesting methods related to gross wood estimation. These results showed that assortment tables which were in use for beech did not give precise estimations or that forest managers did not follow exact procedure for prediction. In both cases this was not acceptable in terms of planning of business efficiency of forest companies.

Quality classes were compared by diameter classes which were used in local forestry organizations. Comparison of the assortment structure was done between harvesting methods in the same compartment and in the whole. In both harvesting methods applied share of sawlogs was larger than predicted, and the share of fuelwood was fewer.

The half-tree length harvesting method gave better structure in L, I and II class than the assortment method, except F logs where better results were obtained in the assortment method.

Comparing of summary, the assortment structure obtained on the all sample plots in both harvesting methods applied with the predicted structure, speaking in general, obtained share of higher value logs was higher than predicted and the share of fuelwood was less. Looking at the relation between harvesting methods showed that the half-tree length method gave "better" assortment structure in high value logs, except F logs.

When comparing damages between the assortment and the half-tree length harvesting method it was shown that damage width was 17.6% larger on A2 (half-tree length method) than on A1 (assortment method) sample plot. On sample plots B1 (assortment method) and B2 (half-tree length method) the average damage width was similar.

The average damage height was 10.5% larger on the sample plot A2 (half-tree length method) than on A1 (assortment method) and 13.4% on B2 (half-tree length method), than on B1 (assortment method).

Within the same stand conditions, the average damage surface was larger on sample plots with the half-tree length harvesting method, 50% were larger damages on the sample plot A2 than A1 and 21.7 % on B2 than B1.

Comparing of system costs it was shown that profit per m^3 of wood was higher on sample plots where the half-tree length method was performed. The difference is more emphasized on sample plots with higher DBH.

Selling price of the fuelwood at the landing site was 30.26 €/m^3. At the moment of investigating the average price of wood chips was about 19 €/loose m^3. It was determined that from 1m^3 of roundwood it is possible to get 2.7 loose m^3 of chips and that chipping cost with chipper Jenz HEM 700 was 2.62 €/m^3 of roundwood fuelwood. From 1 m^3 of roundwood fuelwood with value of 30.26 €, 2.7 loose m^3 of chips with value of 48.68 € can be produced. The value was increased for 18.42 €.

It was very hard to achieve full capacity of chipper when chipping at the forest landing site; especially when chipping with large chippers. The reason was that chipper often should change the place from one to another landing site, waiting for containers, trucks and other. This increased allowance time (delays) and costs consequently. For calculating the utilization rate of each chipper in given conditions, long observations are necessary.

With choosing the chipper with optimal capacity, work could be more or less optimized. In this experiment the investigation was done about chippers who only were available at the labor market in the area.

The chipper must be engaged with enough number of special trucks with containers for chip transport. Transport should be done at the same time as chipping. Transport costs of chips are very uncertain and depend of many factors.

Chipping and using chips is relatively new on the BIH market and this investigation only opens this problem for discussion and for further investigations.

The investigation of chipping of “lower value wood” in this experiment showed that there is a presumption for expanding of this method in beech forest utilization but it should be further examined, especially in terms of optimization of chipper capacity, position of landing sites, chip transport and harvesting time.

9 POVZETEK

Cilj disertacije je bil primerjava učinkov in stroškov dveh metod:

1. Sečnja in izdelava sortimentov pri panju in spravilo do skladišča.
2. Podiranje dreves in delna izdelava sortimentov ter spravilo do skladišča, kjer se izdelava sortimentov dokonča.

Prva možnost je klasična sortimentna metoda (kratek les), druga pa metoda kombiniranih sortimentov oz. pogojno poldebelna metoda (dolg les) kot modifikacija debelne metode.

Raziskava je potekala v severnem delu Republike Srbske na območju občine Ribnik. Objekta raziskave sta bila dva oddelka bukovih gozdov. Pri izbiri oddelkov smo želeli, da bi bile sestojne razmere in gozdna infrastruktura v povprečju razmer v bukovih sestojih Republike Srbske. V vsakem oddelku sta bili izbrani po dve poskusni ploskvi (A1, A2, B1 in B2).

Na poskusnih ploskvah A1 in B1 smo izvajali sortimentno metodo, kjer so sekači z motorno žago in ročnim orodjem izdelali sortimente pri panju. Delovna skupina je imela dva sekača. Izdelali so okrogli tehnični les in izdelali ter zložili prostorninski les (drva dolžine 1 m). Drva so izdelovali iz tanjšega lesa debla in vej. Sortimente so spravljali do ceste (skladišča) z zgibnikom LKT 81T.

Na poskusnih ploskvah A2 in B2 so uporabili poldebelno (novo) metodo, kjer so sekači po podiranju in kleščenju drevesa izvedli delno krojenje. Pri tem je deblo ostalo celo oz. je bilo prežagano na transportne dolžine zaradi lažjega spravila. Prostorninski les so izdelali samo iz vej. Deli debla so bili spravljeni do skladišča, kjer je bilo krojenje in prežagovanje dokončano. Prostorninski les je bil spravljen s konjiskim spravilom.

Po končanem spravilu smo na vseh ploskvah izmerili poškodbe na stoječem drevju. Upoštevali smo vse drevje prsnega premera nad 7 cm. Izvedli smo popolno premerbo in ugotavljali več znakov.

V raziskavi smo skupaj podrli 318 dreves, od tega je bilo 163 izdelanih s sortimentno metodo (ploskvi A1 in B1) in 155 s poldebelno metodo (A2 in B2). Povprečni prsni premer dreves na ploskvi A1 je bil 30,01 cm (med 9 in 54 cm), na ploskvi B1 pa 49,24 cm (med 23 in 78 cm). Na ploskvah A2 in B2 sta bila povprečna prsna premera drevja 27,22 cm (med 10 in 49 cm) in 50,67 cm (med 18 in 69 cm).

Delež prostorninskega lesa je bil pri poldebelni metodi značilno manjši kot pri sortimentni metodi: 1,95% (A2 – poldebelna metoda) in 15,53% (A1 – sortimentna metoda) ter 8,12% (B2 – poldebelna metoda) in 17,13% (B1 – sortimentna metoda). Ti rezultati so bili glede na opis metod pričakovani. Pri sortimentni metodi so izdelovali prostorninski les iz vej in tanjših delov debla, medtem ko so za prostorninski les pri poldebelni metodi uporabili samo veje. Odločitev, pri katerem najmanjšem premeru se prične in konča izdelava prostorninskega lesa je bila zapisana v priporočilih iz sečno-spravilnega načrta za posamezen oddelek.

Razlika v deležih prostorninskega lesa pri isti metodi je bila večja, kjer so imele poskusne ploskve manjši povprečni prsni premer. Razlog je lahko v tem, da so imela debelejša drevesa več vej nad 7 cm premera, iz katerih so izdelovali prostorninski les.

Zaradi različnih dolžin in premera sortimentov, je bila prostornina sortimentov večja pri poldebelni metodi in sicer na ploskvah z manjšim prsnim premerom 19% (A2 : A1) in 27% (B2 : B1) na ploskvah z večjim prsnim premerom.

Relativna struktura produktivnega časa je pokazala, da so postopki "Izdelava prostorninskega lesa" in "Zlaganje prostorninskega lesa" trajali manj časa pri poldebelni metodi kot pri sortimentni metodi. Na ploskvah poldebelne metode sta bila deleža 9,22% in 21,1%, pri sortimentni metodi pa 17,75% in 29,56%. Čas kleščenja je trajal dlje pri poldebelni metodi (33,73%) kot pri sortimentni metodi (20,86%). To lahko razložimo s tem, da se postopka kleščenja in izdelave prostorninskega lesa delno prekrivata. Mejo med postopkoma je pri časovnih študijah težko opredeliti.

Struktura zastojev je bila podobna pri obeh metodah. Koeficienta dodatnega časa sta bila 1,30 pri sortimentni in 1,31 pri debelni metodi.

Produktivnost dela je naraščala z večanjem prsnega premera in je bila večja pri poldebelni metodi. Razlog za to, da je bila produktivnost večja pri poldebelni metodi, je v tem, da so bili nekateri postopki izpuščeni ali zmanjšani (npr. izdelava in zlaganje prostorninskega lesa). Del krojenja in prežagovanja je bil prav tako prenesen na skladišče, kjer je bil lahko izpeljan bolj učinkovito.

Skupaj smo posneli 113 ciklusov spravila s traktorjem. Od vseh posnetih ciklusov, je bilo 68 pri sortimentni metodi (34 ciklusov na ploskvi A1 in 34 na B1). Pri poldebelni metodi smo izmerili 55 ciklusov (22 ciklusov na ploskvi A2 in 23 na B2).

Povprečno število kosov v bremenu je bilo podobno pri obeh metodah. Pri sortimentni metodi smo imeli število kosov v bremenu po ploskvah 9,94 (A1) in 9,00 (B1), pri poldebelni metodi pa 11,09 (A2) in 9,57 (B2). Možna razlaga je, da je povprečno število kosov bolj odvisno od sposobnosti privezovanja pri traktorju, kot od velikosti in dolžine kosa. Tako sklepamo, da je zgibnik vedno delal pod svojo optimalno kapaciteto velikosti bremena. Povprečen kos v bremenu je bil znatno večji pri poldebelni metodi: 0,28 m^3 (A1) in 0,33 m^3 (A2) oz. 0,57 m^3 (B1) in 0,75 m^3 (B2). Razlika je bila opazno večja na ploskvah z večjim povprečnim kosom. Posledično je bilo povprečno breme pri sortimentni metodi 2,80 m^3 (A1) in 4,98 m^3 (B1) oz. pri poldebelni metodi 3,56 m^3 (A2) in 6,62 m^3 (B2). Pri enakih pogojih je bilo povprečno breme pri poldebelni metodi večje za 22 % oz. 25 % od bremen pri sortimentni metodi.

Povprečna dolžina kosov pri sortimentni metodi je bilo 5,38 m (A1) in 5,30 m (B1) oz. pri poldebelni metodi 8,97 m (A2) in 9,19 m (B2). Povprečna dolžina kosov je bila pri poldebelni metodi za 40% oz. 42% večja.

Stroški so bili pri poldebelni metodi za 17 % in 40 % nižji pri enakih pogojih. Razlika v stroških je bila višja pri večjem povprečnem kosu v bremenu.

Izdelavo sortimentov na mestu iztovarjanja smo proučili pri poldebelni metodi spravila. Po predhodni časovni študiji smo sklenili, da ne bomo šli v podrobnosti študija časa, ker je bilo delo zelo nekonsistentno s pogostimi prekinitvami. Pomemben razlog je bil tudi, ker je bilo v produktivnem delu zelo težko razlikovati natančne meje med posameznimi postopki. Kleščenje, krojenje in prežagovanje, odžagovanje grč in drugi postopki so se prekrivali, zato smo jih združili v "Delo na skladišču".

Rezultat je pokazal, da je bil delež zastojev pri delu na skladišču 59 % in 41 % produktivnega časa. Razlaga za relativno prevladujoč delež zastojev je dejstvo, da so delavci, ki so izvajali obdelavo tudi prekinjali prihodi in nakladanje kamionov. Ostanek lesa, ki je ostal na mestu nakladanja po izdelavi okroglih sortimentov, je bil sesekan skupaj z lesom za kurjavo. Količina ostanka ni bila velika, okoli 2 m^3 na 100 m^3 okroglega lesa. To so bili deli lesa, ki so ostali po krojenju po JUS standardu, odžagane grče in druge napake.

Izdelava sekancev je potekala na gozdnem skladišču, na kraju raztovarjanja. Sesekana je bila lesna surovina za energetsko rabo in lesni ostanki, ki so ostali v gozdu ob kamionski cesti po končanem krojenju. Sekalnika sta bila mobilna sekalnika JENZ HEM 700 in Pezzolato PTH 1300/1500. Oba sekalnika je nakladal s surovino Palfinger Epsilon 120 Z Plus na kamionu

Mercedes Benz Actros 2654. Izračunali smo razmerje med okroglim lesom in in nasutimi sekanci in povprečje je bilo 2,7 nm^3/m^3. Pri sekanju prostorninskega lesa je bila produktivnost za 29,5 % nižja. Razlog je bil v težavnejšem delu dvigala, ki je težje podajal les sekalniku, še posebej, če prostorninski les ni bil primerno zložen. Učinkovitost podajanja lesa je bila odvisna od spretnosti nakladalca. Oba sekalnika sta imela manjši učinek od predvidevanj proizvajalcev. Med glavnimi razlogi je bilo pomanjkanje prostora na skladišču. Kalkulacija stroškov sekalnikov je pokazala na manjše stroške po enoti pri večjih sekalnikih. Zaradi nezmožnosti doseganja polnih učinkov, ki je določena z omejitvami uporabe zaradi prostora na skladišču in s tem povezane manipulacije, lLahko priporočamo uporabo manjših sekalnikov, kot je JENZ HEM 561 DQ in manjših.

Na osnovi vrste vsega posekanega lesa smo opravili kvantitativno primerjavo med obema metodama. Pokazalo se je, da je bil količinski izkoristek podoben do okoli 50 cm prsnega premera, nad tem premerom, pa gre razlika v prid sortimentni metodi. Razlog vidimo v tem, da imajo drevesa nad 50 cm prsnega premera velik del vej, ki pa niso bile v celoti izkoriščene kot prostorninski les. Pri poldebelni metodi je bila težnja, da se pri panju izdela (določi) čimmanj prostorninskega lesa.

Razmerje med ocenjeno možno lesno biomaso in lesno biomaso po spravilu pokaže, da do 50 cm prsnega premera ni bilo razlik med metodama glede na ocenjeno bruto količino lesa. Po prsnem premeru 50 cm je bila razlika glede na ocenjeno bruto količino lesa v prid obeh spravilnih metod. Ti rezultati kažejo, da obstoječe (sortimentne) tablice za bukev ne dajejo dovoj zanesljivih podatkov ali pa gozdarji niso opravili ocene po pravilih. V obeh primerih to ni sprejemljivo v smislu načrtovanja poslovne uspešnosti gozdarskih družb.

Kakovostne razrede smo primerjali po debelinskih razredih, ki jih uporabljajo krajevne gozdarske organizacije. Primerjavo strukture sortimentov smo naredili med metodama znotraj istega oddelka (A1 in A2 ter B1 in B2) in skupno (A : B). Pri obeh metodah je bil delež žagarske hlodovine višji kot od napovedanega, delež prostorninskega lesa pa manjši.

Poldebelna metoda je dala boljšo strukturo v L, I in II razredih kot sortimentna metoda z izjemo F hlodov, ki jih je bilo več pri sortimentni metodi. V povprečju je bila sortimentna struktura na vseh poskusnih ploskvah boljša in z višjim deležem boljše hlodovine ter manj prostorninskega lesa, kot je bilo napovedano. Poldebelna metoda je dala boljšo strukturo sortimentov kot sortimentna metoda z izjemo F hlodovine.

Primerjava poškodb stoječega drevja med metodama je pokazala, da je bila širina poškodb na ploskvi A2 (poldebelna metoda) za 17,6% večja kot na ploskvi A1 (sortimentna metoda). Na ploskvi B1 (sortimentna metoda) in B2 (poldebelna metoda) je bila širina poškodb podobna. Višina poškodb je bila za 10,5% večja na ploskvi A2 (poldebelna metoda) kot na A1 (sortimentna metoda) in za 13,4% večja na B2 (poldebelna metoda) kot na B1 (sortimentna metoda).

Pri enakih sestojnih razmerah je bila povprečna poškodovana površina večja na ploskvah s poldebelno metodo: ugotovili smo 50% večje poškodbe na A2 kot na A1 in 21,7% večje poškodbe na B2 kot na B1.

Primerjava stroškov sistema je pokazala, da je bil dobiček na m^3 večji na ploskvah s poldebelno metodo. Večja razlika je bila na ploskvah z večjim povprečnim prsnim premerom.

Prodajna cena prostorninskega lesa na skladišču je bila 30,26 €/m^3. V času raziskave je bila povprečna cena lesnih sekancev 19,00 €/nm^3. Ugotovili smo, da iz 1 m^3 okroglega lesa dobimo 2,70 m^3 nasutih sekancev in da so bili stroški sekanja z Jenz HEM 700 2,62 €/m^3 okroglega lesa namenjenega za energetske namene. Iz 1 m^3 okroglega lesa za ogrevanje z vrednostjo 30,26 €, lahko izdelamo 2,70 nm^3 sekancev z vrednostjo 48,68 €. Vrednost pri tem naraste za 18,42 €.

Zelo težko je bilo doseči polno zmogljivost sekalnika pri sekanju na gozdnem skladišču, posebej pri sekanju z velikimi sekalniki. Razlog je bil v pogostem premeščanju sekalnika med skladišči, čakanje na zabojnike, kamione in podobno. To je povečalo neproduktivni čas (zastoje) in posledično stroške. Za izračun stopnje izkoriščenosti vsakega sekalnika v določenih pogojih, bi potrebovali dolgotrajnejša opazovanja.

Z izbiro sekalnika z optimalno kapaciteto, bi delovni proces lahko bolj ali manj optimirali. V tej raziskavi smo sekanje opravili s sekalniki, ki so bili na voljo na trgu dela v okolišu.

Sekalnik mora imeti dovolj posebnih kamionov z zabojniki za transport sekancev. Transport mora potekati hkrati z izdelavo sekancev. Transport sekancev je tvegan in je odvisen od številnih dejavnikov.

Izdelava sekancev in njihova uporaba je razmeroma nova na trgu B&H, zato je ta raziskava le opozorila na ta problem za razpravo in nadaljnje raziskave.

Raziskava izdelave gozdnih lesnih sekancev iz "manjvrednega lesa" je pokazala na možnost uporabe te metode v bukovih gozdovih, vendar mora biti njena uporaba še naprej raziskovana. To še posebej velja za optimizacijo sekalnikove kapacitete, določanje položaja skladišč, transport sekancev in izdelavne čase sečnje in spravila.

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