## ИССЛЕДОВАТЕЛЬСКИЕ СТАТЬИ

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# COMPARISON OF DIFFERENT STACK MEASURING METHODS

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In the last decades different methods have been developed for measuring piled wood, i.e. wood stacks. There are two main groups of measurements: the first one is manual methods and the second one is automatic measurements. Taking into consideration the amount and market value of stacked wood, the accuracy of applied measurement is of high importance, as the price is calculated according to the measured amount of wood. Manual measurements are mostly time consuming and dependent on individual performance. On the other hand, the automatic methods are fast and their accuracy has increased in the last years. They allow to obtain relevant results when calculating prices at different locations, independent of the measurement time. These methods range from simple manual measurements using a tape to photo-optical measurement systems. Also, other measurement methods (e. g. water immersion) are currently used in practice. The paper describes the individual manual and automatic measurement methods for industrial timber and their working principles. Furthermore, the advantages and disadvantages related with the requirements and accuracy of the individual procedures have been explained and their practical use discussed.

**Keywords:** *stack measurement, industrial timber, photo optical measurement, harvester.*

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## INTRODUCTION

Measuring round wood is probably the most important element of the chain connections between forestry and timber industry. In addition to timber quality, timber volume is one of the most important issues in fixing prices.

The majority of sawmilling companies apply state-of-the-art round wood measurement systems. The round wood is measured either electronically in the factory, or manually, and the volume determined on individual log basis is used for the billing of timber. Therefore, the one by one measurement of logs plays a special role when it comes to determining the prices.

In contrast to sawmilling, pulp, paper and wood-based panel industries process round wood assortments of lower diameter and quality referred to as industrial or stacked timber. The ratio of stacked wood versus logs can be quite high, especially in case of broadleaved species. This ratio depends on many factors, such as wood species, soil quality, climate conditions and age of the stand stock. Due to the requirements or qualities of the industrial wood, their low value compared to round wood and the absence of technical facilities, electronic measurement of these assortments on individual log basis is not possible. Therefore, other measurement methods must be used, which are capable of representing the volume as accurately and efficiently as possible. For this reason different integrated methods were developed which make it possible to estimate the overall volume of the piled or stacked industrial wood. The volume measurements of stacked wood goes back to the previous centuries when different solutions were developed. The methods were continuous developed according to technical possibilities of the time. The last decade seems to be a technical revolution in the field of industrial wood volume determination. More and more innovative solutions appear at the international markets, which compete with each other. Expectedly, within some years, the automatic measurement methods will dominate at the industrial log markets. Although the present standards and scaling manuals give instructions for manual measurements, however, in some cases they mention the application of photo-optical techniques.

The present paper is aimed at surveying manual and automatic measurement systems for industrial logging.

*Requirements and characteristics of the measurement methods.* The various measurement methods for industrial timber must meet specific requirements. In general, a measurement method must be characterised by a high degree of rationalisation and at the same time should provide the highest possible level of accuracy. The measurement values must be understandable and verifiable by all persons involved in the processing and sale of timber. In addition, the sequence of the phases of timber harvesting, skidding and transportation must not be interrupted by the data acquisition and the cost is to be kept as low as possible.

*Historical overview.* As early as in 1875, when the Würzburg Charter was adopted, the states of the German Empire agreed to introduce the terms «Festmeter» (solid cubic meter) and «Raummeter» (volumetric cubic meter) as general calculation units for the sale of timber and timber transactions (Wilwerding, 1995). A general regulation related to grading and measurement of sawmill logs and industrial timber was adopted as late as in 1936 by the «Reichsholzmessanweisung» (Platte, 1957) in Germany.

One of the first methods to measure the stacked wood filling factor was published by G. L. Schnur (1932) who measured the tree solid volume and assigned the cut parts to segmented diameter classes. He also compared the filing factors of the diameter classes. To determine the converting factor of mixed oak cordwood L. I. Barrett et al. (1941) used planimeter, which was the first photo optical device. However, L. I. Barett et al. (1941) determined only the filing factor for manual measurements but not the solid content of every pile. The picture was taken from the end of the stack, calibrated by means of scaling and put to the edge of the stack. C. H. Keepers (1945) used a diagrammatic top-plan view of wood measuring device. The picture taken from the stack butt end was analyzed and the ratio of wood was calculated. These studies and results prove that photo analytical solutions assisted in developing a pragmatic and accurate method.

Scientific examinations, however, revealed that the specified measurement instructions and conversion factors resulted in data scattering and volume errors between – 12 and + 7 % (Dietz, 1966).

The regulations from the «Gesetzliche Handelsklassensortierung für Rohholz» (Forst HKS, 1969), which were adopted in Germany in 1969 and were used until 2009, provided a new regulatory framework for round wood measurements and transactions related to industrial timber. In this context, the conversion factors were revised in order to calculate timber volume as accurately as possible.

The new standard «Rahmenvereinbarung für den Rohholzhandel in Deutschland» (RVR, 2015), used in Germany since 2015, provides new conversion and reduction factors while using existing measurement methods. This suggests that obtaining valid data for industrial timber has not been achieved yet and still depends on numerous factors fraught with errors.

## MANUAL MEASUREMENT METHODS

The limits of this article did not allow for the authors to provide a comprehensive review of manual and automatic measurement methods, that is why only the stream line methods are presented which are widely used or can be a popular solution for automatic measurements in the near future.

*Sectional volumetric measuring method.* The sectional volumetric method is widely used to measure industrial stacked timber both in Europe and in North and South America and also in other parts of the world. The method can be used for stacks of different width, length and height. The most common length of stacked logs is 1.0; 2.0 and 3.0 m in Europe and 2.44 m (8 ft.) in North America. The measurement method is applied to the completed stack and the determined volume is used as a measure for sale.

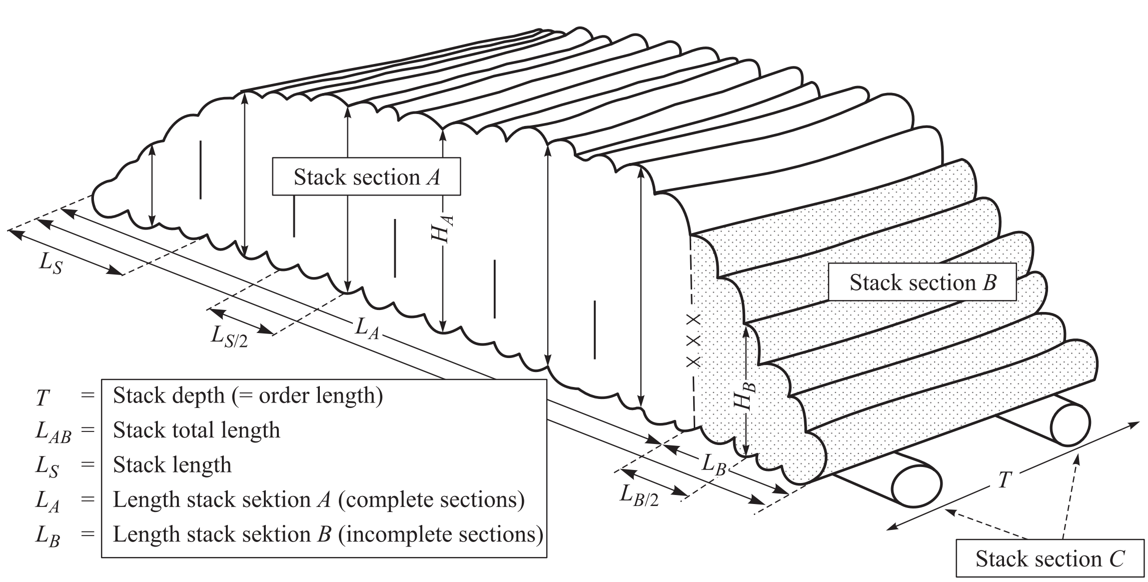


**Fig. 1.** Measuring by sectional volumetric method RVR (2015).

The measurements of the length, height, and depth of the stack (corresponds to the order length of the assortment) are used to determine the gross volume in cubic metres. Usually the measurement values are determined using a measuring tape for the length and a yard stick for the height (Fig. 1).

Depending on the overall length of the stack ($L_{AB}$), it is divided into sections of equal length ($L_S$) (Table 1) for the length measurements.

The section size can differ according to the regulations in different countries. After the division and marking of the sections, an incomplete section is obtained at the end of the stack (stack section *B*) with the length $L_B$. This is measured separately and the volume is added to the determined stack volume from $L_A$.

The respective section centres ($L_{S/2}$) are relevant for the subsequent height measurement and are therefore marked using colour spray.

The section heights are determined vertically to the stack and on both sides. The measuring points at the bottom and topside of the stack must always be determined where the vertical marking leaves the end face of the last log. Height compensation within the respective sections in case of irregular placement of the logs at the top of the stack is not allowed. There are regulations that determine a recommended or maximum height (Nova Scotia…, 2007). There are regulations to determine height or other dimension corrections in special cases (SDC, 2014; RVR, 2015).

The gross volume resulting from the measurement values determined (length and height of the stack) and the order length are reduced according to a fixed measure allowance of 4 % and additional reduction factors depending on the wood species and the assortment length (Table 2). The resulting net volumetric measure without bark valid for the timber sale is thus calculated according to the following formula:

$$\text{Net volumetric measure (m}^3\text{ub)} = $$
$$= (H \times L \times T) \times \text{reduction factor (\%)}.$$

The Swedish SDC (2014) gives a similar solution, which is a little bit more sophisticated by calculating the individual section overall volume instead of average value of stack height.

**Table 1.** Division of section lengths (m) according to RVR (2015)

| Total stack length ($L_{AB}$) | Section length ($L_S$) |
|---|---|
| Up to 10 | 1 |
| 10 to 20 | 2 |
| 20 to 40 | 4 |
| 40 to 60 | 6 |
| 60 to 80 | 8 |
| 80 to 100 | 10 |

**Table 2.** Reduction factors depending on the timber length and type according to RVR (2015)

| Wood species | Assortment length, m | |
|---|---|---|
| | 2 | 3 |
| Spruce/fir/Douglas fir | 0.96–0.94 | 0.94–0.92 |
| Pine/larch | 0.940–0.925 | 0.920–0.905 |

*Conversion factors.* The calculated overall volume complies with the solid wood content and the air space between the logs. The conversion factor is the relationship between staked measure and solid contents. The ratio between these two components of the pile can be different within a range of 0.50 to 0.80. The higher number means the higher solid wood content in a stacked cubic meter. Some prescription defines this ratio in percentage and does not make any diversification within an assortment (Manitoba…, 2013). A. van Laar and A. Akça (2007) determine the conversion factor as 0.80 for pulpwood under bark and in the case of firewood, which is recovered from wood without meeting the quality standards for sawn logs, the conversion factor is found to be 0.70 over bark. There are other official regulations, which provide a fine diversification of converting factors for different assortments and wood species (New Brunswick…, 2003). A scientific investigation was conducted for more accurate determination of conversion factor function in different conditions of stacked piles (Barros et al., 2008). The optimal cost of estimating stacked wood solid content was found by Smith (Smith, 1979).

S. Meyen and K. O'Connell (2012) describe a special method of determining the actual conversion factor using a 0.7 by 0.7 m grid and counting the numbers and diameters of the logs.

*Xylometry.* The difficulty of log volume measurements is due to irregular shape of trees and branches. The stems have bends and twists and irregular surface shapes, which do not allow to obtain a perfect mathematical model for calculating actual surface and volume. A measurement method, which could determine surface unevenness would be perfect. The immersion of logs into water approximates this method the closest or the most appropriate way. R. Özçelik et al. (2008) investigated the xylometry method and compared it to others. Despite the difficulties in making measurements the results shows very a good correlation with the real volume of the stack.

*Automatic measurement methods.* The automatic measurement systems use technical background and computational methods for data analysis. At the present, more and more innovative solutions are developed, which are available on the market. The electro-mechanical harvesting technology is one of the earliest ways of determining the solid contents of stacked wood. In spite of inferior measurement accuracy the advantage is that the measurements are made at the same time as harvesting. Neither additional operations, no time is requested for measurements.

Photo optical solutions improved during the last years. In addition, such applications can be run in smart phones. The more sophisticated technologies use other additional equipment for taking pictures and analysing images.

*Harvester measurement.* In Germany, half of the timber harvesting is already mechanical, which is why measurements made by the harvester are gaining increasing importance (Wagelaar, 1997). The measurement equipment contained in the harvester unit automatically registers the data of the processed log.

The length measurements of the sections are generally carried out by means of toothed feed rollers equipped with sensors. These rollers are pressed mechanically or hydraulically to the surface of the logs in the processing unit and move along during the operation.

With diameter measurements, the data are either obtained by determining the distance of the feed rollers to each other or indirectly by determining the opening angle of the delimbing knife during log processing (Sauter, 2014) (Fig. 2).

In addition to the individual determination of log volume based on the measured lengths and diameters, the quantity is required for the calculation of the total volume of a stack. This is determined fully automatically with each log cut with the chain saw and stored in the system.

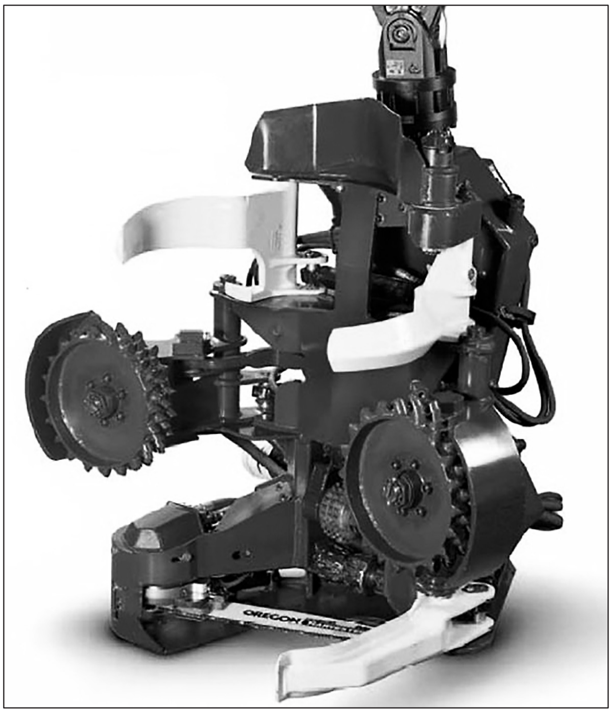

**Fig. 2.** Harvester unit (Ponsse Plc., 2019).


**Fig. 3.** Mobile camera log measurement system by the Dralle company: *A* – general view; *B* – the measurement unit (Dralle, 2015).

Continuous calibration of the measurement systems and changes of the parameters according to the respective timber conditions are a basic requirement for obtaining valid data (Dietz and Urbanke, 2009).

*Photo-optical systems.* Photo-optical measurements become increasingly important over the past years. Currently, different systems exist at the market allowing an automatic mobile capture of individual stacks by means of image analysis (Jorgesen and Kristiansen, 2008).

There is a marked difference between two technologies due to the principles of operation (Fink, 2004). The measurements of stacks are automated with the measurements carried out via camera system on the roof of the car while simultaneous calculations are made with special software. Other photo-optical systems are based on manual recording using digital cameras and automatic external evaluation of photo material.

Fully automated measurement technology of wood stacks allows collecting data at different viewing angles, distances and speeds. The measurements are carried out using a stereo camera system, with two cameras positioned at a certain angle to each other (Fig. 3).

Individual images are recorded within a fixed and known scale without additional reference points. The camera generates several images per second and a stereo film of the stack front. Based on this film, a 3D model with all parameters corresponding to the timber volume, such as cubic measure, solid measure, quantity and diameter distribution, is calculated (Dralle, 2014). Once recorded, the measurement data are immediately transmitted to the server and can be imported and corrected where necessary using a monitor installed in the car (Müller, 2008).

Photo-optical measurements of timber can also be made using a digital camera. Several frontal individual images (i. e. of the end face) of a stack are recorded. In each of these individual images, a scale (e. g. a yardstick) must be used as a reference during image analysis.

The evaluation of the image data cannot be performed on site. Instead, the obtained data sets of the individual images are sent to a central web server in an automated manner. This web server assembles the images of the individual stack sections to a total image of the stack, similar to a panoramic photo (Fig. 4).

The recorded images are used to determine the log quantity, end face diameter and the storage density of the stack. Based on these values and the uniform log lengths, the total volume of the stack in cubic metres, average mid-diameter and size class distribution are calculated first. By the application of conversion factors it is later possible to calculate the total volume in solid cubic metres (FOVEA, 2014).

## DISCUSSION

The manual and automatic measurement methods described and explained here will now be discussed according to their requirements, accuracy, and rationality.

*Requirements and accuracy.* To ensure that the determined volumetric measure is correct, certain conditions and minimum requirements must be fulfilled (RVR, 2015). If these are not fulfilled, the sectional volumetric measurement method cannot be used to determine the sales measure. Hence, it could only be used for determination of a control measure.

- Minimum stack size of 20 $m^3$.
- Stack height as uniform as possible and max. 2.50 m.
- Stacks separated according to wood species.

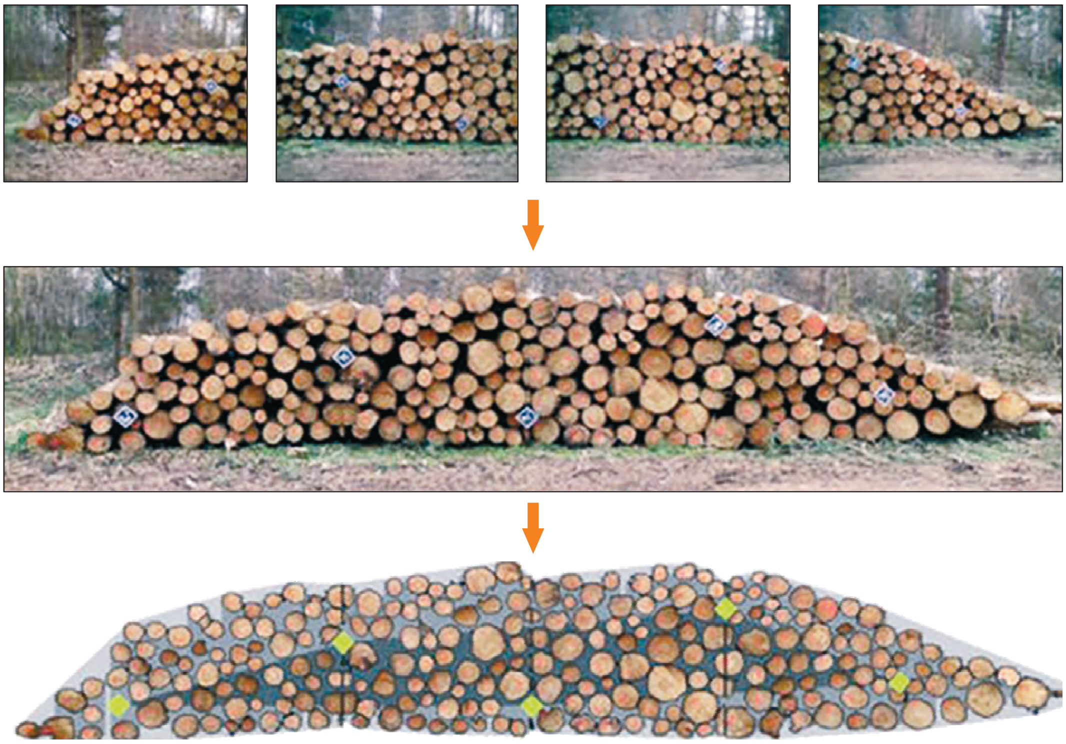

**Fig. 4.** Individual steps of photo-optical stack measurement (AFoRS, 2019).

- Stack placed in a dense and flush way.
- One order length per stack of wood.
- Building stacks without inclusion of branches and foreign material (snow, dirt, etc.).
- Free access to front and rear of the stack.

Even though the aggregates and the board computers are continuously developed by manufacturers, the harvester measurement process and the problems involved still complicate the matter. By permanent calibration of the measurement system and changes of the parameter settings according to the respective timber condition, certain measurement accuracy can be reached, but this does not indicate the exact timber volume.

The main cause is different conditions during the harvesting of timber. For example, if the logs are processed while they are producing sap, major bark portions are removed during delimbing. As a consequence, log portions with and without bark change during measurements, making diameter determination more difficult. Length determination is often complicated by that, with very knotty or bumpy logs processed, the hydraulically pressed measurement wheels temporarily come off the log and that jamming of the length measurement wheel due to, for example, peeled off bark pieces, leads to incorrect results. In addition, external influences such as the season of the year, weather and mechanical factors affect the measurements made by the harvester.

In practice, mistakes often occur when determining the quantity, due to incorrect operations of the systems or software errors.

Because of these errors the harvester measurements are only used as a control and for logistic purposes. For calibration reasons they cannot be used as a sales measure suitable for the calculation of prices (Dietz and Urbanke, 2009).

In Denmark, approximately 300 000 m$^3$ of round wood have been measured by photo-optical methods by the Federal Agency for Nature Conservation every year since 2009 (Stjernholm and Dänemark, 2015). It is claimed that regular calibration of the measurement equipment ensures that specified error tolerances can be met. The accuracy ranges of these tolerances are not specified or mentioned.

The manufacturers of photo-optical equipment advertise high performance of their devices without specifying exact tolerance ranges. According to the current state of knowledge, individual scientific studies have been conducted on the comparability of the results of photo-optical measurement and assessments on an individual log basis of sawmill timber. The tests concerned with the measurements of industrial timber have not been performed yet.

In general, it can be said that the accuracy of the measurement results largely depends on the system, the stack quality and the operation. There are detailed regulations on the distance and the angle to the stack front in which the recording camera is to be positioned. Even small changes lead to inaccuracies and incorrect results. In addition, external influences, such as the incidence of light, affect the correctness of the measurement data as due to shadows or minor darkness individual end faces may not be detected and measured. Similar problems are caused by dark or dirty end faces. While it is possible to subsequently process these logs with special software, this is connected with wasting extra time and efforts.

*Rationality.* If all conditions and requirements are met, the volumetric measurement method is characterised by a high degree of rationalisation. This is mainly beneficial in case of large stacks. Consequently, it is one of the fastest and most cost efficient manual methods (Wilwerding, 1995). In addition, the method can be reproduced by all persons involved in the wood sale at any time and the measurement result is transparent for all parties.

The harvester measurements allow an early determination of measures and therefore a prompt available measure for logistical processes. The data can be made digitally available by means of modern software and interconnected with other database systems via radio.

As explained, the photo-optical measurement methods offer the possibility of early determination of measures. In practice, the method is characterised in particular by its uncomplicated and easy way of data provision and the comprehensive documentation of the measurement. This allows for rationalisation of the complete business process of the timber sale and its transparent representation for all persons involved.

## CONCLUSION

In summary, it can be concluded that although the automatic measurement methods for round wood developed over the past years (harvester, photo-optical methods) have been significantly improved with respect to the rationalisation of timber measurements compared to the manual methods, the measurement accuracy required for the sale of timber should be improved. It remains to be seen whether these systems can be upgraded further with respect to the measurement accuracy and can thus become easy and quick to calibrate.

Therefore, at present the only alternative available for determination of a sales measure for industrial timber is the manual measurement methods used for several decades. The problems mentioned above regarding the requirements and accuracy often give rise to disputes and arguments between the forestry and timber industry. Depending on the situation at the timber market, each side try to impose the measurement method, which is the best, i. e. most beneficial for the respective party.

Looking to the future, it would be necessary and desirable for the forestry and timber industry to generate a measurement system for industrial timber which complies with the required dimensional tolerances while, at the same time, ensures a rational procedure. With today's technical possibilities and the experience of several decades in the sale of industrial timber this should be possible.

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# СРАВНЕНИЕ РАЗЛИЧНЫХ МЕТОДОВ ИЗМЕРЕНИЯ ШТАБЕЛЯ ДРЕВЕСИНЫ

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В последние десятилетия разработаны различные методы измерения спиленной древесины в штабелях. Существуют две основные группы измерений: первая – это ручные методы, вторая – автоматизированные. Поскольку велики количество и рыночная стоимость складированной древесины, точность измерений имеет большое значение, так как цена рассчитывается в соответствии с измеренным количеством древесины. Ручные измерения занимают много времени и зависят от исполнительности работника. С другой стороны, автоматизированные методы быстры, и их точность существенно увеличена в последние годы. Они позволяют генерировать релевантные результаты для расчета цен в разных местах независимо от времени измерения. Эти методы варьируются от простых ручных измерений штабеля с использованием измерительной ленты до фотооптических измерительных систем. На практике в настоящее время используются и другие методы измерения, в том числе погружение в воду. В статье представлены отдельные ручные и автоматизированные методы измерения для промышленной древесины и принципы их работы. Обсуждаются преимущества и недостатки, касающиеся требований и точности отдельных процедур, и их практическое использование.

**Ключевые слова:** *измерения штабеля, промышленная древесина, фотооптические измерения, харвестер.*