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Work Safety and Safety Devices in Brazilian Wood Sawmills for the Improvement of Working Conditions

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Abstract
Workplace safety is essential to ensure the health and integrity of the worker. Sawmills are known for high risk and severe accidents, especially involving circular saws, tenoners and jointers, which can, however, be prevented through the use of personal protective equipment (PPE), employee training, and safety measures on machines and equipment. The aim of this study was to present a compilation of the data presented in the literature about the main risks in sawmills, regulatory standards, the construction of a safety system, and the safety devices to be used. To choose the best safety methods, it is crucial to evaluate the types of risks present. Among the most common risks in sawmill machinery are mechanical, electrical, thermal, noise-induced, vibration-induced, caused by materials and substances, and disregarding of ergonomic principles. To reduce these risks, sawmills should have action plans that comply with regulatory standards, such as the use of PPE, machinery and equipment protection, demarcation of danger zones, workplace cleanliness, and operator training. Safety devices used in sawmills help reduce accidents and should be chosen based on machine's use, the nature and frequency of access, types of risks, and the probability and severity of injury. For circular saws, risks can be minimized through the use of basic protections such as a splitter and guards, in addition to a push device for wood pieces. Tenoners and jointers present higher risks with sharp tools in contact with body parts, protective guarding in hazardous areas is recommended. In all cases, the use of personal protective equipment is essential.

Keywords
Occupational safety — Risk assessment — Sawmill hazards — Regulatory standards

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1. Introduction

Workplace safety is a set of knowledge and practices in preventing accidents that result from operational risk factors present in machinery and equipment, material storage, transportation, handling of dangerous products, lack of training, incorrect operation and maintenance, lack of cleaning, electricity, fires, and explosions (Mendes, 2001; Saliba, 2004).

The aim of workplace safety is to prevent future accidents that may occur in various segments of the company. This prevention occurs through proactive measures, ensuring the physical integrity of the worker, the company's assets, and environmental protection. In Brazilian wood sawmills, this is accomplished through legislation that addresses these issues, such as the Brazilian Federal Constitution, the Civil Code, the Penal Code, the Consolidation of Labor Laws (CLT), and Regulatory Standards (NRs) (Bahls, 2013).

No area of industry is free of risks, however, work in sawmills can be identified as one of the most dangerous, even in countries with high levels of compliance with occupational health and safety regulations (Mongare; Mburu; Kiiyukia, 2017; Awosan *et al*., 2018).

According to Guimarães *et al*. (2021), the activity '16.10-2 - Wood Splitting,' as defined by the National Classification of Economic Activities (CNAE), predominantly exhibits typical accidents. These accidents arise from the occupational activities performed by workers. Typical accidents are predictable, common, and can be prevented.

According to the Informative Guide for Guidance on Adapting Woodworking Machines corresponding to the Special Sector Notification sent to companies in the sector, in Brazilian sawmills the most part of the body affected by these accidents are fingers and hands (60%) and upper limbs (9%), with the most common injuries being cuts and laceration (33%), fractures and dislocations (30%), crushing (12%) and 5% of amputation accidents (Brasil, 2022).

It is known that three of the most common machines used in the wood splitting and processing process, the

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circular saw, tenoners and jointers, are the main causes behind accidents resulting in permanent injuries such as finger and hand amputations (Pignati; Machado, 2005). The states of São Paulo, Santa Catarina, Paraná, and Rio Grande do Sul account for 77% of these accidents, due to the concentration of the sector's industry in this region. A study conducted by the Health Department of the State of Paraná shows that the wood industry has the highest number of accidents involving amputations, with the circular saw accounting for 15% of all recorded amputations (Araújo; Salgado, 2002). Also, Lacerda (2007) mentions that lack of attention or haste in carrying out work, incorrect execution of procedures and an unsafe working environment are the main causes of accidents in the mechanical wood conversion industry.

The aim of this study was to present a compilation of the data presented in the literature about the main risks in sawmills, regulatory standards in Brazil, the construction of a safety system, and the safety devices to be used.

2. Regulatory Standards Applied to Sawmills

In this context, regulatory standards (NR) play a crucial role in preventing accidents in sawmills and wood processing plants. For this type of wood processing activity, special emphasis is given to NR-6 and NR-12.

NR-6, as classified by the Ordinance of the Secretariat of Labor Inspection No. 787, of November 29, 2018, regulates the execution of work using Personal Protective Equipment (PPE), without being restricted to specific sectors or economic activities. PPE is considered any device or product for individual use by the worker, intended to protect against risks that may threaten safety and health at work. In the wood industry, PPEs do not prevent accidents but can prevent injuries or mitigate their severity, protecting the worker's body from the aggressiveness of substances with toxic, allergenic, or other characteristics that can cause occupational diseases (Mendoza; Borges, 2016). The main PPE used in sawmills and wood processing are (Figure 1):

- Mask: Prevents inhalation of dust, suspended sawdust particles, and toxic particles through the respiratory system. There are two types: maintenance-free (disposable) and low-maintenance, which have special filters for replacement;
- Transparent face shield: Protects the eyes and face from possible splashes during handling;
- Gloves: Protect the worker's hands. Especially in sawmills, they should be resistant to protect hands from possible cuts;
- Transparent glasses: Protect the eye area from dust, sawdust, and airborne particles;
- Ear protection: Protects the ears from noise from equipment, common in sawmills;
- Apron: Made of material resistant to organic solvents and possible cuts;
- Boots: Should be waterproof, preferably high top, and resistant to organic solvents and possible falls of cutting or piercing objects.

NR-12 proposes preventive measures for safety and occupational hygiene to be adopted by companies in relation to the installation, operation, and maintenance of machines and equipment, aiming to prevent workplace accidents.

This normative is one of the most extensive and was created by Ordinance No. 3,214, dated 06/08/1978 of the Ministry of Labor, being modified sometimes through other ordinances. It aims to ensure that machines and equipment are safe for workers to use. In ensuring this safety, NR-12 requires complete information about the entire life cycle of machines and equipment, including transportation, installation, use, maintenance, and disposal at the end of their useful life. In summary, NR-12 aims to ensure worker safety; improve working conditions for machines and equipment for general use; and ensure inherently safe machines and equipment.

The Observatory of Safety and Health at Work (2019) reports that machines and equipment were the leading causes of workplace accidents in Brazil from 2012 to 2018.

3. Hazards Caused by Machines in Sawmills

To better choose which safety measures will be adopted for each machine, it is first necessary to evaluate the risks it poses to the worker, which can be divided into various categories as described by Franceschi (2004). In a sawmill, a machine can cause various harms to humans, such as:

- Mechanical Hazard: risk factors that can cause some type of injury to the worker due to mechanical activity, usually involving machines, tools, parts, or projections of materials. The most basic forms of mechanical risk are crushing hazard, shear cutting, amputation, shock, and perforation;

- Electrical Hazard: electrical shocks can cause injuries such as burns and even death. They can be caused by direct contact or proximity to frequently energized

Figure 1. Examples of personal protective equipment (PPE) used in sawmills and wood processing. Adapted from Brasil (2011).

parts, usually with high voltage or by contact with accidentally energized parts due to insulation defect;

- Thermal Hazard: can cause burns due to contact with materials at high temperatures, flames, or explosions;

- Noise-Induced Hazard: noise can cause permanent hearing damage, ringing in the ears, fatigue, effects such as disturbance in balance, decreased concentration ability, among other consequences;

- Vibration-Induced Hazards: vibrations can pass throughout the body, mainly hands and arms. The more intense or with lower intensity but with a long exposure period, they can cause vascular and neurological disturbances;

- Hazards caused by materials and substances: materials and substances processed by machines can pose various dangers, such as hazards resulting from contact or inhalation of fluids, gases, mists, and others that have harmful effects on humans; fire and explosion hazards; biological and microbiological hazards;

- Hazards caused by disregarding ergonomic principles: can cause physiological effects, such as faulty postures and excessive or repetitive efforts, psychophysiological effects, like over or under psychic load and stress and human errors.

When assessing risk, one should consider the most serious injury or health damage that can result from each identified hazardous phenomenon, even if the probability of such injury or damage occurring is not high (Bahls, 2013).

4. Work Safety in Sawmills

Inappropriate machining conditions, lack of protection for moving parts of the machine, precarious state of sharpening, lack of training, and absence of safety devices in case of any issues are some of the risks that can put the integrity and safety of the operator, making them more prone to accidents (Souza, 2004).

To resolve such risks, all sawmills must have action plans to ensure full compliance with their activities under the NRs. Among the most important adjustment actions, can be mentioned protection of moving parts of equipment; demarcation of danger zones; adoption of safety devices for start-ups, shutdowns, and emergency stops (Figure 2); floor cleaning; and operator training before taking on the role or retraining when significant changes occur in the facilities and machine operation (Hegedus et al., 2011).

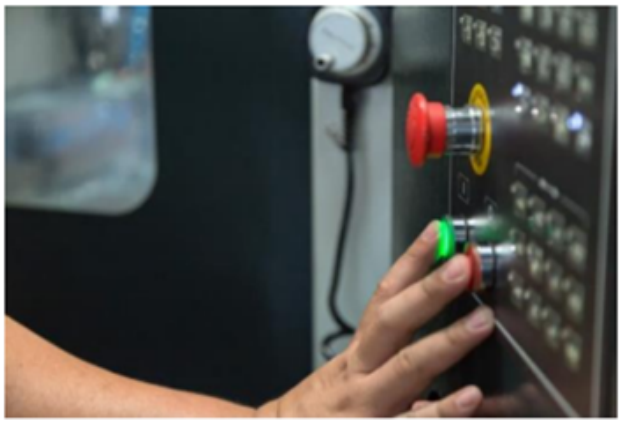

Figure 2. Example of a safety devices for start-ups, shutdowns, and emergency stops. Adapted from Brasil (2022).

5. Risk assessment

Risk assessment helps designers and safety engineers establish measures that achieve the highest possible level of safety. Bahls (2013) mentions some basic

Figure 3. Examples of signs present in sawmills. Adapted from Brasil (2022).

steps that should be considered for the construction of an efficient machine safety system in sawmills, such as:

- Specify machine limits: determine the machine's use, performance, space limits, movement variations, required installation space, and lifespan.

- Identify hazards and risk access: consider everything about the machine, like transport, installation, normal use, misuse, and maintenance, to identify risks. The degree of damage caused and the probability of occurrence should also be documented.

- Reduce hazards and risk limits as much as possible: this can be done by removing hazard points, such as crushing, cutting, and piercing, reducing the force and speed at which the operator works with the machine, among other safety principles.

- Design safety devices against remaining risks: where components that pose risks cannot be removed, protective devices should be designed. These can include interlocking guards, two-hand controls, position sensors, among others.

- Inform the worker about any risks present in the machine: this can be done through signs, symbols, warning signs, etc (Figure 3).

- Consider any other precautions: the designer must determine what other procedures are necessary in emergencies.

6. Safety devices used in sawmills

There are several machine protection methods that help reduce accidents. When choosing the most suitable method, some criteria should be considered, such as the machine's use, the nature and frequency of access to it, the hazards it may pose, and the probability and severity of the injury it can cause. Additionally, factors like materials to be used, worker activities, site layout, among others, should be taken into account.

To minimize accidents, both the protections and the machines should be designed to allow tasks such as maintenance and lubrication to be performed without the need to remove the protections.

Worker involvement during the design and implementation phases of safety systems can ensure that protective devices are correctly used. Operator training should include the risks posed by each machine, the protections that must be used, how the protections work, when and by whom they can be removed, and what to do when a protection no longer ensures the safety of the worker and the machine. In addition to safety measures, safe work practices, such as training, safe work procedures and inspections should be adopted, which are the responsibility of machine users and companies (Hegedus et al., 2011).

It is important that safety measures are easy to use and do not hinder the normal operation of the machine; otherwise, they may be disregarded for better machine utilization. The protective equipment of a machine must meet certain prerequisites to ensure safety, including preventing contact, high durability, protection against contact with foreign objects, avoiding hazardous situations, and not interfering with work.

The protections can be divided, according to NR-12, into 4 general classifications: barriers or screens for protection, safety devices, isolation or separation by a safety distance, and other auxiliary protection mechanisms (Menegon; Rodrigues, 2019).

6.1 Barriers or screens for protection

They can be divided into physical protection, movable protection, adjustable protection, interlocking protection, and interlocking protection with a locking device (Figure 4).

Physical protection is one that is always kept in its original position and does not depend on moving parts to perform its function. It can be permanently fixed, welded to the machine, or secured by fastening elements such

Figure 4. Safeguarding work at height in the sawmill installed at UNESP Itapeva. Source: the authors.

as nails and screws. It can be divided into enclosure protection, which prevents the operator from coming into contact with the machine from all sides, and distant protection, which does not completely cover the risk area but reduces worker access.

The movable protection is fixed to the machine or an adjacent fastening element and can be opened without the use of tools. It can be divided into energy-activated protection, where energy is supplied by means other than human or gravity; self-closing protection, where the protection is opened by a machine component, the workpiece, or a part of the machining device, allowing only the workpiece in operation to pass through. Automatically, the protection returns to its resting position, due to the action of gravity or spring, once the workpiece has passed through the opening, and command protection, where the protection is linked to an interlocking device, and the machine parts covered by the protection do not operate if the device is open, only resuming operation when the protection is closed.

The adjustable protection is a fixed or movable protector that is adjustable as a whole and contains adjustable parts. The adjustment remains unchanged during a specific operation, allowing work with various sizes of materials.

In interlocking protection, the machine parts covered by the guard do not operate until the protective device is closed. When the guard is opened or removed, the machine stops functioning. The machine should not resume operation until the safety device is closed, and the machine is restarted. In other words, simply closing the guard does not restart the machine; it only allows it to resume operation.

In interlocking protection with locking device, the machine parts covered by the guard do not operate until the protective device is closed and locked. Closing and locking the guard does not start the machine operation; it only allows it to operate.

6.2 Safety devices

They can be divided into position sensor devices and safety control devices.

Position sensor devices are devices that stop the operation of a machine when a worker enters the danger zone. They can be classified as photoelectric, radiofrequency presence by capacitor, electromechanical sensor, and drag restriction devices.

In the photoelectric device, light beams are placed near the hazard areas, and when interrupted by the presence of a person, the machine stops functioning. It is important to note that these devices are only effective when machines can be stopped before the operator reaches the danger zone.

In the radiofrequency presence by capacitor device, electromagnetic wave beams are part of the machine, and when interrupted, they cause it to stop operating. Like photoelectric devices, these devices should be used in cases where the machine can stop before the worker accesses the danger zone.

In the electromechanical sensor device, before allowing operation, a probe or a contact bar tries to position itself at a predetermined distance from the machine, scanning the area. If there is something or some object preventing the device from positioning, the machine will not function.

The drag restriction device uses cables attached to the hands or wrist of the worker. When the machine starts operating, a mechanical system automatically pulls the operator's hands away from the danger zone. It is criticized for literally tethering the worker to the machine, also limiting some movements.

Safety control devices are manually activated. According to NR-12, machines and equipment must have activation and stop devices located so that they can be operated or turned off by the operator in their working position, not located in the hazardous zone of the machine or equipment, can be operated or turned off in case of emergency by someone other than the operator, cannot

be operated or turned off involuntarily by the operator or in any other accidental way, and does not pose additional risks.

They can be impact safety control devices, pressure bars, disengagement rod type, safety cables, two-hand controls or doors. Impact safety control devices are quick means to deactivate a machine in an emergency. Ropes and impact bars can be used for this. Pressure bars are devices that, when pressed, activate the system that stops the machine. It is important that the device stops the machine before any part of it reaches the danger area.

Disengagement rod-type safety devices, when tightened by hand, stop the machine's operation. It should be easily accessible so that the operator can activate it in an emergency. Safety cables stop the machine when activated by the operator. They are installed near the machine's danger zone and must be designed so that the worker can activate them with either hand.

In two-hand controls, for the machine to operate, both hands of the operator must be pressing the devices. The worker can only release them when the machine's risk movement is finished. Doors are types of movable barriers that protect the operator during the machine's operation. They must be closed for the machine to start operating. Another common application for doors is delimiting safety areas.

6.3 Isolation or separation by a safety distance

The machine and its dangerous parts must be kept out of reach of the worker during its operation. Some examples of how this can be achieved include fences that prevent worker access, protective walls, or even designing the machine so that its dangerous parts are at a height that the worker cannot reach.

According to NR-12, circulation areas and spaces around machines and equipment must be dimensioned so that materials, workers, and mechanized transporters can move safely. Circulation paths must be properly marked and permanently kept unobstructed.

Many methods of material extraction and feeding can pose risks to workers. These methods are divided into four categories.

In automatic feeding, the worker is exposed to fewer risks as they program the machine and wait for it to operate. In semi-automatic feeding, the operator uses mechanisms to feed the machine and does not need to access the risk area. Some semi-automatic feeding mechanisms include rotary or tilting drum, drawer, and turntable.

In automatic extraction, devices such as compressed air and mechanical apparatus can be used to remove material from a machine. It is also common to use controls that prevent the machine from operating until the extraction is completed. In semi-automatic extraction, similar to semi-automatic feeding, devices can be used to prevent the worker from coming into contact with the machine's hazard zone.

6.4 Other auxiliary protection mechanisms

Other mechanisms that can be used in occupational safety are devices that can be opened or moved during machine operation and provide protection from hazards when used in the appropriate location, such as warning barriers and manual tools. The aim is to provide the worker with an additional margin of safety.

Warning barriers identify the risks, consequences, and precautions that must be taken to avoid accidents. Warning signs should be written in the language of the country. Warnings should be clear, concise, visible, legible, and placed near the danger area or in a location where the worker will be when reminded of the danger. Warnings may include figures to facilitate understanding and should use the correct word to identify the intensity of the danger.

"DANGER" represents an imminent risk that will result in severe injury to a person or even death. "CAUTION" means risks or unsafe practices that could result in severe physical injury or death, and "WARNING" represents risks or unsafe practices that would result in minor injury to a person or damage to equipment.

Manual tools are safety complements that help workers handle materials that will be processed by machines. Some examples of these tools include tweezers, pliers, and hooks.

In conclusion, it is important to emphasize that sometimes the use of a combination of different protection devices listed above may be convenient.

In addition to the presented safety devices, the importance of maintaining the equipment used in the production system should be highlighted. Maintenance can be corrective, where the machine is allowed to fail before any decision is made about maintenance; this is the most expensive maintenance method.

Preventive maintenance is based on the scheduled maintenance of machines and equipment. It assumes that machines degrade over time, and there is a prediction for the right time to perform maintenance before the machine develops a problem. Predictive maintenance is a preventive maintenance program based not only on the life span of machines but also on regular monitoring of the mechanical, electronic, pneumatic, hydraulic, and electrical conditions of the machines, as well as the performance of these equipment in the production process, determining the average time to failure or reduced performance of the equipment. Predictive maintenance

improves process quality, reduces maintenance costs, and extends the life of equipment.

7. Conclusion

In light of all the above and considering circular saws, tenoners, and jointers as the main causes of accidents, the following observations are made.

For circular saws, the risk exists when basic protections for the operator are not in place, such as a splitter that prevents wood kickback and a hood or guard that reduces the possibility of body parts being exposed to the blade. Additionally, there may be devices for pushing the wood piece, aiming to keep hands away from the saw teeth as the operation approaches its end. Furthermore, the use of the previously mentioned PPEs is essential.

In tenoners and jointers, the greatest risk is the cutting tools contact with body parts, such as hands and fingers, which can cause crushing or amputation. The most recommended protection is a cover for the part of the tool holder not covered by the work piece, manually adjustable according to the dimensions of the piece being worked, or self-retractable. The tool holder should also be protected in its section behind the guide. The use of pushers and PPEs are also beneficial as a preventive measure against accidents.

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