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REVIEW PAPER

Analysis of modern wood processing techniques in timber terminals

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Abstract

The transportation of forestry products is performed over long distances and is quite expensive, which limits the development of biofuel plants in Russia and around the world. The use of timber terminals contributes to transportation cost reduction and mitigates negative environmental impacts. This work aims to analyze various technological solutions for optimization of forestry products processing at temporary terminals and cost reduction of transportation, shipping, and wood treatment. The work presents a discussion on the technological and economic possibilities of the mobile pellet plant, the mobile essential oil production plant, and an enhanced autonomous electric generator system. It is shown that the use of mobile plants for obtaining pellets and essential oils allows processing wood residues at the terminal, which reduces the cost of transportation and shipment of raw materials and improves the quality of the finished products. The current study also examines some of the modern scanning technologies used to detect log defects and obtain complete biometric information in real time while assessing the productivity of wood processing operations. The results of the study can be used to develop efficient movable timber terminals.

Key words: energy wood; equipment; fuel; storage location; supply chain

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1. Introduction

With the aim of reducing the impact of human activities on climate change and environmental ecology in the global community, different actions to reduce the extraction of fossil energy resources and the transition to renewable energy sources in the production and transmission processes have been undertaken (Dogaru 2020; Halkos & Gkampoura 2020; Morita et al. 2002). The success of such a transition depends on optimizing the supply of renewable raw materials, developing competitive production systems, and long-term regulation to compete against fossil fuel products (Giuliano et al. 2016).

Currently, there is an excess of forest biomass in Northern European and Russian countries, which includes discarded wood, forest residues, branchwood, and stumps (Athanassiadis & Nordfjell 2017). In the Russian forestry sector, there has been a gradual impoverishment of quality roundwood in the developed commercial forests and the associated continued growth of the logging transportation arm, which has already exceeded 300 km in Siberia and the Far East (Lobovikov & Pryadilina 2020; Likhouzova & Demianova 2021). Mature and over-mature forests in proximity to the main wood processing centers, often remain only in less developed swampy or heavily rugged areas (Mokhirev & Goryaeva 2017). The growth of the harvested timber transportation arm along with an increase in the specific fuel consumption for the transportation of a depleted cubic meter of wood and the specific depreciation of wood trucks leads to a significant increase in the cost of harvested timber. It is associated with the need to finance the building and maintenance of an extensive network of forestry roads. At the same time, the prospects for offsetting the costs of developing a network of forest roads for forest users

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are still not developed (Kozlov et al. 2019). Despite the comparatively low payment rate for forest resources in Russia, timber harvested from natural forests is becoming less and less competitive in terms of production costs, which is illustrated in Fig. 1.

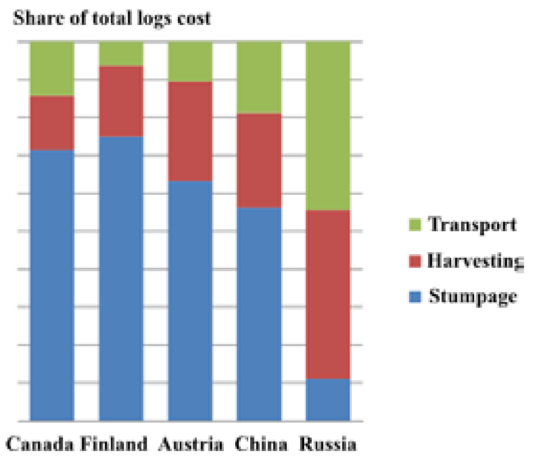

Fig. 1. Indufor analysis of sawn logs costs (InduforGroup 2021).

Moreover, the ongoing removal of forest harvesting sites for mature and overmature stands away from the personnel residences of forest companies (sites) leads to increased use of shift logging methods. In turn, it is associated with establishing shift work camps and some infrastructure of their service, which also increases the cost of harvested wood (Tambi et al. 2017). The cost structure for roundwood with its own leasing base is shown in Fig. 2.

The cost of wood harvesting can be reduced by optimal planning of transportation from the logging site (Mokhirev et al. 2019; Rudov et al. 2019).

The difficulties of forestry enterprises and the exhaustion of available quality resources of mature forests lead to a shortage of wood raw materials for domestic wood processing enterprises. For example, in March 2018, the Ministry of Industry and Trade of the Russian Federation (2021) held a meeting of the subcommission on customs-tariff, non-tariff regulation, and protective measures in foreign trade, at which it was decided to introduce a temporary two-year restriction on the export of veneer blocks. The study of the situation with raw materials at Russian veneer enterprises showed a negative trend in the supply of veneer logs to processing industries and an increase in exports of these raw materials to China. For a while, this has helped mitigate the shortage of raw materials for domestic veneer enterprises, but it is only a reprieve. This is largely due to the incorrect policy in the field of reforestation and the absence of a policy on the cultivation of deciduous plantations of seed origin (Kuzminyh et al. 2020; Uvsh et al. 2020). The solution for this problem might be the development of the target cultivation (planting) of wood, as is accepted in most countries of the world (Bulat et al. 2017; Kemppinen et al. 2020).

Currently, the most requested round woods in Russia are conifer logs (diameter, 14–38 cm), balance logs (diameter, 6–24 cm), and plywood logs (diameter, 18 cm onwards). There is also a problem of low-quality wood accumulation on the rental bases of forest companies that require extensive development and implementation of technological processes for effective wood processing. It is needed, at least, to ensure that the added value of products derived from such timber covers the costs of its harvesting (Loučanová et al. 2017). To address this issue in Russia, government strategies for collecting and processing non-wood (food) forest products have been adopted since 2009. However, this process calls for very specific machine and equipment systems. Besides, harvested forest food products cannot be transported over long distances. Such wood must be processed in the nearest places to the logging sites and in the shortest possible time in order to avoid significant quality loss (Lovrić et al. 2020; Stryamets et al. 2020).

In the development of forest areas away from wood-processing sites, there is increasing use of the temporary timber terminal principle. Timber terminals are traditionally used as storage and transshipment points for round-

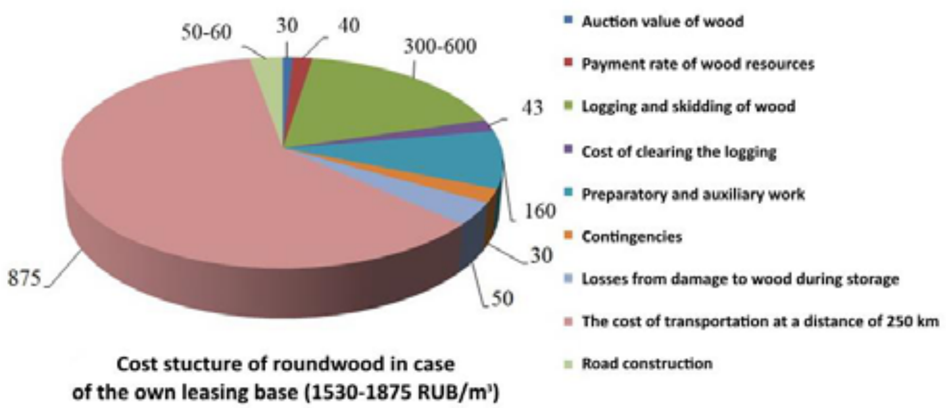

Fig. 2. Cost structure of roundwood in case of the own leasing base, RUB per m^3 (Tambi et al. 2017).

wood within forest industry supply chains (Korpinen et al. 2018; Berg & Athanassiadis 2020). Currently, timber terminals are primarily in place to facilitate the distribution of roundwood supply and processing. The principle of timber terminals placement in the leasing base under development is illustrated in Fig. 3.

The principle of temporary timber terminals based on mobile wood processing equipment is the primary processing of harvested wood with the further production of timber, the stacked-volume ratio of which is close to 100%. In the future, the wood obtained using mobile sawmills can be treated with antiseptic, if necessary (for example, during the warm season) and then exported to specialized sawmills for the final processing into high-quality sawn wood (Gedjo et al. 2020). Furthermore, wooden terminals may also be used to produce pellets and other products. For example, in many developed countries, such as Japan and South Korea, there is a trend towards decreasing the consumption of fossil fuels and switching to renewable energy sources (Jafari et al. 2020; Junginger et al. 2020). Japan has adopted a strategy that aims to increase pellet fuel consumption to 20% by 2030; as a result, the demand for this type of product is constantly increasing (Pambudi et al. 2017). The largest pellet supplier to these countries is Canada, which accounted for approximately 63% of pellet imports in 2015 (Ahl et al. 2018). In the European Union, there is a similar trend of utilizing wood pellets as fuel in thermal power plants and for building heating purposes (Dafnomilis et al. 2017). Given these trends, the demand for wood pellets will only grow bigger, which necessitates the need to improve production processes and logistics in Russia to enable import to Europe and Asia. Virkkunen et al. (2016) explored the cost-effectiveness of using terminals for biomass storage, processing, and fuel supply under any conditions in Finland. The study results on the costs for maintaining satellite terminals and developing forest fuel logistics showed that terminals are not more efficient compared to direct raw material supply chains. Furthermore, dust emissions and explosions, destruction during storage, self-heating, and ignition are important criteria in the design of a terminal for wood pellet plants. Also, it may significantly affect related logistics. However, based on a review of existing technological solutions in various European countries (Dafnomilis et al. 2018), there is a small volume of wood pellet plants, but constant equipment modernization and the rebuilding of terminals contribute to increased volume of products received.

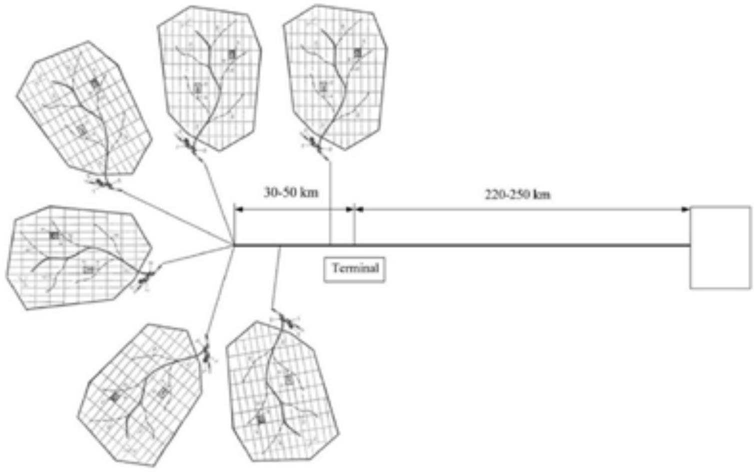

Fig. 3. Principle of a temporary timber terminal establishment in the developed leasing base (Marques et al. 2012).

In addition to that, producing essential oils from timber by-products, such as branches and shoots of spruce and pine, at timber terminals can increase the output of essential oils without losing their valuable properties. Labokas et al. (2017) discovered that storage of pine leaves at cold temperatures has an adverse effect on the overall yield of pine essential oils compared to when the leaves are fresh. Therefore, developing a mobile system for producing essential oils is an urgent task. Consequently, it is important to consider the operating and energy costs in planning and designing the terminals. The current state of terminals and available modern technological solutions are of great relevance when it comes to process optimization, and mobility/maintenance cost reduction. Timber terminals as temporary yards usually have no centralized electricity generation. The use of internal combustion engines as power stations considerably increases the cost of wood processing, given that the cost of fuel is rather important and that the efficiency factor of internal combustion engines is much lower than that of electric motors (Bhandari et al. 2015; Savelev et al. 2019). Besides, the transition from traditional to renewable energy sources enables efficient use of technology with full processing cycle of logging and wood industry waste.

Modern energy can be characterized by tendencies to diversify sources, increase autonomy, reliability, safety, environmental friendliness, and use of new materials (Aruova et al. 2020). Alternative and renewable energy sources include wind and hydroelectric systems, biogas plants, solar collectors, photovoltaic inverters, and heat pumps for the extraction of low-potential heat from the ground, water, and air (Vo et al. 2020). Another alternative source of electricity at mobile timber terminals can be a gas generator (Tsyvenkova et al. 2020), which uses waste (tree bark, branches, and stumps) from wood processing operations as fuel. The use of modern technologies in material engineering (Pomiguev et al. 2018) makes it possible to increase gas generator's efficiency, stabilize electricity generation from biofuels, and reduce the size of the terminal for better transportation (Zagrutdinov et al. 2017). In addition, timber by-products may be a basis for the production of many other products (e.g., essential oils, pellets, and shavings), some of which can find use in pharmaceutical, chemical and light industries.

Main objective of this study is to analyze various modern technologies and ways to optimize the structure of timber terminals. To this end, the work provides a review of modern techniques and systems for processing logs and forestry materials to obtain high-quality products and reduce the cost of transporting raw wood and other products through Russia. The results of the analysis of waste-free production techniques and advices made based on them can be useful in designing timber terminals for better process optimization and to increase the quality and range of timber products.

2. Technological and energy features of the mobile pellet line at timber terminals

For sawing up to 50 m^3 of wood per shift, it is sufficient to equip the sawing terminal with a single-passage sawmill with an energy consumption of about 37 kW. When sawing 80–210 m^3 per shift, it is optimal to equip the timber terminal with a mobile crossover line with feed speeds up to 30 m per min. The electricity consumption of this line is approximately 340 kW. For 300 m^3 per shift sawing, the timber terminal is ideally to be equipped with a mobile feeder with a speed of up to 50 m per min. The power consumption of this line is approximately 750 kW (Tambi et al. 2019).

The use of mobile granulation devices allows obtaining not only the thermal (electrical) energy but also the finished product in the form of pressed biofuel from the primary wood treatment at the terminal (Ghaffariyan et al. 2017).

The dimensions of the mobile pellet line correspond to the dimensions of a 40- foot container (drying module), an extended 20-foot container (pelletizingmodule), and a 20-foot container (wood preparation module). The equipment of the modules is located on specially created power frames with landings for its installation on standard container trucks and the necessary slinging elements for loading and unloading operations (Fig. 4).

To install the line on the top warehouse, a level horizontal platform with a specific load capacity of 1000 kg per m^2 is required. The actual demand of the line is 250.0 kW with an installed power factor of 0.7. The use factor may vary depending on the feedstock properties (species

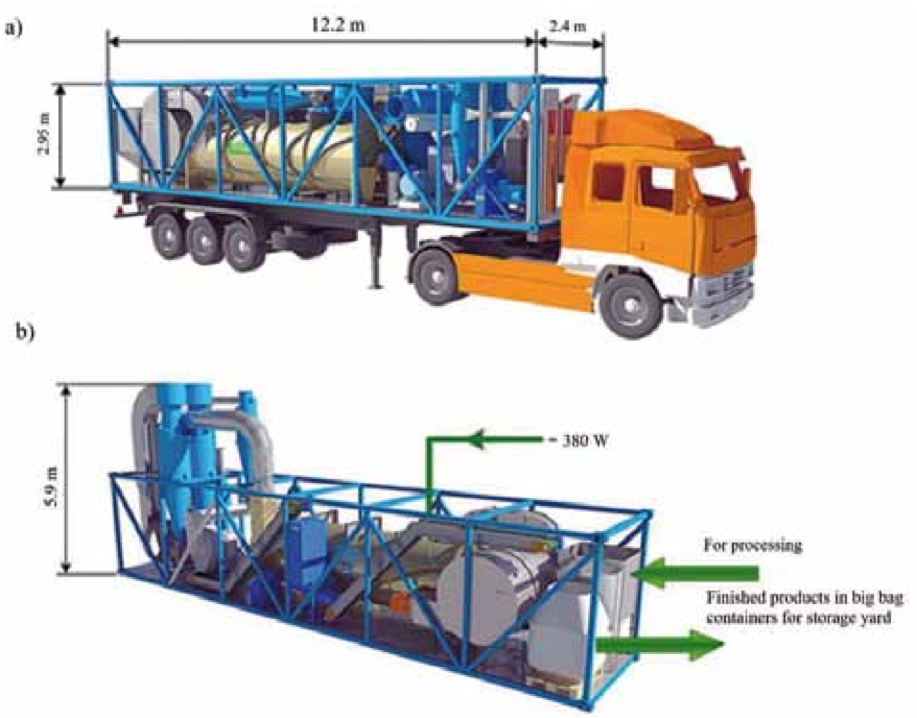

Fig. 4. Mobile pellet line: a) in transport position; b) in working position (Tambi et al. 2019).

composition, incoming moisture, etc.). There are three employees on duty handling the shift.

The time required to prepare the line for operation shall not exceed 20 hours. It consists of unloading the line and installing the line modules, joining them together, installing cyclones and gas ducts, which are in the transport and working position, and connecting the line to the power supply grids. The height of the line in the working position is increased by installing projecting elements (cyclones and gas lines) up to 5.6 m. The raw materials for production, the non-commercial wood up to 370 mm in diameter, first arrives on the hydraulic trestle. Then, it goes to the wood splitter piece by piece with subsequent cross-cutting of the tree-length log into pieces up to 0.5 m and their splitting. Afterward, the raw material is delivered by the conveyor belt on the chipper with further delivery of the received wood chip to the hopper-feeder. Then, the disk separator sorts out the bark and other casual subjects (including stones), which should not go into further processing. The sorted chips go into the hammer grinder. Then, using a conveyor, the finished wood pulp enters the heat generator and the rotating drying drum through a raw material dispenser. The dried wood gets into the pneumatic discharge cyclone and the hammer grinder. Exhaust gases are discharged from the cyclone through a flue gas vacuum through a stack into the atmosphere. After a hammer grinder, the groundwood enters a pellet press by a cyclone. The finished granulates are transported by a conveyor belt to the chiller and then to the vibrating screen. Afterward, pellets ready to be sieved using a scraper conveyor enter for packaging. Unsorted pellets and dust after the chiller and vibrating screen are reoriented for granulation using the cyclones and pneumatic conveying system. The line is controlled using only one control panel.

As an option, on request, the line can be equipped with any additional equipment (including the gas purification system, the food, and raw material pretreatment system, the gas or liquid fuel burner, etc.).

3. Technology features of the mobile essential oil distillation system

It is possible to deliver not only roundwood (logs, assortments) to the timber terminal, but also the crown part (with minimum stacked-volume ratio) for processing in mobile extractive plants with obtaining quite demanded biologically active substances (Yousuf et al. 2021). For instance, in recent years the demand for essential oils from *Pinus sylvestris* and *Picea abies* has increased (Neis et al. 2019). However, traditionally, this product is obtained only in complex woody greenstuff (WG) processing facilities in a unique process stream with the production of extractive substances. Pine and spruce plants contain a small number of essential oils, and the production of essential oils only under steady-state conditions is not economically viable. The main expense is the WG transportation to the processing site with an extremely low stacked-volume ratio in the truck.

Technological processes of logging operations with the use of feller-buncher machines, tractors with bundle grapple, processors at the top storage, gasoline-powered saws, and systems for skidding trees with crowns and delimbers at the top storage allow concentrating biomass of tree crowns, including WG, by the roadside. The use of harvesters and forwarders allows collecting concentrated heaps of logging residues with special pickers, bringing them to the roadside. From there, a small mobile unit for the distillation of essential oil will be located at the place of WG concentration near the road.

Wood from twigs and branches is intended to use as fuel, and the air from a battery-powered fan is used to cool down the isotropic mixture of water vapor and oil. The material is expected to be mounted on a car trailer.

Mobile facility for the production of essential oils under logging site conditions, Fig. 5, consists of steam generator, two distillation devices (reservoirs for WG), condenser, separating flask, and box for the equipment used. The unit operates with a closed water cycle, separating flask is used for steam production, which reduces energy costs and improves the efficiency of essential oils. Equipment technology parameters are designed to operate at air temperatures between –10 °C and +20 °C. Technological characteristics of the unit are described in Woodex (2020).

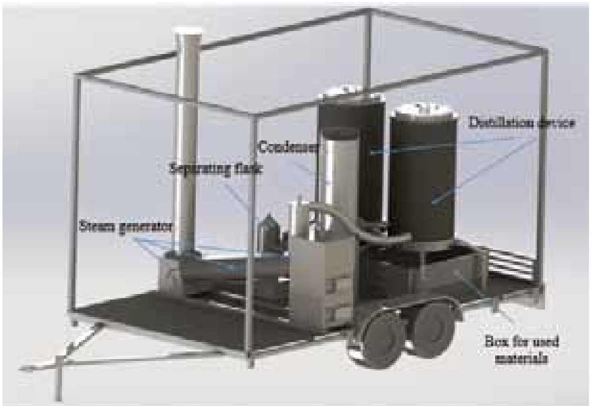

Fig. 5. Mobile Facility for Essential Oil Production (Woodex 2020).

After loading the tanks (water, WG, fuel), a cycle lasts about 3 hours, of which the evaporation process itself is about 2 hours, with the cooling capacity of 40 kg of steam per hour.

The duration of the cycle depends on many parameters, such as the state of the source material, physical condition of the operator(s), and others. Usually, one operator is enough, but considering the safety requirements and the possibility to significantly reduce the time of preparatory and auxiliary works, two operators are required (operator/operator or operator/driver).

A manual woody greenstuff chopper is used to disprerse (prepare) the material. A manual woodchopper or machete can be employed as well. The needles are not fully separated, they are used at the same time as small twigs. Waste is left on site. The dismantling or reassembly of the equipment takes about half an hour.

When the plant reaches the site, the operating area is determined and the equipment is deployed. Then, the water is poured and boiled, WG is being prepared (dispersed) and loaded, the vapor is being passed through a distiller, the vapor is being passed through the second distiller, the first is released and loaded again, and so on. Produced essential oils are purchased by the manufacturers of medications for the disinfection of living spaces and the prevention of colds.

4. Innovative technologies of wood log processing

One of the innovative technologies used in timber processing that can also be applied in mobile timber terminals is a portable laser scanning technology (Pyörälä et al. 2018). Through laser scanning and real-time data processing, such systems accurately and safely examine the volume and biometric characteristics of logs. The market offers ground and air-based laser scanners that allow the collection of data before logging using unmanned aerial vehicles and mobile robots (Székely et al. 2017).

Woodtech.Logmeter's solution to obtain general information about logs (WoodTech 2021) is an excellent fit for timber terminals. The company uses a modern log scanning technology (Logmeter) that allows examining the logs without unloading the truck (Fig. 6). This scanning system can be installed at the entrance/exit to the terminal.

Fig. 6. An automated scanning system (Logmeter) to estimate biometric characteristics of logs (WoodTech 2021).

Information from the Logmeter is transmitted immediately to the operator, who, based on the volume and biometric estimates, determines a class to which the raw material can be classified. This information then goes to other workshops and system elements for further processing operations. The limitation of this system is that it provides data about the external structure of the logs, and the internal structure analysis would require computed tomography.

In timber production, computed tomography became widely used since its first application in internal defect detection in the early 90s. X–rays penetrate a log without damaging it, permitting the internal structure analysis prior to sawing. Timber mapping allows the production of high quality timber products with less waste, as well as the rational use of raw materials (Rummukainen et al. 2021). The wood processing enterprises currently use industrial stationary scanners, which are part of an automated log processing system.

Data from the scanner also serve as an input for AI-aided sawing simulations. Using artificial intelligence to simulate sawing and cutting operations makes it possible to evaluate different sawing/cutting options and chose the best one according to the accepted timber quality standards (Olofsson et al. 2019). Using a computer-based model, one may implement an integrated approach to establishing the value of the end product up to the sawing stage. For this, a software needs to be developed to link the properties of logs and final products.

The BoardMasterNOVA scanner (FinScan 2021) enables an automated sorting of logs and can provide complete analysis of both green and dry boards, performed in different directions. BoardMasterNOVA is capable of accurate wood defect detection and product classification. The Logeye 300 Stereo True Shape Log Scanner from Microtec (2021) is based on a stereoscopic imaging technology that allows you to scan a log in real time while creating 3D images. With the help of innovative technology, Logeye 300 Stereo is able to scan logs of various sizes and diameters, as well as optimize the sawing process.

After sawing, timber boards are tested on modern systems that use multi-point scanners to distinguish good wood from defective wood. One example of such scanners is Gocator 250 (LMI Technologies 2021), a scanning system produced by LMI Technologies (Fig. 7).

As shown in Fig. 7, Gocator 205 is equipped with a vision module that uses color to capture external wood defects, such as twigs, cracks and rot.

Besides scanners that collect data, one may need a powerful software to process data. Lucidyne produces scanners with integrated GradeScan's Perceptive Sight Intelligent Grading software (Lycidyne 2021), which automates the wood processing operations and identifies softwood from hardwood. USNR (2021) has applied a Deep Learning technology to image processing systems to achieve faster and more accurate grading. Another innovative technology for wood scanning is the Autolog GEN3 log optimizer (Autolog 2021), designed to optimize primary log breakdowns and reproduce sowing curves with log rotations.

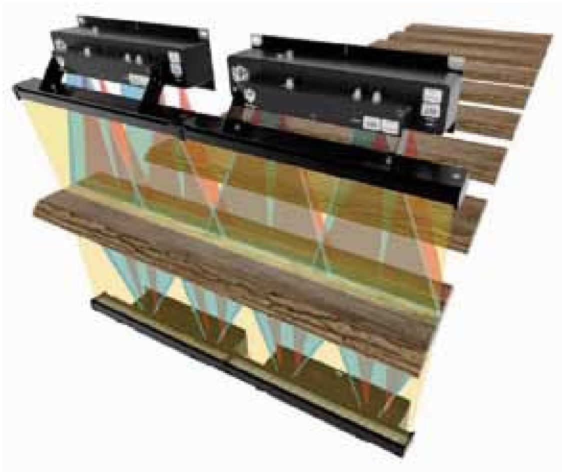

Fig. 7. Gocator 250 scanner to identify wood defects in timber boards (LMI Technologies 2021).

5. Discussion

The use of proposed developments and upgrading techniques might help optimize the energy efficiency of the temporary timber terminals and reduce the costs of transportation and primary processing of raw materials. Besides, the production of fuel pellets, essential oil, and gas synthesis from low-quality wood at the terminals saves on transportation and waste disposal, increasing product quality, since the process occurs immediately after wood treatment. When designing a timber terminal, it is also possible to adapt the location of production lines to the leased area. It will reduce energy costs and increase the rapid transportation of finished products without impairing the quality.

Many studies have focused on the rationality of using terminals in the production of fuel pellets in different European countries. Berg and Athanassiadis (2020) based on the Combopt optimization method, modeled terminal options to minimize the costs of collecting, transporting, and logging waste in Sweden. Six options were modeled to meet the anticipated demand from processing plants, with an estimated cost of SEK 3.1 to 35.4 million, which was 0.5 to 6.1% of the total procurement cost. These results are consistent with the findings of this study, indicating that the use of temporary terminals for the treatment of forestry waste is efficient and cost-effective.

Similar results were achieved in the work of Gautam et al. (2017), where the benefits of including a terminal in the developed network of the biofuel supply chain were studied. Modeling of raw material supply process with and without terminals has shown that the use of terminal in the production of biofuels allows reducing the shipment of raw materials by 4–11% while reducing the cost of supply by 11–32%. In another article of Palander and Voutilainen (2013), the authors also modeled the process of biofuels supply through road terminals and obtained similar results. Thus, the inclusion of terminals has been shown to reduce the total operating costs of biofuels supply by 18.3% from 7.1 to 5.8 million euros. Similar results were obtained in the work of Kühmaier et al. (2016), comparing the maintenance costs of the terminals by region. It has been shown that the reduction of the terminal zone has economic benefits when the annual turnover is less than 50000 m^3 of bulk materials.

Labokas et al. (2017) found that freshly harvested pine foliage contained a minimum of 17 kg of coniferous essential oil per hectare of mature pinewood, but the total yield of essential oils decreased after transportation to the processing plant. Installing a mobile processing station at the felling site or at timber terminals can significantly reduce the amount of waste from essential oil production and enhance the product quality, and the use of biomass gasification technology will facilitate waste recycling (Kislukhina & Rybakova 2018).

All of the above results indicate that the rational layout of the terminals and the use of additional waste treatment technologies can significantly save the costs of shipment and purchase of raw materials. Moreover, this can increase the profit of enterprises, reduce waste, and mitigate the negative impact on the environment.

6. Conclusions

Proposed technological solutions for the upgrade and optimization of forest material treatment at temporary timber terminals significantly reduce the costs of transportation, shipment, and processing of low-quality wood and residues. Also, they provide autonomy and mobility of the terminals from the central power supply. It is shown that the use of a mobile pellet system allows obtaining biofuel from waste wood cleaning with a specific carrying capacity of 1000 kg per m^2 and power consumption of 250.0 kW. The installation of a mobile plant for essential oils production on the terminals was found to have an annual economic effect. The overview of modern scanning technologies revealed that portable laser scanners provide complete information about the biometric characteristics of the logs, while the use of computed tomography and deep learning technologies permits the real-time assessment and classification of internal wood defects. The wood processing simulations help to choose the best sawing patterns and thus improve the quality of wood and minimize waste. The results of this review can be used to develop efficient movable timber terminals.

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