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ANALYSIS OF VOLUME DIFFERENCES IN MEASURING TIMBER IN FORESTRY AND WOOD INDUSTRY

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Abstract: *The process of production and realization of timber can be divided into three stages: planning the structure and volume of timber for felling, harvesting and realization (sale) of timber. In all these stages, the volume of timber is determined. Data on the volume of timber give basic information for planning and control of production, purchase and sale and groundwork for remuneration, invoicing supplies, accounting and inventories, financing supplies and determining the productivity of stands. The use of computer technology was associated with automation in timber measurement. At present, however, there is no operative comprehensive norm in the Czech Republic adapting calibration and setting automatic measuring systems. It can be one of causes of volume differences in timber measurement. The paper describes methods used for the determination of timber volume in particular stages, compares volumes determined in concrete "planning – production – realization" chain and analyses volume differences and causes of their origin. In conclusion, financial impacts are specified of volume differences on subjects involved.*

1. Introduction

Wood production remains an important function of forest management even at present when stress is laid on other functions of the forest. It is also the case of the Czech Republic (CR) where the annual cut amounts to about 14 – 15 million m^3 in recent years. Harvesting the coniferous timber reaches almost 90% and namely Norway spruce 75%. According to data from 2000, the yield of round timber assortments in conifers amounts to 51%, other 37% are created by pulpwood and remaining 12% are other industrial wood and fuel-wood (Neruda, Simanov, 2006).

Sales for realized wood are a decisive factor and many times the only source of means of a forest owner serving to fund all costs for logging and hauling operations, reforestation, tending and protection of forest stands as well as for keeping and developing non-wood- producing functions of the forest. Under conditions of the CR, sales for realized wood amount to about 85% of all revenues in forestry (Simanov, 2004). The amount of sales for wood is affected by two factors, the first being the price of wood according to its quality. For the present, we will suppose that the price of wood is the resultant of supply and demand on the market. The second factor is the amount of wood; the problem of its determination is, however, far more complicated.

The paper presented deals with the topical problem of determining the amount of wood with respect to present trends in the field of timber measurement, viz. using electronically measured data. Findings obtained are applied on a selected demonstration area and volume and financial differences originating in the "planning - production - sale" chain are calculated.

2. Analysis of present conditions

The process of timber production can be divided into three subsequent operations, namely planning, production and realization (sales) of wood. In all three operations, various methods are used to determine the amount of wood. Data on the amount of wood serve to determine the productivity of stands, supposed yield of assortments, as a basis for the control of production, purchase and sale, a basis for remuneration, invoicing the timber supplies, accounting, inventories etc. It is evident that in all operations, we try to express the amount of wood as accurate as possible in order to eliminate differences between the amounts of wood determined in particular stages of the chain.

To determine the amount of wood it is possible to use various methods. Therefore, in accordance with standards used in EU, "Recommended rules to measure and classify wood in the CR" originated in 2002. These rules describe allowed methods of wood measurement and volume calculation. Unfortunately, even no other rules used in the CR at present, do not include minimum requirements for technical parameters of electronic measuring systems, the method of processing the data obtained in this way or accurate specification and the required accuracy of the system calibration. Probably thanks to this fact, different values are determined among suppliers and consumers, which results in doubts about the accuracy of measurements. The aim of the paper is to quantify volume differences originating between the amounts of wood measured by a supplier and customer and to express the financial value of these differences, to propose a possible check method and to determine potential causes of volume differences.

An important and at present often neglected stage is planning, determining the volume of assortments before the actual logging. Therefore, the paper also deals with possibilities of assortment methods known at present. Thus, the chain of "planning – production – realization" is created where it is possible to monitor the amount of wood.

3. Material and methods

The main commercial species in the Czech Republic is Norway spruce (*Picea abies (L.)* Karst.) and thus, the study of changes in the volume of wood in the chain mentioned above was carried out in spruce stands. Two mature stands dominated by spruce were selected for the study. These stands are in the ownership of state forests and occur in the region of central Moravia at an altitude of 400 m. The stands were clear felled.

Table 1: Selected mensurational characteristics of the stands

	Age	Proportion of spruce (%)	Stocking	Area of felling (ha)	Number of stems for felling	Skidding distance (m)	Slope (%)
Stand No. 1	128	83	9	1	442	350	14
Stand No. 2	111	70	10	0,67	158	100	5

The measurement of standing volume and assortment structure were carried out in February, logging was realized at the turn of February and March and the last assortment was transported from the roadside landing to a customer in mid-April.

Table 2: Specification of produced and planned assortments

Quality class	Diameter (cm)			Length (m)	Allowance (m)	Customer
	Top end	Mid	Butt end			
II.	30+			4	0.1	Less & Trade s.r.o., Bohdanec
III. A,B,C	12+	-29		3	0.06	Mayr Melnhof holz s.r.o., Paskov
III. A,B,C	29+	-39		5	0.1	Mayr Melnhof holz s.r.o., Paskov
III. A,B,C		39+	-56	4	0.08	Pila Alba s.r.o., Hostejn
III. D	16+		-56	4	0.08	Pila Alba s.r.o., Hostejn
V. Pulpwood			-50	2	0	Biocel a.s., Paskov
V. Pulpwood			50+	2	0	Biocel a.s., Paskov

Note: Quality class II – special logs for sawn timber and other processing, logs for the production of rotary-cut veneer; Quality class III - logs for sawn timber; Quality class V – wood for the production of pulp, wood-based panels, pulpwood

3.1 Planning stages

The stage includes determination of the supposed volume of a stand intended for felling, selection of the most suitable structure of produced assortments and division of the whole volume to intended assortments of timber. To determine the volume and subsequent assortment structure, it is possible to use a number of various methods. At present, determination of the assortment structure of wood to be cut is on a very low level in the CR. It starts mainly from rough ocular estimations and local usage and experience. Of course, it often results in quite incorrect (wrong) results of the assortment structure determination. The need to know as accurate as possible the amount of particular assortments before the actual felling increases with the increasing proportion of production of commercial assortments already at stump. This fact together with the development of computer technology/techniques resulted in the creation of various software applications carrying out the virtual simulation of sorting and being able to calculate very accurately the supposed volume of assortments defined by a user.

To determine the volume of particular assortments in a stand a software application TreeProfit version 1.03B was used for needs of this study. This application makes possible, on the basis of measured data on particular trees in the stand and assigning the defined model of the stem form according to an entered assortment matrix, to carry out the virtual sorting of particular trees in a stand just into commercial assortments. The actual measurement consisted of two parts. In the first part, the stand was completely enumerated using a 2-cm interval and defects affecting the assortment structure, particularly rot, dead standing trees, crooked stems etc. were registered. In the second part, sample trees were selected according to a statistic scheme. Using a Field-Map apparatus (enabling to measure the stem diameter at various height) the sample trees stem profiles were measured for the construction of the stem form model, crown height and the diameter of knots serving also for the construction of models. On the basis of measured sample trees a model of the stem form was constructed, which could be expressed by the equation of typical morphological curves (Tauber, 2006):

$$\Phi(D_{1,3};x) = B_0 + B_1 \cdot x + B_2 \cdot x^2 + B_3 \cdot x^3 + B_4 \cdot x^4 + B_n \cdot x^n + \\ + D_{1,3} \cdot (C_0 + C_1 \cdot x + C_2 \cdot x^2 + C_3 \cdot x^3 + C_4 \cdot x^4 + C_n \cdot x^n) \quad (1)$$

where Φ is symbol of mathematical function, $D_{1,3}$ breast high diameter, *B, C* – coefficients, *n* is polynomial degree.

Table 3:Coefficients of the equation of a morphological curve for monitored stands

Stand No. 1 - polynomial degree 30			
B0	3.352964	C0	-0.04425
B1	-44.2689	C1	3.406932
B2	192.123	C2	-8.03321
B3	-311.072	C3	11.03002
B4	164.1327	C4	-5.6475
B5	2.440248	C5	0.524071

Stand No. 2 - polynomial degree 5			
B0	0.66099	C0	0.018748
B1	53.84218	C1	3.143636
B2	-183.72	C2	-13.6671
B3	299.0415	C3	32.73529
B4	-277.803	C4	-33.9666
B5	110.3626	C5	12.76378

Entering the callipering manual and assigning the stem form model and the model of defects the stand assortment structure is carried out according to a sorting rule (in this case the same as in a harvester). A basic method of the analysis of the stand assortment yield is to compare sorting rules with dimensional and quality properties of a stem. To calculate the volume of particular assortments it is possible to use several possibilities in the TreeProfit application. Tabular and graphic summaries of the assortment structure for particular trees and aggregate data on the volume of commercial assortments are the output from the software application.

Table 4: An example of the assortment structure output of a particular tree in the TreeProfit application

Tree No.	**Assortment**	**Butt end [cm]**	**Mid [cm]**	**Top end [cm]**	**Length [m]**	**Volume [m3]**	**Allowance [m]**	**Volume [m^3]**	**Price [Euro]**
1	III. A,B,C – 5 m	48.11	33.03	31.56	5	0.4864	0.1		
1	III. A,B,C –3 m	31.56	31.16	30.66	3	0.2286	0.06		
1	III. A,B,C –3 m	30.63	29.97	29.18	3	0.2114	0.06		
1	III. A,B,C –3 m	29.14	28.22	27.17	3	0.1874	0.06		
1	III. A,B,C –3 m	27.13	25.97	24.69	3	0.1588	0.06		
1	III.D – 4 m	24.69	22.81	20.69	4	0.1633	0.08		
1	Pulpwood up to 50 cm	20.69	19.53	18.29	2	0.0599	0		
1	Pulpwood up to 50 cm	18.29	16.97	15.55	2	0.0452	0		
1	Pulpwood up to 50 cm	15.55	14.04	12.41	2	0.031	0		
1	Pulpwood up to 50 cm	12.41	10.65	8.77	2	0.0179	0	**1.59**	**62,20**

Table 5: Results of sorting for both monitored stands

Assortment	m^3 u.b.	Yield [%]
II. – 4 m	27.9	4
III. A,B,C - 4 m	29.93	5
III. A,B,C - 5 m	136.7	21
III. A,B,C - 3 m	301.1	46
III. D – 4 m	63.09	10
V. - Pulpwood	88.22	14
Total	646.95	100

3.2 Production stages

All harvested wood is measured either manually or by the electronic measuring systems of harvesters for needs of primary forest management records. With an increase of harvester cuts in the CR to present circa 20% (Kolektiv, 2006) and providing the future increase of wood processed in this way up to 50% the traditional measurement by a tape and a calliper is replaced by the electronic measurement of log dimensions by a harvester and subsequent volume calculation. Prints of the harvester production configuration can be accepted as sources for the determination of the amount of harvested wood. In the CR, it is a problem sometimes although the majority of suppliers of harvester measuring systems give accuracy to 1 cm (length measurement) and the accuracy of diameter measurement to the order of mm. In addition to the measurement of dimensions and determination of the volume of particular logs a method of determining the volume by the spatial measurement of stacked felled wood is also used in the CR.

A harvester Timberjack 1270D, which was equipped with a harvester head TJ 758 HD and the Timbermatic TM 300 measuring and control system felled the monitored stands. The system controls simultaneously and continuously the length and diameter of stems during their feeding through the harvester head. The measurement of length is carried out by means of an impulse device, which is attached to a separate measuring wheel on the harvester head. The stem diameter is measured by means of sensors (potentiometers) placed in arms of delimbing knives in the harvester head. The stem diameter is mostly measured by 1cm length and evaluated by 10-cm sections as the result of 11 measurements at every m of the stem length. The position of delimbing knives enables nearly a cross measurement and thus, each of the measurements is calculated as a mean of two measurements. For the accurate measurement of lengths and diameters the system calibration has to be carried out correctly. The calibration consists of the comparison of values measured by a harvester with values obtained by the manual measurement of the same wood. Checking the calibration accuracy should be regularly tested, which was also carried out in the studied stands. Because the knowledge of the stem diameter u.b. is necessary for the stem volume calculation the Timbermatic 300 program includes a model with stored parameters and algorithms of the bark deduction

Table 6:The proportion of assortments after the realized logging according to the production configuration of the harvester

Assortment	Number	m^3 u.b.	Yield (%)
II. – 4 m	69	32.71	5
III. A,B,C – 4 m	54	27.93	4
III. A,B,C – 5 m	288	123.17	19
III. A,B,C – 3 m	2 724	307.55	47
III. D – 4 m	301	66.71	10
V. - Pulpwood	1 669	94.25	14
Waste		5.81	1
Total	**5 105**	**658.13**	**100**

The log volume is calculated according to the following formula:

$$V_{b.k.} = \frac{\pi}{4} \cdot d_{b.k.}^2 \cdot l \cdot 10^{-4} \quad (2)$$

where $d_{b.k.}$ is a mid-diameter u.b. in cm, l is a nominal length in m. For the calculation of volume in monitored stands two methods of calculation were used, viz. one for logs where values of a mid-diameter and a nominal length (without allowance) were introduced into the formula and the second one for pulpwood when values of mid-diameter and actual length were introduced into the formula. Following data given in Tab. 7 are the sum of volumes of produced assortments given in a production configuration of the harvester for both stands.

Table 7: The proportion of assortments in the stage of realization including the average realization and the type of reception

Assortment	Number	m^3 u.b.	Yield (%)	€/m^3	Reception
II. – 4 m	111	55.46	9	87	Manual measurement
III. A,B,C - 4 m	31	15.16	2	62	Manual measurement
III. A,B,C - 5 m	289	119.22	18	67	Electronic
III. A,B,C - 3 m	2 726	296.36	45	62	Electronic
III. D – 4 m	280	54.18	8	37	Manual measurement
V. - Pulpwood		114.79	18	25	“atro” weight
Total	3 437	655.17	100		

3.3 Stages of realization

Under the term realization we mean reception of wood for the purpose of its sale, ie determining the amount and quality of wood at a customer. Present trends of using computer technology were also transferred to the field of timber reception. It refers particularly to the electronic reception of wood, which consists in the measurement of dimensions of particular logs of delivered wood by an optoelectronic measuring device. In the CR, both 2D and 3D systems are used for this purpose. According to data from 2006, in 43% log volume electronic reception was carried out mostly in large-scale processors in the CR. In smaller plants, however, the reception of logs by manual measurement always prevails. The reception of pulpwood in the CR is carried out both by “lutro /air-dried weight/ reception” and “atro /oven-dry weight/ reception”.

For the purpose of monitoring the amounts of wood in the chain, volumes of particular assortments were adopted for the study from records on the wood reception or from confirmed delivery notes. In case of the monitored flow of wood, part of roundwood assortments (III. A,B,C – length 3 and 5 m) was received at a customer who used the 3D electronic reception. Reception by the electronic measurement of wood consists in the measurement of dimensions of particular logs by the optoelectronic measuring device and subsequent calculation of the log volume. The measurement of log diameters is carried out through a scanning device placed on the measuring frame. The log conveyer, which goes through the measuring frame, is interrupted in the place of measurement. From several light sources, directional rays of infrared light are emitted falling the opposite photocells. The number of shaded photocells gives the stem diameter in the certain place of measurement. In the 3D electronic reception it refers in principal to scanning the circumferential curve of the stem cross section, which enables to set at each other two perpendicular measurements in such a way the resultant arithmetic mean from these measurements to be minimal.

In the electronic reception of logs, the length of measured roundwood is scanned as the track of a conveyer. During the track, the photocells are shaded. The conveyer path is determined by an impulse device placed at the shaft of the conveyer driving wheel. The log length measurement is usually accurate to 1 cm; as for diameter measurement it is accurate to mm. Also in these systems, calibration of measuring instruments is necessary for their correct operation. The log volume is calculated according to formula 2.

The remaining part of roundwood assortments (II., III.A,B,C and III.D 4 m long) was received at smaller processors, who use a method of the manual measurement of dimensions by a calliper and a tape with a subsequent scaling according to volume tables. In the course of production, particular 4-m assortments were differentiated by a colour in such a way the forwarder operator could easily sort the assortments on the landing. However, in spite of the careful sorting, assortments of the quality II., III. A,B,C and III.D were mutually re-sorted by reason of the higher price per m^3 and due to the decrease of requirements for quality on the part of a customer requiring class II.

All pulpwood produced was received at a plant, which uses “atro” weight (oven-dry weight) reception. The reception is based on the principle of determining the wood supply weight and conversion from the actual weight to absolute dry matter (DM). The weight is determined by weighing and a sample to determine DM is obtained through sampling sawdust from the supply. DM is determined as the proportion of the sample weight in dry to the sample weight in green. To determine “atro weight” the weight of supply in green is multiplied by the DM value. The conversion of atro weight to m^3 is carried out by a conversion coefficient.

After the placement of all harvested wood to consumers, the structure and volume of realized assortments was as shown in a following table. In each of the assortments, data on the type of reception and average price per m^3 are completed in the table.

4. Results and discussion

Because it refers to the first part of the project, our objective was to describe methods used to determine the volume of wood in the chain mentioned above, to follow changes in the volume of wood in a concrete chain, to determine possible procedures of measurement, bottlenecks and, generally, to determine possible causes of the origin of volume differences. On the ground of the small amount of measured relevant data we do not carry out statistical evaluation yet even create general conclusions. After obtaining data on the volume of assortments in the whole chain it is possible to present results obtained. Tabular values were converted into the following general diagram, which indicated, how the volume of wood changed in the chain under investigation.

Results of our studies have shown that it is possible to achieve very accurate results using present-day methods. Differences in the volume between planned and produced assortments occur in values up to 3%. It follows that the software application working with models of the stem form is very advanced. The measurement of sample trees necessary for the calculation of a sufficiently exact model of the stem form is very time-consuming and hardly utilizable in forest practice. Former studies dealing with the course of the stem form show that the stem form is affected by the number of factors, particularly species, mensurational characteristics of a tree, stand and site. At present, there is a hypothesis that trees of the same species under similar site conditions and similar mensurational characteristics show a very similar course of the stem morphological curve and thus, it is possible to construct locally linked models of the stem form utilizable for the stand assortment structure in the given locality. Because the harvester measures and stores information on the course of the stem form we will collect these data from stands, add mensurational and site characteristics of studied stands and a clear geographical identification in our future research. Thus, the database will be created of local models of the stem form serving for the needs of the creation of the stand assortment structure in the studied area. A present, we also test Dendroscaner software (Tauber, 2006), which processes data determined by the analysis of the sample tree digital photos for the calculation of the stem morphological curve and the stem form model.

Interesting results are also given comparing volumes between the stage of production and realization. At the assortment III A,B,C at a length of 3 m, where reception was varied out electronically, the assortment volume decreased from 123.17 m^3 determined by a harvester to 119.22 m^3 determined at a customer. Similarly, also at the assortment III A,B,C 5 at a length of 5 m, the assortment volume decreased from 307.55 m^3 determined by a harvester to 296.36 m^3 determined at a customer. It was found only thanks to another method of measurement the volume difference in both cases being about 3%. After financial expression included in the next diagram, the difference amounted to € 966. In pulpwood, the situation was different. A customer using DM weight ("atro-weight") reception determined 114.79 m^3 and a harvester measured 94.25 m^3. Thus, the volume of timber determined at the customer increased by 20% as against production, however, thanks to the low price of pulpwood, the financial effect was not so marked and the difference amounted to € 520.

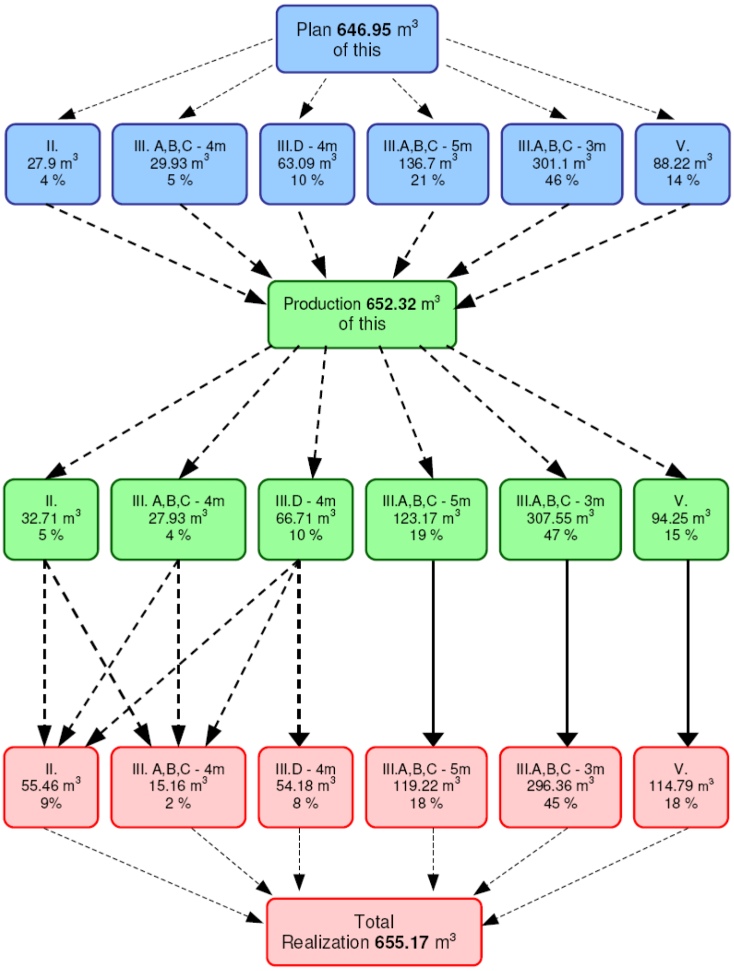

Figure 1: The diagram of changes in the volume of wood in the chain " plan – production – realization" of wood

By reason of decreasing the quality requirements of the customer of the 2nd quality class assortment mutual re-sorting of 4-m assortments occurred. Therefore, data on the change of volume can be assessed as a whole only. A decrease between the produced and received wood amounted to 2% and thus, a financial expression and comparison is irrelevant in this case.

Possible causes of the origin of volume differences between the stage of production and the stage of timber realization are as follows:

- A human factor – wrong calibration or setting the measuring system or methodically incorrect sampling to determine DM in weight reception can result in errors in the measurement.
- Effects of weather – for example, ice accretion on stems can cause problems with measurement.
- The factor of bark thickness – at a harvester, bark thickness is only estimated for the purpose to determine mid diameter while already barked logs go through electronic reception. It is also associated with the problem of the wood fibre decrease along the stem girth during barking.
- Effects of rounding the log diameter – in electronic reception, up to threefold rounding (down) to whole cm occurs. Nevertheless, causes of diameter rounding at present systems are not already substantiated and can be found in the past when a calliper carried out the measurement and volume was read from tables.

The enumeration of possible causes is not, without any doubt, complete, however, it should outline the complexity of the problem of volume determination and where causes of volume differences can occur.

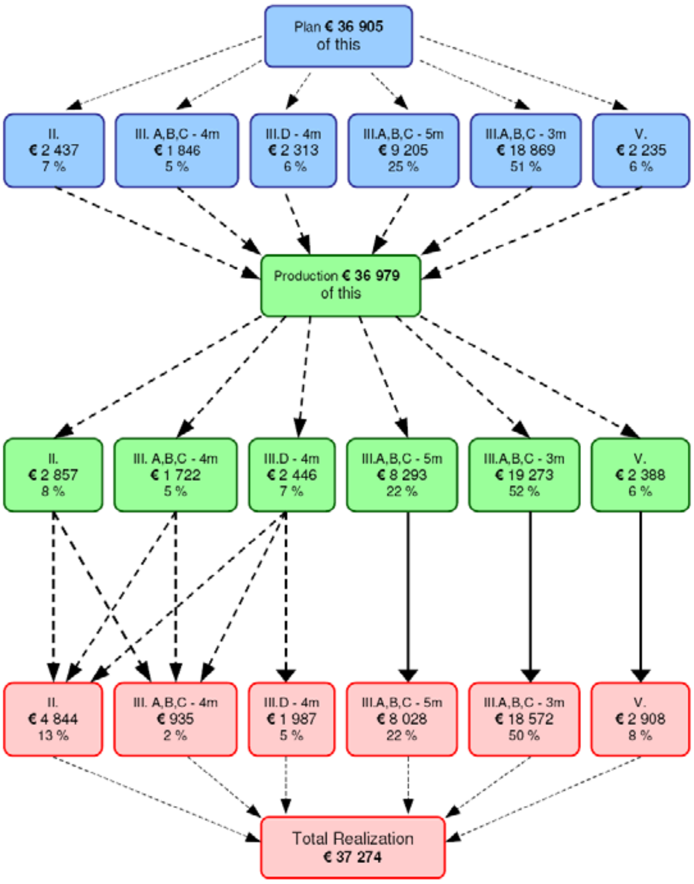

Figure 2: Financial expression of the movement of wood in the "plan – production – realization" chain

Note: The financial values originated by multiplying the volume determined and the mean realization of assortments.

For further measurement it is necessary to accept following recommendations:

- To introduce check measurements – on the ground of the possible comparison of a volume determined by a harvester with a volume determined at a customer it is necessary to introduce check manual measurement between the two measurements. By reason of large time-consumption check measurements cannot be carried out at the whole volume of monitored wood. Therefore, the extent of check measurements will be chosen so that to reach significant reliable results. Diameter measurements will be carried out in unbarked logs by means of a metal calibrated calliper on top end, in the centre and on butt end 2 times perpendicular at each other accurate to mm. The log length will be measured by a tape as the shortest distance between both ends of the log accurate to cm. In addition, bark thickness will be measured by means of a slide gauge accurate to mm. The calculation of volumes will be identical with formula 2.

- The measurement will be carried out at a roadside landing where timber of one assortment going to one customer will be measured. Measured logs will be numbered on the log end for easier registration.
- To carry out measurements in the selected area throughout the year.
- To attend to the calibration of measuring systems and measuring aids.

5. Conclusion

In all stages of the chain "planning – production – realization" of wood, we do not require the same accuracy of determining the wood volume. While in the stage of planning, accuracy up to 5% can be considered to be satisfactory and sufficient, in the stage of production and realization of wood when we measure concrete logs and determine their volume we are interested in every hundredth of m^3, because even this amount directly affects the economics of management of subjects involved.

If we have a look at the size of volume differences found in this research study to assess them then a question originates, viz. are these difference large or small? Is it a success for a harvester that it reached such accuracy or findings from practice and previous measurements have been proved that electronic reception of logs at customers systematically undervalues the volume of supplied logs and thus deprives the forest sector of considerable financial means? We hope that the follow-up research will provide answers to the questions.

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