Master in Occupational Safety and Hygiene Engineering

INTEGRATED RISK MANAGEMENT METHOD (IRMM) IN THE FORESTRY SECTOR

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HIGHLIGHTS

1. Relevant and current information that features the forestry industry sector prominently.
2. The proposed occupational risk matrix contemplates all the processes in the production cycle of the forestry industry.
3. The risk assessment of the identified occupational risks was assessed using three different and well-established methods.

ABSTRACT

Introduction – The global market for wood usage is increasing and forestry is still recognized as one of the most dangerous activities in the world. In some European countries, as many as one out of every eight workers is involved in an accident each year. Companies have evolved technologically through the introduction of mechanized equipment, which increased productivity and lowered accident rates. However, this mechanization is not always possible in every aspect of production, and it has also introduced new accident risks. The adopted solutions used in harvesting vary widely from case to case making it a demanding sector to tackle from an Occupational Health and Safety perspective but also a crucial one.

Objective – Through the systematic review and characterization of the production cycle of the harvesting process in the forestry industry, this work aims to develop a risk assessment matrix where all the identified sub-processes are matched with examples allowing hazards, accident risks and triggering events to be described. Based on this information the risks are then evaluated through three different methods, the NTP330, the William T. Fine (WTF) and the Integrated Risk Management Method (IRMM).

Methodology – The systematic review was conducted according to PRISMA guidelines in four online databases: SCOPUS, Web of Science, INSPEC and Dimensions. Four groups of keywords were used to achieve an adequate number of records, which were related to both the forestry work and the occupational risk. Additionally, several articles were found through researching citations of the previously obtained articles. The approach used to achieve the occupational risk assessment in this research is based on the principles given by ISO 3100:2018 and the necessary steps that must be taken to obtain sufficient and complying data to this standard. This data was then inserted into the three chosen occupational risk-evaluating methods.

Results - This dissertation resulted in the construction of an occupational accident risk matrix containing the analyses of 87 selected examples in different stages of the production cycle in the forestry industry. Then, the three methods were applied to the matrix and the occupational risk was assessed.

Conclusions - The risk matrix constructed in this work is an important tool, which can be adapted for individual use. A comprehensive view of the contemplated occupational accident risks in the forestry industry also allows for the identification of the most frequent urgent and critical sub-processes. It is concluded that the IRMM provides the most balanced and promising results out of the three used methods, but future work on adapting this method to the context of the forest industry while taking into account all of the existing sub-processes will produce more accurate occupational accident risk evaluations is needed.

Keywords– Risk Assessment, Occupational Risk, Occupational Accident, Forestry

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LIST OF ABBREVIATIONS

FAO - Food and Agriculture Organization of the United Nations
FTE - Full-Time Equivalents
IBA - Brazilian Tree Industry
IRMM - Integrated Risk Management Method
ISO - International organization for standardization
NM - Not mentioned
NR - Regulatory Norm
OHS - Occupational Health and Safety
OWAS - Ovako Working Posture Assessment System
PRISMA - Preferred Reporting Items for Systematic Reviews and Meta-Analyses
REBA - Rapid Entire Body Assessment
RULA - Rapid Upper Limb Assessment
OA - Occupational accident
U.S. - United States
RI – Risk index
PPE - Personal Protective Equipment

PART 1

Base Knowledge

1 INTRODUCTION

1.1 Overview

Wood usage is increasing worldwide due to its renewability as a resource and its versatility as a material. This consumer demand funnels down to all wood related industries to increase their production (Júnior & Colodette, 2013). According to the Food and Agriculture Organization of the United Nations (FAO), the world production of roundwood, which is all wood felled or otherwise harvested and removed, has been and can be predicted to continue rising in the future (Figure 1).

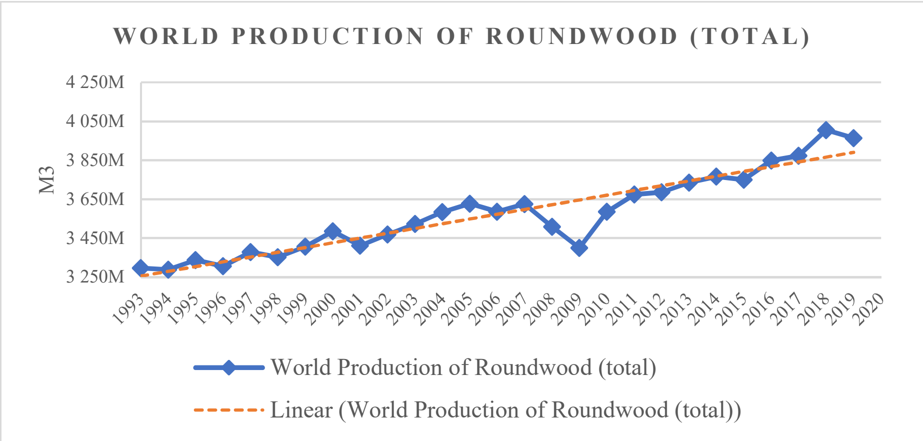

Figure 1 - World Production of Roundwood (Total) – FAO (2020) [1]

Therefore, it is safe to say that forestry industry companies worldwide will continue growing their production and consequently their socioeconomic impact.

Naturally, there are countries where this industry plays a more significant role than others. In Figure 2, it is possible to see the countries that lead the total Roundwood production in the world. [1]

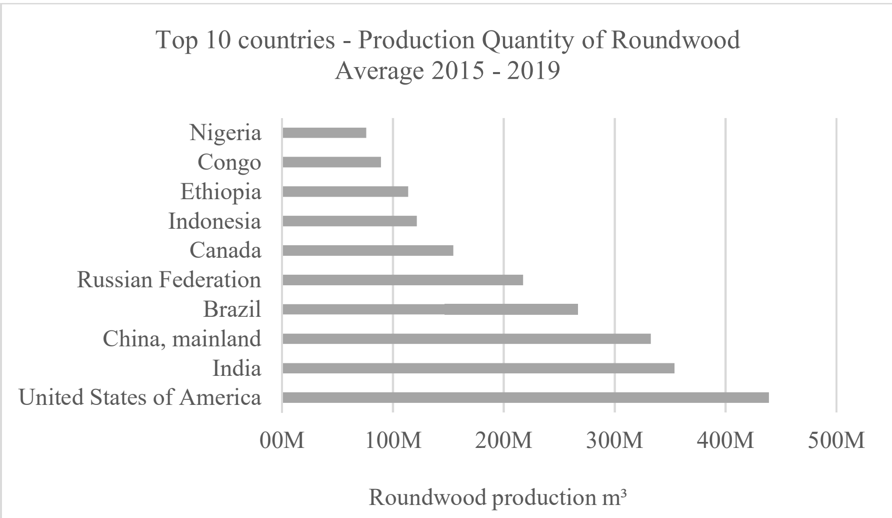

Figure 2 - Top 10 countries - Production Quantity Roundwood, Average 2015 to 2019 – (FAO 2020)1

[1] http://www.fao.org/faostat/en/#data/FO/visualize (accessed on 10/12/2020)

The total production of roundwood can be divided into two major groups, “industrial roundwood” and “wood fuel”. Wood fuel is used for energy production and Industrial wood covers all the other industries that further process this material (FAO Forestry Department, 2019). These weigh differently in the economy on a country-by-country basis. In the United States and Russia, their production tends heavily towards industrial purposes. India, on the contrary, dedicates its production to wood fuel for the most part, while both China and Brazil present an evenly spread percentage between both categories.

The source of the wood is also essential for the characterization of the sector. It can originate from “natural forests,” “non-forests” or “planted forests”. Planted forests are increasingly important for the sustainable growth of the forestry industry. In 2012, the percentage of wood sourced from planted forests ranged between one-third to half of the world’s total production volume. The United States and Brazil were found to be the biggest producers of industrial roundwood from these plantations (Jürgensen et al., 2014).

Taking Brazil as an example, according to the Brazilian Tree Industry Association (IBA), gross revenues in the planted tree industry in 2019 reached R$ 97.4 billion. They had a growth of 12.6% over the previous year. In 2019, the total area of planted trees totalled 9.0 million hectares, representing a 2.4% increase over 2018. The forest-based sector plans to invest around R$ 20 billion applied to expansion projects in recent years and another R$ 35.5 billion planned through 2023 for new units and expansions, which will generate 36,000 new jobs and opportunities for an estimate of 3,75 million Brazilians (IBA, 2020).

This fast-paced growth brings with it not only economic opportunities but also associated challenges, such as, Environmental Management and Occupational Health and Safety (OHS) Management (Lima et al., 2020).

1.2 Theoretical framework - The importance of OHS assessment

The forestry industry is an old industry that has changed and evolved rapidly in a heterogeneous form throughout the world. This modernization was mainly due to the introduction of mechanization in some processes, which resulted in the reduction or elimination of some occupational risks but also in the creation or even amplification of others. Therefore, the forestry industry is still broadly regarded as a dangerous activity to the Health and Safety of its workers. All countries that provide relevant statistical data report that the forestry industry has a higher occupational accident (OA) rate than most other industries, and that the registered occupational accidents (OAs) are often severe and, in some cases, fatal (Drewiske & Kalcec, 2020; Kim et al., 2017; Nkomo et al., 2018; Özden et al., 2011; Rosecrance et al., 2017).

According to the United States (U.S.) Bureau of Labor Statistics, the national rate of nonfatal occupational injuries or illnesses resulting in days away from work or job restrictions in 2019 was 1,6 workers per 100,000 full-time equivalents (FTE), while the forestry and logging industry had 2,4 workers per 100,000 FTE.

In terms of fatal occupational injuries, the U.S. Bureau of Labor Statistics reports a rate of 47,6 per 100,000 FTE for logging in 2019, which is much higher than the 3,5 per 100,000 FTE figure derived from the total number of hours worked for all industrial activities.[2,3]

In Europe, some countries reported that one in eight workers experience an accident every year and others reported a much lower number, one in two hundred. The difference is speculated to come from inconsistent methods of collecting and reporting data and, of course, from the different characteristics of the operations (ILO, 2019) Unfortunately, this is no surprise to anyone familiarized with the

[2] https://www.bls.gov/iif/oshsum.htm#14Summary_News_Release (accessed on 01/08/2021)

[3] https://www.bls.gov/iif/oshwc/cfoi/cfoi_rates_2019hb.xlsx (accessed on 01/08/2021)

forestry industry. Although OAs are mostly under-reported and unfitting for data aggregation, the current available information corroborates that forestry work is one of the most dangerous non-military activities(Garland, 2018).
The type of risks to which workers are exposed to is interconnected with the adopted logging system and regional characteristics where the forestry industry is located. There are almost limitless different equipment configurations that adapt to the company´s resources as well as environmental challenges and they range between manual to fully mechanized systems(Lagerstrom, Magzamen, Brazile, et al., 2019)
Traditional motor-manual configurations with the predominant use of the chainsaw are typically used in areas with steep and sinuous terrain where fully mechanized alternatives are not possible to be implemented. (Rosecrance et al., 2017)
Mechanized configurations have been preferred wherever possible due to their ability to increase productivity while lowering the risk of an occupational accident (OA) occurring to the operator. Countries such as Brazil, New Zealand, Canada and the United States reduced the accident frequencies following the introduction of more mechanized means, and although this may be true it does not mean that mechanized logging is not hazardous (ILO, 2019).
New and unique occupational risks have emerged with the use of these equipment. Machines pose a threat themselves thus introducing new risks and new variables to be considered in OAs characterization (Bonauto et al., 2019; Jankovský, Allman, & Allmanová, 2019a; Kim et al., 2017; Lagerstrom, Magzamen, Kines, et al., 2019; Laschi et al., 2016; Zimbelman et al., 2017).
In this context, measures have been taken internationally to mitigate the occupational risks inherent to the forestry activity and through the implementation of OHS standards, companies were led to actively reduce their workers exposure to occupational risks. However, as these measures are considered insufficient, more research and studies are greatly needed (Lima et al., 2020).
The existing methodologies can be divided into three groups: quantitative, qualitative, and semi-quantitative.

- Quantitative studies represent over half of the identified risk evaluation methods in Marhavillas et al. (2011). The quantification of all risk elements is complex and come at the expense of great amounts of time and resources. Some quantitative methods also require extensive data bases.
- Qualitative studies come in second with almost one third of the cases (Marhavilas et al., 2011). They present a simpler approach but are subjective by nature and are dependent on the experience of the person performing the study. Considering they identify the Severity and Probability, they are employed as a first screening procedure to identify hazards and risks, or when quantification is not justifiable (Castelo Branco, 2018).
- Semi-quantitative methods are the minority within the three groups identified in Marhavillas et al. (2011). They quantify the risk elements through the aid of matrixes, usually easy to apply and without the requirement of an exact outcome on the consequences. The downside of these methods is also the experience of whoever applies these methods resulting in conflicting outcomes.

2 STATE OF THE ART

2.1 Legal Framework

The international market has become more judicious concerning legislative compliance and the trade of raw materials benefits if conducted under the wing of a forest certification scheme, such as FSC (Forest Stewardship Council) or PEFC (Programme for the Endorsement of Forest Certification). Among other environmental and social requirements, these certification schemes also demand compliance to OHS management standards such as the ILO Code of Practice on Safety and Health in Forestry Work (FSC, 2015; Lima et al., 2020; Soranso et al., 2019).

International risk management principles and guidelines are provided by ISO 3100:2018. Here, fundamental standards are established and a globally recognized framework for managing processes in all forms of risks in any company, regardless of size. The ISO 31010:2019 takes the principles given on ISO 3100:2018 and provides compatible risk assessment and management techniques.

Also noteworthy, and widely adopted by countries throughout the world, is the ISO 45001:2018. This standard replaces the former world reference OHSAS 18001 and offers practical solutions to companies in order to improve the health and safety of their workers as well as a continued effort on controlling the risks and opportunities consequent of their activities.

2.2 Scientific Framework

A bibliographic research was carried out with the objective of identifying methods for occupational risk evaluation applied to the forestry sector. The systematic review was done based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Page et al., 2021). To conduct systematic evaluations and meta-analyses, this methodology defines a set of parameters to be followed.

2.2.1 Search strategy

The research was conducted in four online databases: SCOPUS, Web of Science, INSPEC and Dimensions. Four groups of keywords were combined 1) "forestry" AND "risk assessment" AND "safety", 2) "forestry" AND "occupational risk", 3) "logging" AND "occupational" AND "risk", 4) "forestry sector" AND "health" AND "risk". The keywords were chosen through a careful selection of terms that are usually used in scientific papers and articles where the forestry industry is the main theme and “Risk” is our common denominator in the four groups. Each group has a different reasoning for the keywords combination that incorporate them but, overall, it can be said that a balance between broader scope keyword(s) combined with more focused or specific keyword(s) was attained through trial and error until satisfactory results were achieved.

2.2.2 Selection process

The research resulted in 1012 records. From here, the following exclusion criteria were applied:

1. Date - Documents dating back a maximum of 5 years (2015-2020);
2. Document type - Articles and Articles in press;
3. Source type - Journals, trade publications (whenever possible to ascertain);
4. Language - English;
5. On topic - Quick analysis of the keywords, abstract and introduction when needed.

From this screening, 885 records were rejected, leaving 127 articles for full reading and further analysis (Table 1).

Table 1 - PRISMA research summary, partial and total results

Data base	Keywords combination				TOTAL
	1)	2)	3)	4)	
SCOPUS	7	28	22	5	62
Web of Science	7	9	10	2	28
INSPEC	1	0	4	2	7
Dimensions	4	9	14	3	30
TOTAL	19	46	50	12	127

At this point, all of the selected articles were exported from the respective databases in BibTeX files, which were then imported to Mendeley[4]. Mendeley is a reference manager software which is used to aid the collection of files from different databases into the same library and generating bibliographies. The software located 63 replicas, leaving 64 articles for full reading. The inclusion criteria used during reading were the following:

i. Forestry Industry context;
ii. Identification of occupational risks or description of occupational risk assessment and evaluation.

The results of this last selection process allowed the elimination of 36 articles and the dismissal of 4 because the full article could not be obtained. The remainder 24 were included in this literature review. The flow diagram of the collection of records according to PRISMA statements is presented in Figure 3.
Furthermore, additional relevant articles were searched while maintaining the same exclusion criteria, thanks to extensive reading and research of the citations of the articles found using the PRISMA statement. This is a method also known as "snowballing" (Wohlin, 2014). A total of 12 articles were collected through this method and added to the literature review. These are mentioned in the box of additional records identified through other sources in the flow diagram presented in Figure 3.

2.2.3 Literature analysis

A table was created from the 36 articles that were found to be relevant to the overall understanding of the subject under study and to support the analysis and conclusions made in this chapter. Appendix 1 contains the summarized review table, and the appendix 2 contains the full table.

A primary analysis was made concerning the articles geographical provenance. According to the graphic presented on Figure 4, it is possible to observe that the majority of the collected articles came from the United States of America (USA), ten, followed by Italy with five. Also noteworthy is the combined number of articles that came from European countries (Croatia, Moldavia, Italy, Romania, Serbia, Slovenia, Slovakia), totalling 14 articles.

[4] https://www.mendeley.com/reference-management/reference-manager/ (accessed on 07/01/2020)

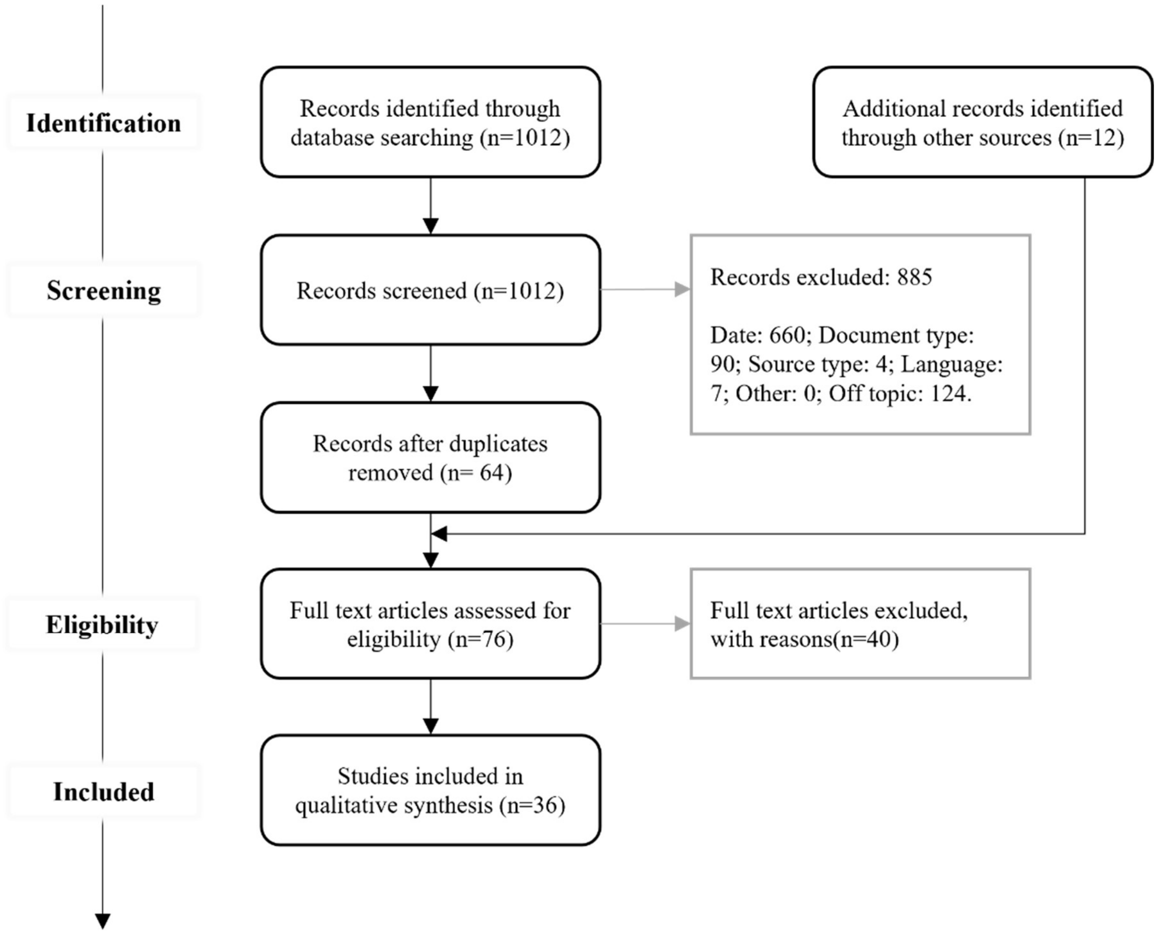

Figure 3 – Systematic review flow diagram according to PRISMA 2009

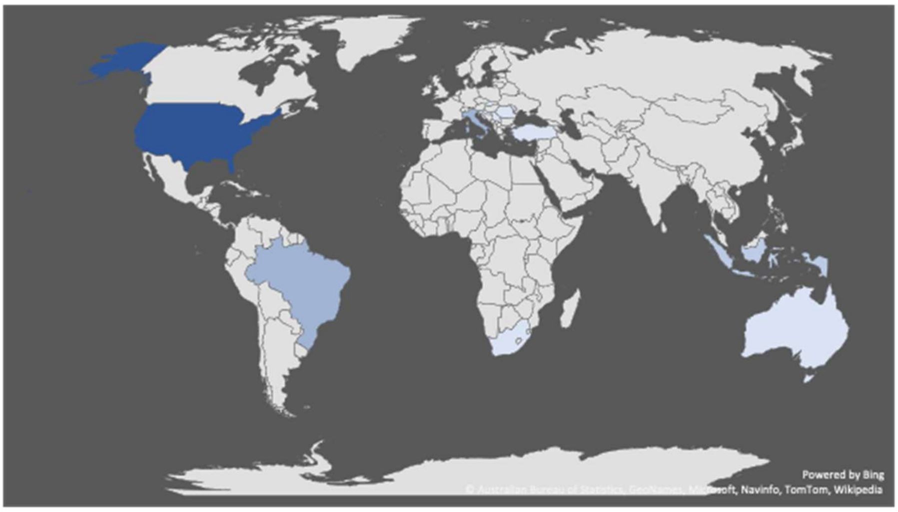

Figure 4 - Geographical distribution of the selected articles

Data collection method

In the inspected papers for this dissertation, two types of methodologies for data collection were identified: qualitative (≈40%) and quantitative (≈60%). Table 2 specifies this subject in more detail. The fact that some articles mentioned both quantitative and qualitative methods in their research justifies the overlapping and the resulting sum to be higher than the total number of collected articles.

Table 2 - Data collection type/method

Qualitative methods	
Interviews/meetings/questionnaires	13
Observation / technical visits	9
Quantitative methods	
Surveys	6
Data base, injury/accident reports	9
Other quantitative methods (OWAS REBA RULA methods, exposure to heat, noise, vibration, particulates in the air, heart rate monitoring, and physical workload)	14

Considering the methodology used for data collection, interviews, meetings, and questionnaires make excellent tools for open-ended questions on studies such as investigation of good practices, workers perception of hazards, and injury prevention. These studies are subjective by nature and usually lack the population size or enough data to back up or refute their allegations. Future investigations on these works are of great importance to ascertain their applicability to other unbiased populations, namely other companies, or other countries (Conway et al., 2017; Kim et al., 2017; Lagerstrom, Magzamen, Brazile, et al., 2019; Lima et al., 2020; Nkomo et al., 2018; Rodriguez et al., 2019; Rosecrance et al., 2017; Yovi & Nurrochmat, 2018; Yovi & Yamad, 2019).

Observation and technical visits were found in articles which are more focused on the risk assessment and overall OHS conditions (Lima et al., 2020; Menegon Bristot et al., 2019; Soranso et al., 2019; Yovi & Yamad, 2019; Yovi & Yamada, 2015).

The surveys found in the articles focused on the characterization of the non-random population under study and were usually complemented with interviews or questionnaires to answer a question which was introduced to that population (Conway et al., 2017; Lagerstrom, Magzamen, Kines, et al., 2019; Melemez, 2015; Newman et al., 2018; Rodriguez et al., 2019).

With nine articles, the mentioned data bases contain injury reports or accident reports which enabled a statistical hypothesis supporting the authors to draw some conclusions concerning the scope of their analysis. Some of the difficulties encountered in these articles were shared among the majority of the authors. The lack of rigor and detail in said injury/accident reports, or that forestry, is grouped together with agriculture injury/accident, which is an activity with a completely different set of characteristics. Therefore, a call for an improvement in the reporting system is concluded. Most of these articles failed to provide an exact number for the population under study (Bonauto et al., 2019; Danilović et al., 2016; Garland et al., 2019; Ghaffariyan, 2016; Iftime et al., 2020; Jankovský, Allman, & Allmanová, 2019b; Jankovský, Allman, Allmanová, et al., 2019; Laschi et al., 2016; Nkomo et al., 2018).

The quantitative studies tend to funnel their scope on a specific problem, namely on postural studies for machine operators under the Ovako Working Posture Analyzing System (OWAS), the Rapid Upper Limb Assessment (RULA) and the Rapid Entire Body Assessment (REBA). (Cheţa et al., 2018; Corella Justavino et al., 2015; Enez & Nalbantoğlu, 2019; Landekic et al., 2019; Micheletti

Cremasco et al., 2019; Spinelli et al., 2017; Yovi & Prajawati, 2015) and the rest considered risks such as, exposure to heat, noise, vibration, particulates in the air, heart rate monitoring and physical workload (Cheţa et al., 2018; Eroglu et al., 2015; Fonseca et al., 2015; Iftime et al., n.d.; Marchi et al., 2017; Poje et al., 2016, 2019; Soranso et al., 2019).

However, none of the described methods, nor any of the reviewed articles, were capable of making a complete risk assessment for the entire productive process of the forestry industry.

How does occupational risk occur in the forestry industry?

The collected articles were also examined with the question in mind "how does occupational risk occur?". Two main aspects must be identified: firstly, the hazard to which workers may be exposed to and secondly, the task, the operation or the procedure that will endanger the worker to the mentioned hazard (Garland et al., 2019).

The key hazards that were found are shown in Figure 5. It is possible to see that, chainsaw, logs, unspecified logging machinery and trucks, in this order, have a considerable lead over the other identified hazards. Unspecified logging machinery refers to an assortment of mechanized machines used for felling and processing trees.

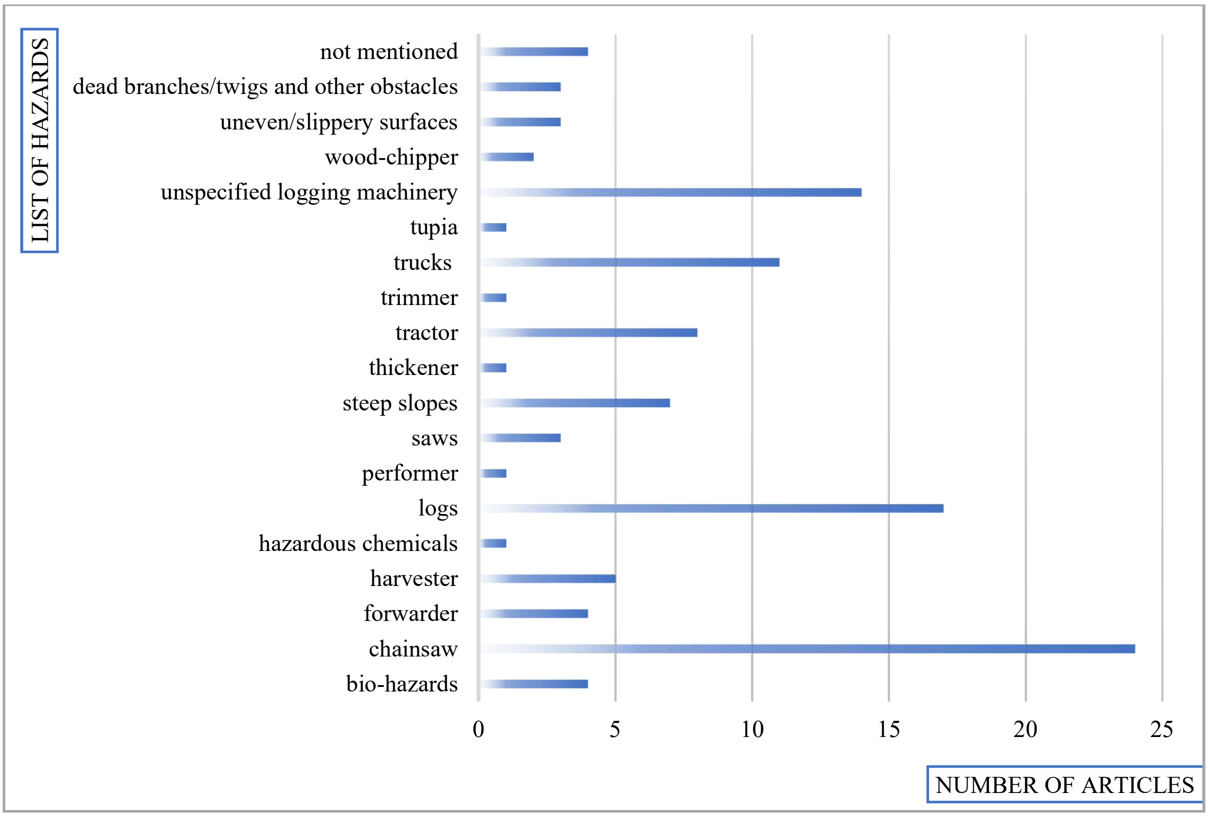

Figure 5 - Identified hazards in the literature review

The operations or procedures identified by the authors of the literature review give us an overview of what aspects of the forestry industry are currently being studied and are given more relevance by the scientific community. A chart was compiled with a general description of the tasks referred the most when talking about the workers exposure to hazards (Figure 6). The results show that chainsaw operations, tree felling and cutting, wood loading and transport, skidding, operation of an unspecified machine, and driving short haul vehicles are the most frequently mentioned tasks. This information is quite interesting because it reveals that not only these tasks require and match the equipment previously identified as hazardous but also because it highlights the vital parts of the wood logging process, felling, skidding, processing, and transporting (Lima et al., 2020).

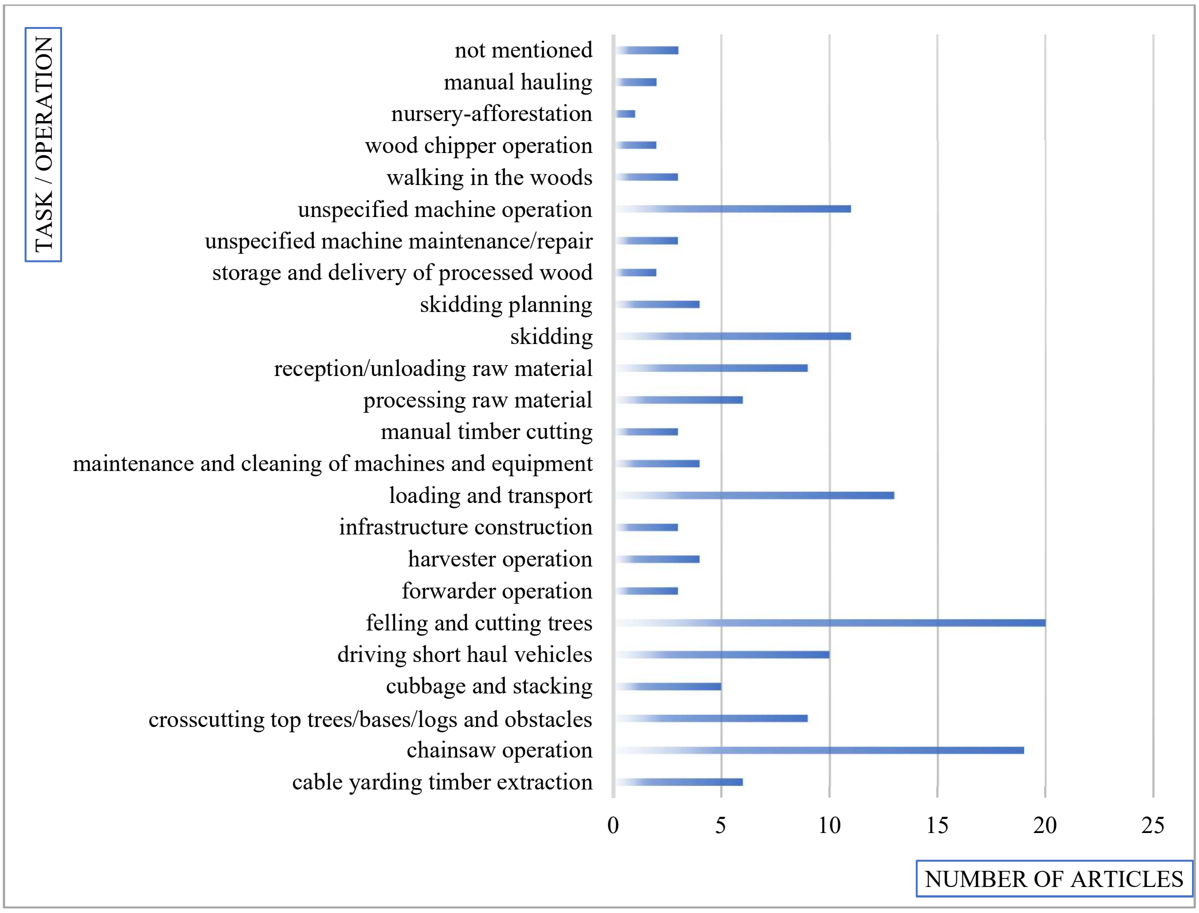

Figure 6 - Tasks identified in the literature review

An occupational risk is considered a result from the possibility of an undesired event coming to fruition with undesirable consequences that vary in severity.

It is important to make a distinction between the types of occupational risks. In this dissertation three different categories of occupational risks were identified: occupational disease risks, occupational accident risks, and occupational psychosocial risks.

An occupational disease is defined by the consequence of contracting a disease due to exposure during work related activities[5] , an occupational accident is defined as an occurrence that results in a fatal or non-fatal injury and an occupational psychosocial risk is referred to the likelihood of exposure to hazards of a psychosocial nature as defined in ISO 45003:2021.

Figures 7-9 show the percentage or number of times that the risks were mentioned in the universe of the literature review used for this dissertation. They do not reflect the frequency to which they happen. Instead, they only reflect the frequency of their featuring in this literature review.

[5] https://www.ilo.org/global/topics/safety-and-health-at-work/normative-instruments/code-of-practice/WCMS_107793/lang--en/index.htm - (accessed on 28/07/2021)

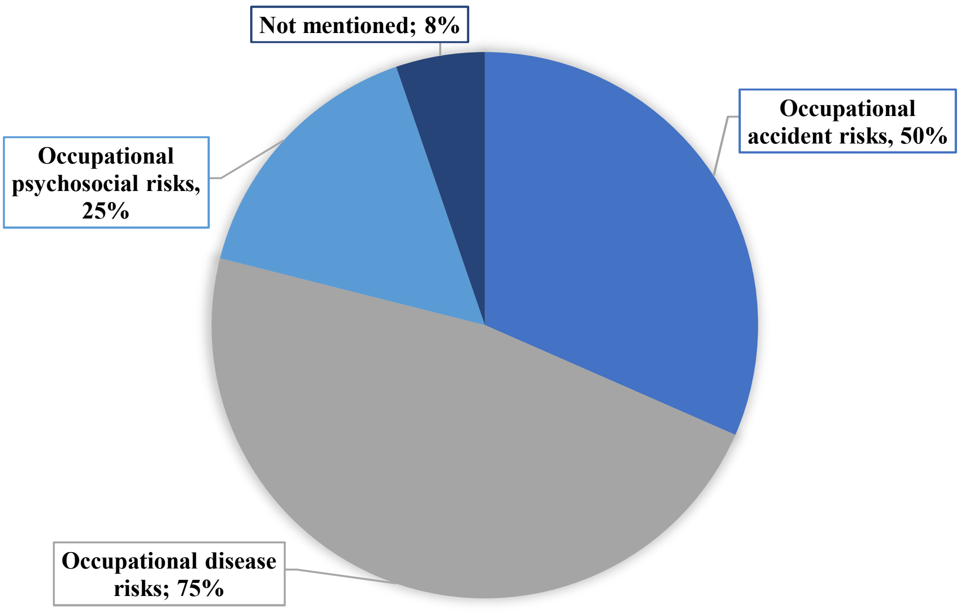

Figure 7 - Types of occupational risk identified in the literature review

Within these categories, presented on figure 7, occupational accident risks and occupational disease risks are the most referred.

The introduction of more mechanized means in the harvesting operations brought new risks to this industry, the majority of them linked with occupational diseases which might explain the predominance of this category. This does not mean that occupational accidents stopped happening or that they are not relevant anymore. In fact, the same variables also introduce accident risks which must be scrutinized (Bonauto et al., 2019; Garland et al., 2019; Jankovský, Allman, & Allmanová, 2019a; Lagerstrom, Magzamen, Brazile, et al., 2019).

This dissertation will focus solely on occupational accident risks. Figure 8 depicts that falls, struck by/against inanimate objects, followed closely by slips, trips and unspecified physical injury are among the most common investigated occupational risks of accident. Nevertheless, the same analysis was made in Figure 9 for occupational disease risks, and it revealed that the most relevant were ergonomic (incorrect postures), physical overexertion and noise exposure. Although these risks are not included in the objective of this dissertation, it might be interesting to correlate these risks as potentiators of occupational accident risks in the future (Iftime et al., 2020).

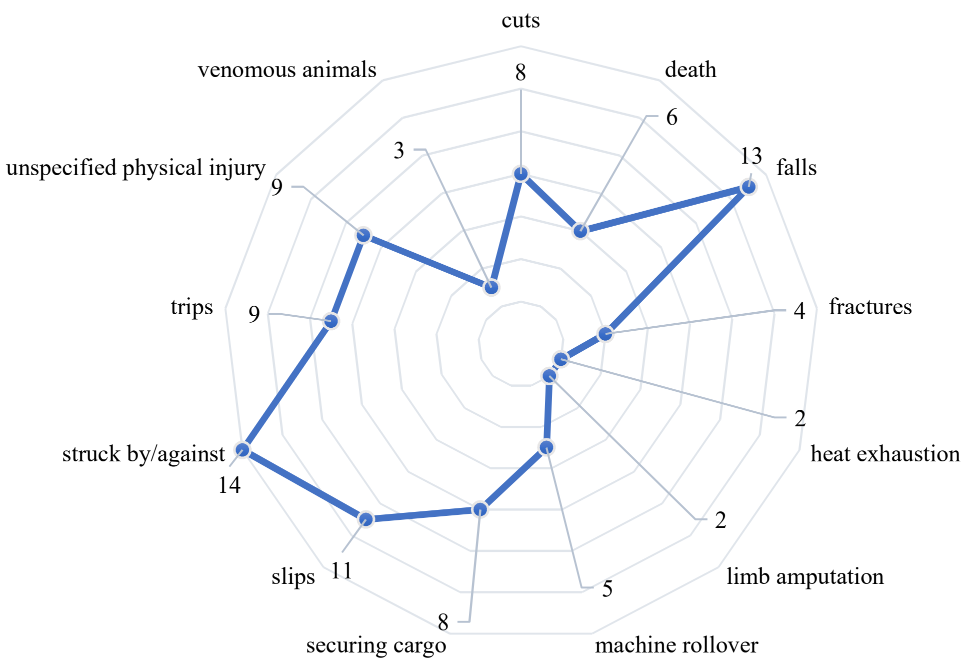

Figure 8 – Occupational accident risks identified in the literature review

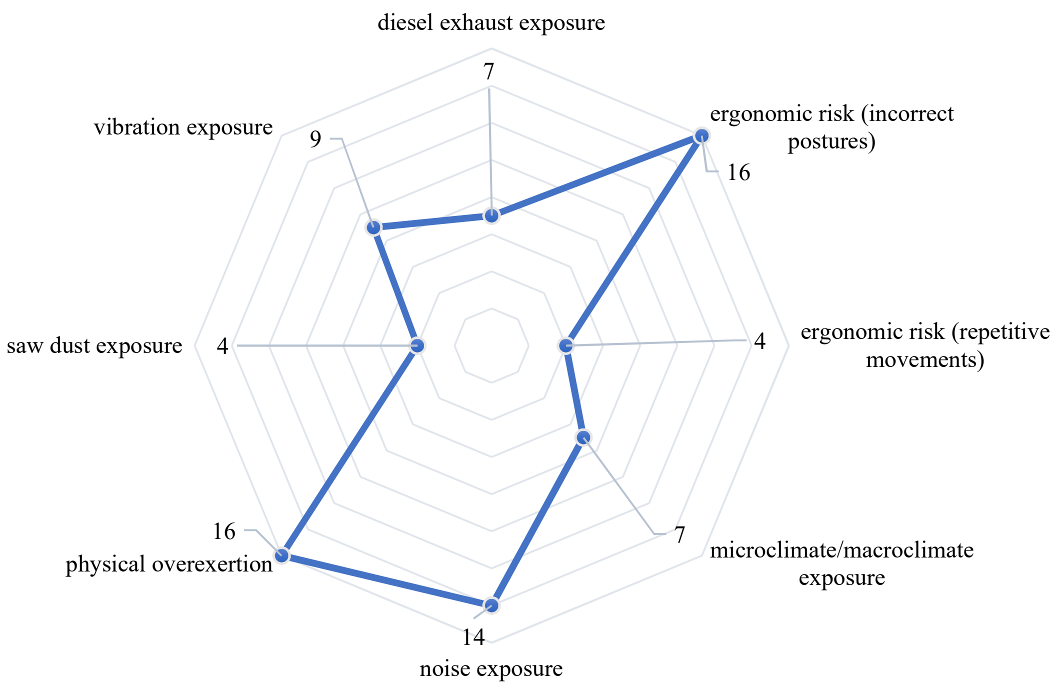

Figure 9 - Occupational disease risks identified in the literature review

Preventive and protective measures

To actively address and treat the identified occupational risks, some authors have proposed preventive and/or protective actions in order to eliminate or minimize the workers' exposure to the risks of accident. However, the efficacy of most of these suggestions was not scientifically validated. Figure 10 provides an overall look on this matter.

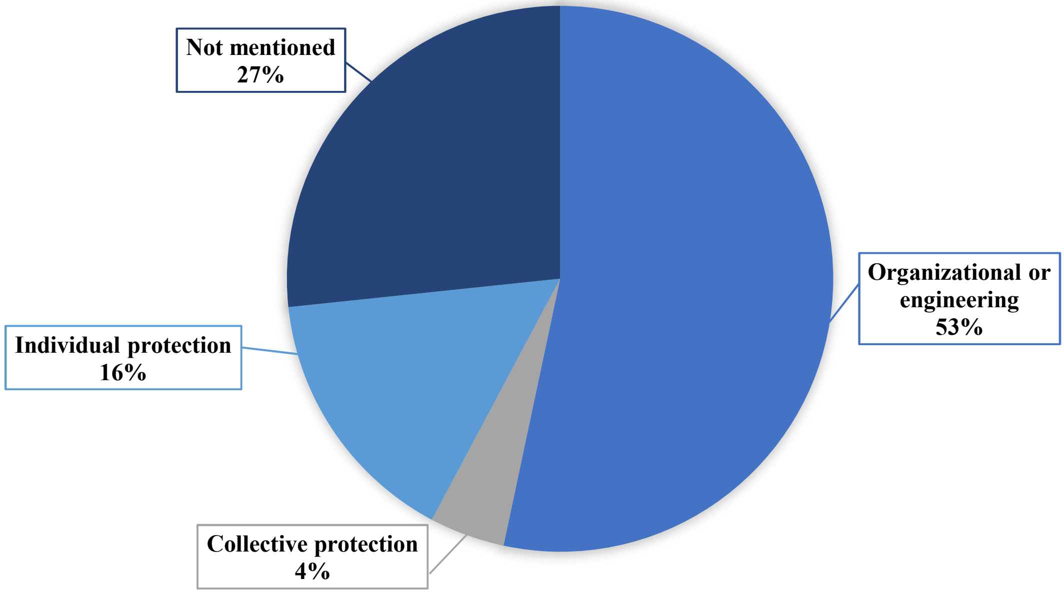

Figure 10 - Preventive/protective measures reported in the literature review

Most of the preventive and protective measures that were suggested fit into the category of organizational and engineering measures. The most relevant examples of this category are:

- Effective OHS training to be provided to workers especially a training focused on hazard awareness (Ghaffariyan, 2016; Iftime et al., n.d.; Kim et al., 2017; Nkomo et al., 2018; Rosecrance et al., 2017; Yovi & Yamad, 2019);
- Better distribution of assignments, shifts and breaks(Cheţa et al., 2018; Iftime et al., n.d.; Laschi et al., 2016; Poje et al., 2016);
- Increase in acquisition of mechanized means to perform certain tasks (Bonauto et al., 2019; Garland et al., 2019; Jankovský, Allman, & Allmanová, 2019a; Jankovský, Allman, Allmanová, et al., 2019; Lima et al., 2020; Yovi & Yamad, 2019);
- Guarantee of adequate training for machine operators (Kim et al., 2017; Melemez, 2015; Micheletti Cremasco et al., 2019).

As for individual protection measures, the most referenced was the lack of adequate personal protective equipment (PPE) (Cheţa et al., 2018; Ghaffariyan, 2016; Iftime et al., n.d.; Kim et al., 2017; Menegon Bristot et al., 2019).

Unfortunately, there is a lack of both follow up data and implementation on these proposed measures, making it difficult to ascertain their relevance. It is possible, however, to draw the conclusion that there is an overall idea that mechanizing processes will eliminate the exposure to some occupational risks or even reduce the severity of their consequences, but there is also a concern for the proper use of these means not only for the health and safety of the operator but also for the workers who have to perform motor-manual tasks around these machines. The full list of protective and preventive measures featured in the reviewed literature can be found on Table 3.

Table 3 - Reviewed productive/preventive measures list

Protective/Preventive measures	
Organizational or engineering	**60%**
better distribution of assignments	(Eroglu et al., 2015; Iftime et al., 2020; Laschi et al., 2016; Poje et al., 2016)
checklist for periodic maintenance of equipment and material	(Menegon Bristot et al., 2019)
delimitate and signal hazardous areas	(Menegon Bristot et al., 2019)
emergency first aid training	(Menegon Bristot et al., 2019)
emergency stop system on machines in case of failure or abnormal situation	(Menegon Bristot et al., 2019)
enforcing safety measures	(Jankovský, Allman, & Allmanová, 2019a; Melemez, 2015)
environmental organization and cleanliness	(Menegon Bristot et al., 2019)
health and safety training	(Ghaffariyan, 2016; Jankovský, Allman, Allmanová, et al., 2019; Kim et al., 2017; Melemez, 2015; Nkomo et al., 2018; Rosecrance et al., 2017; Yovi & Prajawati, 2015; Yovi & Yamad, 2019; Yovi & Yamada, 2015)
improve awareness of diesel exhaust exposures	(Kim et al., 2017)
improve awareness of the risk of MSD's	(Ghaffariyan, 2016; Iftime et al., n.d., 2020; Kim et al., 2017; Micheletti Cremasco et al., 2019)
improve design or upgrade machines to newer models	(Jankovský, Allman, Allmanová, et al., 2019; Poje et al., 2019; Spinelli et al., 2017)
increase wages	(Yovi & Yamad, 2019)
maintenance of machines	(Kim et al., 2017)
organized breaks	(Cheţa et al., 2018; Eroglu et al., 2015; Iftime et al., n.d.)
proactive proximity detection in the logging machines	(Kim et al., 2017)
provide safer and more ergonomic logging machines	(Garland et al., 2019; Kim et al., 2017; Lima et al., 2020; Yovi & Yamad, 2019)
reduction of working time	(Iftime et al., n.d.)
training on the mechanics of the operated machines	(Iftime et al., 2020; Kim et al., 2017; Melemez, 2015; Micheletti Cremasco et al., 2019)
Introduce more mechanization in the logging operations	(Bonauto et al., 2019; Garland et al., 2019; Iftime et al., 2020; Lagerstrom, Magzamen, Brazile, et al., 2019)
health checks	(Eroglu et al., 2015; Iftime et al., 2020)
Collective protection	**5%**
maintenance of the collective protection equipment and material	(Melemez, 2015)
provide new collective protection equipment	(Menegon Bristot et al., 2019)
provide workers with training for the appropriate usage of the collective protection equipment	(Melemez, 2015; Menegon Bristot et al., 2019)
Individual protection	**14%**
maintenance of the personal protection equipment and material	(Menegon Bristot et al., 2019)
provide adequate PPE	(Cheţa et al., 2018; Ghaffariyan, 2016; Iftime et al., n.d.; Kim et al., 2017; Melemez, 2015; Menegon Bristot et al., 2019)
provide workers with training for the appropriate usage of the personal protection equipment	(Kim et al., 2017; Melemez, 2015; Menegon Bristot et al., 2019; Yovi & Yamada, 2015)
use of high visibility PPE	(Kim et al., 2017)
NM	**20%**

2.3 Dissertation objectives

Although several studies attempt to approach the OSH in the forestry industry, none was found that correlates the OSH to the productive process as a whole, thus providing a base to be applied individually to different companies with different configurations. To do so, the following specific objectives were formulated:

- Identification and characterization of the forestry production process;
- Identification of occupational hazards, occupational risks and related triggering events that may occur during the forestry production process;
- Evaluation and analysis of the occupational risks through three different methods, the NTP330, the William T. Fine and the Integrated Risk Management Method.

3 MATERIALS AND METHODS

3.1 Methodology for occupational risk assessment in the forestry industry

The approach used for this research is based on the principles given by ISO 3100:2018 and the necessary steps that must be taken to obtain sufficient and complying data to this standard. The evaluation of risk to the safety and health of workers requires a systematic study of the performed activities which expose them to a hazard that might lead to a harmful occurrence. This process provides valuable information that can be used to support decisions regarding the implementation of worker's preventive and protective actions, as well as the reduction of the risk at a minimum level or even its elimination whenever possible. Generally, the following steps are considered:

- Systematic assessment of all the production processes and sub-processes carried out in an organization;
- Hazard identification, sources of harm or injury based on the processes and sub-processes characterized on the previous point;
- Risk identification, which aims to assess the OHS risks from the identified hazards;
- Risk analysis, characterization of the identified risks while considering triggering events and its most likely consequence;
- Risk evaluation is achieved by applying the information taken from the risk analysis and apply it in the three chosen semi-quantitative methods, which produce quantitative results. The NTP 330 and the William T. Fine method are well established and researched methods with known advantages and disadvantages, while the IRMM is a promising new method that has never been applied to the forestry industry.

In order to correctly assess the occupational risks inherent to the production phase in the forestry industry, a model, presented on figure 11, was developed.

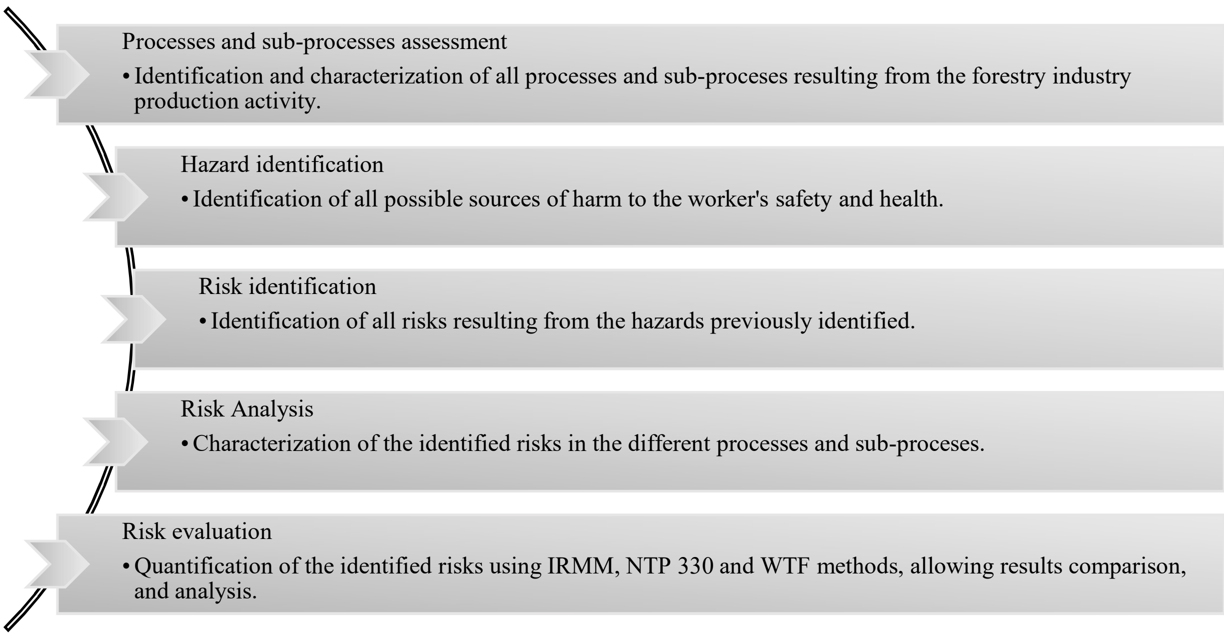

Figure 11 - Graphic representation of the adopted methodology for occupational risk assessment in the forestry industry.

3.1.1 Processes and sub-processes identification

Harvesting aggregates all the procedures connected to the production of raw material in the forestry industry, from pre-harvest planning to post harvest assessment for subsequent processing into industrial products.
It is important to understand the harvesting systems and methods so that the processes and sub-processes can then be characterized accurately. This characterization includes, how the work is performed, the number of people involved in this activity or in the vicinity, which equipment is used, and a description of the operating procedures. With the purpose of identifying all the processes and sub-processes inherent to this production, the scientific papers provided by the systematic research carried out on this topic were examined, as well as some technical reference documents. Additionally, images of the productive processes and sub-processes in loco from several organizations were also analysed. The complexity of this sector leads to unique adaptations depending on available resources the type of terrain, environmental agents, and others. Therefore, it was not possible to scrutinize every aspect of production due to its wide range of possible solutions, varying not only region to region but also company to company. Instead, the decision was made to find a common thread within the reviewed literature and structure the work into its main and most common structure.

Harvesting operation[6,7]

There are multiple harvesting systems available, none of which are inherently superior or inferior. They are classified as follows:

- Full tree systems, where trees are extracted from the felled location to a processing site with the full crown;
- Tree length systems, in which the tree is debranched prior to its extraction;
- Short wood systems (also known as cut-to-length), where the tree was fully processed (debranched and crosscut) before being extracted.

During planning, the decision on which system to adopt and how the subsequent processes will be carried is based on economic, environmental, social, and silvicultural objectives.[8]

Processes, sub processes and tasks:

The most relevant processes identified are Felling, Processing, Extraction, Loading and Transport. The definition of these terms is clear in the International Labour Office code of practice Safety and health in forestry work (ILO, 1998)

- Felling is the process of cutting down a tree;
- Extracting is the process of removing the tree from the site where it was felled to a cleared area where produce is collected;
- Processing or conversion entails the sub-process of debranching and the sub-process of crosscutting typically done on-site where the tree was felled;

[6] https://www.forestryfocus.ie/growing-forests-3/harvesting/ (accessed on 27/08/2021)

[7] https://safetree.nz/wp-content/uploads/2015/02/Mechanised-Harvesting-and-Processing.pdf (accessed on 27/08/2021)

[8] http://www.fao.org/sustainable-forest-management/toolbox/modules/wood-harvesting/basic-knowledge/en/ (accessed on 27/08/2021)

- Loading and Transport entails the loading of the trees that were already processed into logs into transportation vehicles taking them away from the forest site and their delivery to different destinations according to their future use.

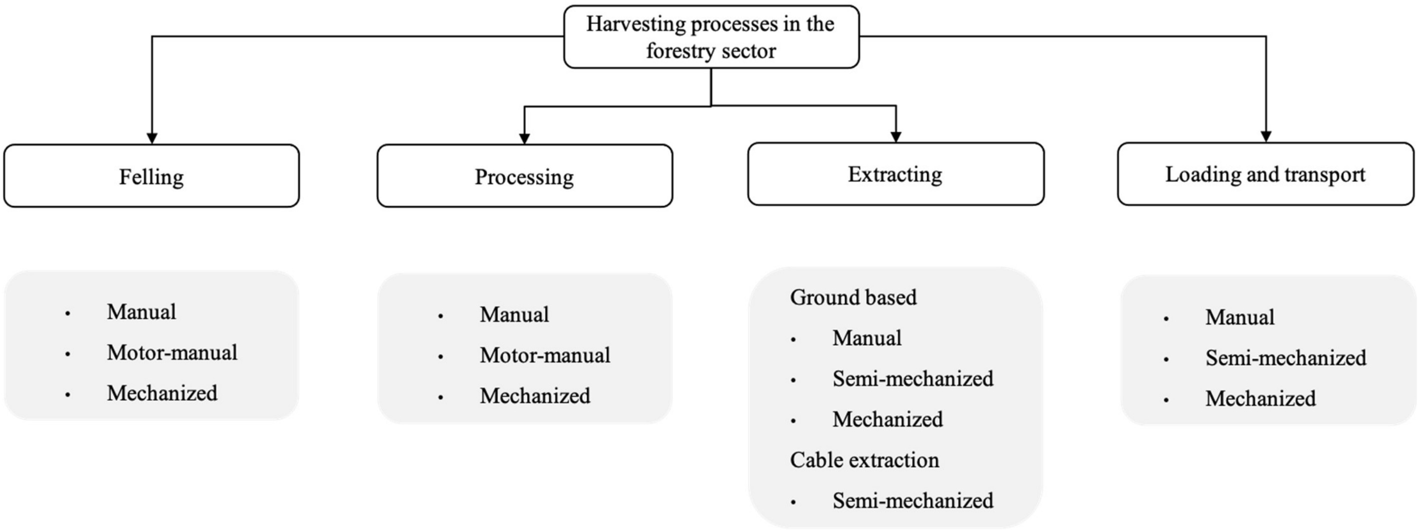

Figure 12 - Harvesting processes and methods

The sub-processes deriving from the previously listed processes were identified based on the collected information and material from the reviewed literature and other relevant bibliographic sources. The sub-processes contain specific tasks that differ from one another in terms of execution, used equipment, materials, adopted work practices and the number of workers involved (FAO, 2008). Photographic examples were collected portraying each of these sub-processes, presented on the appendix 3.

Felling[9]

Manual felling

This practice is considered as an abandoned system in the forestry industry. Therefore, no detail is presented.

Motor-manual or chainsaw felling

[9] https://www.safeworkaustralia.gov.au/system/files/documents/1703/guide-timber-harvesting.pdf (accessed on 27/08/2021)

Figure 13 - Motor-manual felling[10]

The practice of motor-manual felling is less common today than it was in the past. There are several scenarios when a chainsaw is still necessary, such as the felling of large trees, trees with irregular stems and broad branches, trees on very steep slopes where the harvester cannot work, or areas where deploying a mechanical harvester would not be cost-effective. The chainsaw operators and their helpers have to navigate through the active operation site to reach the target trees performing the planning, felling the tree and retreat sub-processes as many times as the number of trees they are tasked with for the workday. The typical PPE used include helmet, gloves, work boots, face-mask and ear mufflers.

Table 4 - Motor-manual or chainsaw felling

Sub-process	Start	End	Number of workers involved	Machines, equipment used
Navigating through rough and potentially active terrain	The feller moves to target location	The feller reaches his target location	01 Chainsaw user 01 Helper	None
Planning the felling	The feller plans where the tree will fall	The feller finishes preparing the area and escape route	01 Chainsaw user 01 Helper	Chainsaw, axe, trimmer
Felling the tree	The feller cuts the tree	The tree starts to fall	01 Chainsaw user 01 Helper	Chainsaw, axe, other manual tools
Retreat from the falling tree area	The tree falls, and the feller uses the escape route	The tree is on the ground and the feller returns to the tree location	01 Chainsaw user 01 Helper	None

[10] https://letabaherald.co.za/wp-content/uploads/sites/113/2016/10/tree-cutting-with-chainsaw.jpg

Other activities are necessary for the completion of the tasks:

- Operating a chainsaw;
- Operating other potentially hazardous equipment (trimmers,manual tools, etc.);
- Refuelling the chainsaw and small maintenance procedures (sharpening chain blade, tensioning the chain, lubricate grease points, etc.).

Mechanized felling

Figure 14 - Mechanized felling[11]

Land clearing machines help to prepare the area when necessary and mechanized feller bunchers or harvesters cut the trees down. Both feller bunchers and harvesters consist of a base machine with a harvesting head installed on a hydraulic arm that can swiftly fell a tree. Harvesters can also remove the branches, and section the stem into marketable length. The machine's movement is controlled by the operator in the cabin. The sub-processes of assessing, felling, and positioning the tree can be very quick and performed in groups depending on the operation. Consequently, they can be considered continuous sub-processes. When the operator is on the ground, the typical PPE used is composed by a helmet and work boots (FITEC, 2005d).

[11]https://media.sandhills.com/img.axd?id=6118215447&wid=4326182721&rwl=False&p=&ext=&w=350&h=220&t=&lp=&c=True&wt=False&sz=Max&rt=0&checksum=8EPR83m1BUL1T%2BsrEhzG4xYBf4q6UQg6n5HWQXaunfQ%3D

Table 5 - Mechanized felling

Sub-process	Start	End	Number of workers involved	Machines, equipment used
Assessing previously defined work area for hazards	The machine operator drives the machine to the felling location.	The machine operator exits and enters the machine as many times as needed to make a general assessment of the area	01 Machine operator 01 Planner	Harvester or feller buncher
Assessing the tree	The machine operator approaches the tree while assessing surroundings	The machine operator establishes a plan for where the tree must fall	01 Machine operator	Harvester or feller buncher
Clearing the base of the tree	The machine operator uses machine to clear any material at the base of the trees impeding the felling operation	The machine operator confirms that the base of the tree is visible	01 Machine operator	Land clearing machine, harvester or feller buncher
Felling the tree	The machine operator positions the cutting head of the machine against the tree and starts to cut it	The tree is felled	01 Machine operator	Harvester or feller buncher
Positioning the felled tree	The machine operator repositions the felled tree to optimize the next stages	The machine operator confirms that the tree is positioned according to the plan	01 Machine operator	Harvester or feller buncher

Other activities are necessary for the completion of the tasks:

- Operating a land clearing machine (usually a bulldozer typed machines with a rotating brush cutter, that can also be adapted from another machine, like a skidder for example);
- Conducting maintenance procedures (as for example lubricating grease points, sharpening chain blade, tensioning the chain, checking for damaged or loose parts, etc.).

Processing

This process entails the removal of the branches (called debranching or delimbing) and cutting the tree transversely into logs with predefined lengths (also known as crosscutting or bucking the tree). These tasks may occur sequentially or not, before or after extracting the tree from its felling location. (FITEC, 2005d).

<u>Manual</u>

This practice is considered as an abandoned system in the forestry industry. Therefore, no detail is presented.

Motor-manual

Figure 15 - Motor-manual processing[12]

The practice of motor-manual processing is used in combination with motor-manual felling, or in combination with mechanized means when, due to some sort of malformation in the tree stem or the presence of large branches, it is not possible to process the tree using a mechanized method. This practice is done in small groups a few times per day or in between the felling processes.

Table 6 - Motor-manual processing (debranching)

Sub-process	**Start**	**End**	**Number of workers involved**	**Machines, equipment used**
Debranching the tree	The chainsaw operator ensures that the tree is in a stable position	The chainsaw operator and the helper assure that the tree is debranched	01 Chainsaw operator 01 Helper	Chainsaw, axe, saw, other manual tools

In between these two tasks (debranching and crosscutting), extraction may or may not occur, depending on the adopted harvesting system.

[12]https://encrypted-tbn0.gstatic.com/images?q=tbn:ANd9GcQmR70OQ3C3YdrA1DVmwSy3Er5q70HF1zavqin-ed2TWAaMeuXdJKogs4acvZdGvNsO0Mo&usqp=CAU

Table 7 - Motor-manual processing (crosscutting)

Sub-process	Start	End	Number of workers involved	Machines, equipment used
Crosscutting the tree	The chainsaw operator checks for possible tensions or movements before and after cutting	The chainsaw operator and the helper assure that the log is sectioned into the desired lengths	01 Chainsaw operator 01 Helper	Chainsaw, axe, saw, other manual tools

Other activities are necessary for the completion of the tasks:

- Operating a wood-chipper. The branches resulting from processing might have to be disposed of on the felling site or at the landing site, wood-chippers provide a solution for transforming this by-product;
- Refuelling the chainsaw and conducting small maintenance procedures (sharpening chain blade, tensioning the chain, lubricate grease points, etc.).

<u>Mechanized processing</u>

Figure 16 - Mechanized processing[13]

The practice of mechanized processing can be performed by the same machine which felled the tree or by different machines, both in debranching and crosscutting. It could also be performed by a mix between mechanized and motor-manual methods. In any case, the mechanized processing is done as part of a continuous process during the day.

[13] https://i2.wp.com/skogservice.no/en/wp-content/uploads/2011/03/spesialmaskiner.jpg

Table 8 - Mechanized processing (debranching)

Sub-process	Start	End	Number of workers involved	Machines, equipment used
Assessing the tree	The machine operator assesses the general characteristics of the tree and the processing site according to machine's capability	The machine operator decides on the processing methods to follow	01 Machine operator 01 Planner	None
Debranching the tree	The machine operator chooses the best positioning for the machine according to the terrain conditions and the stem orientation	The machine operator assures that the tree is debranched and stockpiled	01 Machine operator	Processor machine

In between these two tasks (debranching and crosscutting), the extraction process may or may not occur, depending on the adopted harvesting system.

Table 9 - Mechanized processing (crosscutting)

Sub-process	Start	End	Number of workers involved	Machines, equipment used
Assessing the tree to make logs	The machine operator assesses the general characteristics of both the tree and the processing site according to machine's capability	The machine operator decides on the processing methods to follow as well as on the cutting instructions	01 Machine operator 01 Planner	None
Crosscutting the tree	The machine operator chooses the best positioning for the machine depending on the terrain conditions and on the stem orientation	The machine operator assures that the logs are cut to the specified lengths and stockpiled	01 Machine operator	Processor machine

Other activities are necessary for the completion of the tasks:

- Operating a wood-chipper. The branches resulting from processing might have to be disposed of on the felling site or at the landing site, wood-chippers provide a solution for transforming this by-product;
- Conducting small maintenance procedures (Lubricating grease points, sharpening chain blade, tensioning the chain, check for damaged or loose parts, etc.);
- Clearing debris.

Extraction

The extraction process consists in moving the stems or logs from where they were felled to the landing area, which is where they will be further processed and loaded for final transport to other industries. This process may involve two ground-based methods known as skidding and forwarding, and one cable-based method known as cable extraction method (ACT, 2015). Extracting stems or logs by dragging them through the ground is called skidding. This can be done by humans, draught animals, or machines called skidders. Another way of extracting this material is forwarding, which means that the logs or stems are carried on some sort of trailer pulled by the same type of resources as mentioned before. In this case, the machines are called forwarders. Cable yarding involves extracting the stems or logs by suspending and dragging them, which means using a machine in a fixed position with winches to drag the material to the landing area. These machines are called yarders.

Manual

This practice is considered as an abandoned system in the forestry industry. Therefore, no detail is presented.

Semi-mechanized/mechanized ground-based extraction

Figure 17 - Ground-based extraction[14]

In mechanized extraction, the machine operator requires no assistance. As for semi-mechanized skidding and forwarding, one or more workers are helping and/or guiding the machine operator to perform the described tasks. Skidders are typically used in combination with feller bunchers and forwarders in combination with harvesters. The same team rotates sequentially through all the associated sub-processes repeating them as many times as possible (FITEC, 2005b).

Table 10 - Semi-mechanized/mechanized ground-based extraction

Sub-process	Start	End	Number of workers involved	Machines, equipment used
Planning the extraction	The machine operator moves out from landing to extraction location	The planner makes the plan and marks in the map the location where to extract the material	01 Machine operator 01 Planner	Extraction machine

[14] https://nfportalen.nordfarm.se/media/wysiwyg/Skog-och-ved/Farmi-vinschar/Farmi-vinsch-JL501.jpg

Hook-on, grab, or load stems or logs	The machine operator chooses the best positioning for extraction depending on the terrain conditions and both stem or log orientation	The machine operator and the helper assure that the stems or logs are ready to be moved or carried out of the felling area	01 Machine operator 01 Helper	Extraction machine and securing equipment
Travelling to the landing area	The machine operator starts to move with attached cargo	The machine operator arrives at landing area	01 Machine operator	Extraction machine
Unhook, drop, or unload stems or logs	The machine operator releases or unloads the transported cargo	The machine operator and collaborators assure that stems or logs are stockpiled and organized in the landing area	01 Machine operator 01 Measurer 01 Helper 01 Loader operator 01 Data annotator	Extraction machine and securing equipment

Other activities are necessary for the completion of the tasks:

- Operating loader machines, that can be fixed, wheeled, or tracked usually with a mechanized arm, grapple, shovel or hook which enables to move the materials for short distances before being extracted (different types require different procedures on how a task is performed);
- Conducting small maintenance procedures (make sure all the securing equipment is in working conditions, lubricating grease points, check for damaged or loose parts, etc).

Semi-mechanized suspended cable extraction[15]

Figure 18 - Suspended cable extraction[16]

This practice consists of the use of cables to move the trees from the forest to the landing area. The tree is fully or partially suspended during transport. There are four main rigging configurations that

[15] https://www.fs.fed.us/forestmanagement/equipment-catalog/cable.shtml (accessed on 27/08/2021)

[16] https://encrypted-tbn0.gstatic.com/images?q=tbn:ANd9GcSIPor0bwQUSVxEiVb1smfMe677z_1-LXSRYaaAS40tDOX58N4vvkadl3LYbGEXyYfo4l8&usqp=CAU

can be used in cable logging: highlead, standing, running and live. This work will not go into detail about setting up the landings for each of configuration. Instead, it will approach the running phase of these configurations. Both sending and receiving sides of these operations are ran continuously by the same team throughout the workday (FITEC, 2005a; WorkSafeBC, 2006).

Table 11 - Semi-mechanized suspended cable extraction

Sub-process	Start	End	Number of workers involved	Machines, equipment used
Moving loads and materials	The loader operator selects loads according to weight and size specifications	Position materials to be extracted	01 Loader operator 01 Supervisor	Loader
Hauling materials to the landing area	Rigging loads to cables or lines	Load is carried until landing area	02 Choker setters 01 Supervisor 01 Yarder Operator	Yarder machine, Hand tools
Receiving materials in the landing area	Disconnect cables or lines from the loaded materials	Position the material stockpiled in the landing area	02 Chasers (unhook chokers) 01 Supervisor 01 Yarder Operator 01 Loader operator	Yarder machine, Loader, Hand tools

Other activities are necessary for the completion of the tasks:

- Conducting small maintenance procedures (making sure all the rigging equipment is in capable working conditions, lubricating grease points and winch drums, check for damaged or loose parts, etc.).

Loading and Transport[17]

The most common form of log transport from the harvesting operation is by truck. Other forms of transport include rail or water systems, but still in these trucks are preferentially used to transport the stems or logs from the landing site to the rail or water transport systems. The loading phase of the logs or stems can be done manually, using semi-mechanized or using mechanized systems (FITEC, 2005c).

<u>Manual loading and transport</u>

Lifting or rolling the material up ramps to the truck can be done by using simple hand tools or by using draught animals. Although this system is still being used in developing countries, it will not be approached in this dissertation since it is considered an abandoned system.

<u>Semi-mechanized/mechanized loading and transport</u>

[17] https://iloencyclopaedia.org/component/k2/item/584-timber-transport (accessed on 27/08/2021)

Figure 19 - Semi-mechanized loading and transport (source)

The distinction between mechanized and semi-mechanized loading is made depending on the requirement of a groundworker to assist the loader operator securing and guiding the cargo.
The continuity of the loading and transporting sub-processes are dependent on the harvested quantities, but it can be said that these sub-processes are usually continuous.

Table 12 - Semi-mechanized/Mechanized loading and transport

Sub-process	Start	End	Number of workers involved	Machines, equipment used
Preparing and positioning the truck	The truck driver and helper remove the extension pins, lower the supports, and remove any existent debris	The truck is in position according to the collaborator's instructions	01 Truck driver 01 Data annotator 01 Loader operator 01 Helper/Controller	Truck and trailer
Loading the cargo	The loader operator grabs the stems or logs and places them in the truck	The required height is reached, and the truck is fully loaded	01 Truck driver 01 Data annotator 01 Loader operator 01 Helper/Controller	Loader machine
Securing load	The cargo is checked	The cargo is secured	01 Truck driver 01 Data annotator 01 Helper/Controller	Truck, trailer, and securing equipment
Transport the load	The truck moves out of the landing	The truck arrives at destination	01 Truck driver	Truck and trailer

Other activities are necessary for the completion of the tasks:

- Handling the securing equipment and other accessories such as (ropes, belts, chains, shackles, locks, etc.).
- Conducting small maintenance procedures (make sure all the securing equipment is in capable working conditions, check for damaged or loose parts, etc.).

- Keeping the landing area organized and securing the stockpiles.

3.1.2 Hazard identification

Based on the processes and sub-processes identified on the previous point, an assessment of the occupational hazards and their possible interactions with the workers in prejudice of their health and safety was made. In agreement with ISO 3100:2018, this practice optimizes the identification of hazards and reduces the chances of overlooking any critical details. As for the interactions, they must be considered on their capability of triggering events but also on the frequency they may occur.

The material and the equipment used by the workers carry the potential of triggering hazardous events:

- Knowledge of the production process and sub-processes;
- Overall state of the equipment;
- Physical and chemical characteristics of each material;
- Surface temperature of the equipment or tools;
- Components or features likely to produce noise, vibration, dust, mechanical actions or environmental conditions;
- Energy sources used;
- Operating condition;
- State of preservation of the infrastructures where the tasks are carried out.

Concerning the execution of tasks, the following points must be taken into account:

- Operating conditions;
- Task execution manner;
- Working time;
- Complexity of the task;
- Type of environment, transported cargo or materials while performing the task;
- Type of physical effort required to perform the task;
- Number of workers involved in the task.

3.1.3 Risk identification

Taking into consideration the characterization of processes/sub-processes, the identified hazards and their triggering events, the next step is to assess the frequency of these occurrences thus identifying the underlying risks. The existing protection mechanisms must also be deliberated. An example of the risk matrix is presented on Table 13. Here, it can be seen how the information is organized per column following the described requirements. Hazards, triggering events, number of workers involved, a description of the event, protective and/or preventive measures in place, accident risk and consequences. All the necessary information to perform a risk analysis.

Table 13 - Example of the risk matrix

Risk ID	Process	Method	Sub-process	Photo	Hazard	Triggering event	Number of workers involved	Frequency	Observation/Description	Protective / Preventive measures in place	Accident Risk	Consequences	Suggestions
R1	Felling	Motor-manual	Navigating through rough and potentially active terrain		Floor	Slipping on a wet surface	2	Daily continuously	Lost footing or balance. It happens frequently due to the rough terrains the workers must navigate to reach the desired target while carrying their work equipment.	Protective PPE (Helmet, gloves, visible work clothing and work boots)	Same level fall	Strains or sprains	Being alert to the work environment, OSH training, introduce mechanized equipment
R2	Felling	Motor-manual	Navigating through rough and potentially active terrain		Floor	Tripping on vegetation or other obstacles	2	Daily continuously	The worker has to walk through the forest floor to reach his target location while carrying his tools. Depending on terrain conditions and the nature of the operation the distance and type of terrain vary but there are always obstacles and slopes to overcome.	Protective PPE (Helmet, gloves, visible work clothing and work boots)	Same level fall	Upper limb fractures	Being alert to the work environment, OSH training, introduce mechanized equipment
R3	Felling	Motor-manual	Navigating through rough and potentially active terrain		Wild animals	Disrupting the natural habitat or coming into contact with a wild animal	2	Daily continuously	The forest houses a variety of animals depending on the region, some of which might be venomous. While navigating through the forest it is possible to disrupt the habitat of a wild venomous animal and it might attack the worker.	Protective PPE (Helmet, gloves, visible work clothing and work boots)	Getting bitten	Limb amputation	Being alert to the work environment, wear appropriate PPE, introduce mechanized equipment

3.1.4 Risk analysis

To achieve an outcome in favour of the proposed goal of this dissertation, a risk assessment and management methodology becomes necessary. For the sake of improving the reliability of the results and reduce its subjectivity, an assessment method based on a risk matrix is apparent.

The method presented below is based on Antunes et al. (2010), who proposed an integrated risk assessment methodology for the chemical industry, grounded on the principles of the "process approach" defined in NP EN ISO 9001:2000, where the assessment of all activities associated with each process and sub-process are critical.

In this analysis, the operations of the organization are described by identifying the inputs, roles, and outputs within each process. The outputs will be fed into subsequent processes, and so on. As a result, all outputs from one process must have a matching input in the next, ensuring that no parts are overlooked. This method considers four hierarchical categories, process, subprocess, activity and task (F. Antunes et al., 2010). This principle resulted in homogeneous results even when applied to other industries thus minimizing the issue of subjectivity typically linked to the performer of the study. (Castelo Branco, 2018).

3.1.5 Risk evaluation

Only semi-quantitative methods fit into this “process approach” premise. The decision was made to use the following three methods in order to evaluate and quantify the identified risks in the forestry industry:

- Integrated Risk Management Method
- NTP 330 method
- WTF method

This will enable to draw some conclusions regarding the accuracy of each method in the forestry industry reality, as well as the necessity of intervention to mitigate the identified risks.

IRMM

This method, IRMM (Integrated Risk Management Method), is in fact based on the process approach given by NP EN ISO 9001:2000 with the objective of quickly assessing environmental impacts associated with occupational risks for small and medium sized companies (F. Antunes et al., 2010) It relies on 5 major parameters.

- Severity of the event (S);
- Extension of the impact (E);
- Frequency of occurrence of the event (F);
- Performance of the prevention and control systems (PPC);
- Costs and technical complexity of the preventive/corrective measures for the event (CPC).

Originally, these parameters are then divided into different levels of classification; originally (E) was divided into four levels, (PPC) and (CPC) had three possible levels each, (S) and (F) were given five. Since then, this method has been successfully adapted to a variety of industries (Alves de Sousa, 2015; F. J. Antunes, 2009; Bessa, 2015; Guimarães, 2016; Neves, 2020; Sousa da Silva, 2017). In these adaptations, one recommendation to reduce technical difficulty and improve consistency overall was highlighted in order to harmonize the classification of these parameters giving them all five different levels (Sousa, 2015). Another adaptation was considered, changing the extension of the impact parameter from a percentage to a direct number of workers (Castelo Branco, 2018), because forestry workers usually operate either alone using a machine or piece of equipment, or in small teams in the same area. The adopted model for this dissertation can be found in attachments.

NTP 330

This methodology[18] allows for the quantification of risks in a rational manner, thus facilitating the prioritization of corrective or preventive measures. It is dependent on the performer of the study to rate as accurately as possible the four different variables necessary for the completion of the risk evaluation: Deficiency level (ND), Exposure level (NE), Probability level (NP) and Consequence level (NC). The quantification of these variables is aided by tables and contain four possible escalations.

After attaining the four initial values, they are used to in equations that ultimately lead to a representative number of the risk magnitude (R). This number is, once again, compared to a table which will classify the risk into one of four possible level of urgency in applying corrective actions. A more detailed explanation can be found in the appendix 3.

WTF

The William T. Fine method (W. T. Fine, 1971) is a mathematical evaluation model with three parameters: consequence (C), exposure (E), and probability (P). Each parameter has five or six levels of subdivision. The risk level (R) is obtained through the multiplication of the three parameters.

Equation 1 - WTF risk level formula

$$R = C \times E \times P$$

Each parameter is split into five or six levels, and the result can be one of five outcomes: 1) acceptable risk, 2) probable risk, 3) significant risk, 4) high risk, or 5) extremely high risk.

This method has been subject to adaptations, mainly concerning the consequence parameter where a monetary value is attached to each subdivision. This is notoriously hard to ascertain, especially for less experienced evaluators. Regarding frequency, the ends of the scale are subjective and imply previous knowledge of occurrences (Sousa, 2015).

The method is further explained in appendix

[18] https://www.insst.es/documents/94886/326827/ntp_330.pdf/e0ba3d17-b43d-4521-905d-863fc7cb800b (acessed on 19/07/2020)

PART 2

4 RESULTS AND DISCUSSION

This dissertation resulted in the construction of an occupational accident risk matrix containing the analyses of 87 selected examples in different stages of the production cycle in the forestry industry. The occupational accident risks were then evaluated using the NTP 330, the WTF and the IRMM methods. This information can be found in the appendix 3.

4.1 Results and discussion for NTP 330 method

The NTP 330 method resulted in the evaluation presented on Table 14, which categorizes the intervention level in four levels of urgency.

Table 14 - NTP 330 intervention level

Intervention level	Meaning	Number of risks	%
I	Situation critical and requires urgent correction	42	48%
II	Correct and implement control measures	31	36%
III	Improve if it is possible. It would be convenient to justify the intervention and its cost-effectiveness	11	13%
IV	There is no need to intervene, except if other more demanding analysis justifies it.	3	3%

The results increase steadily and uniformly from less urgent to critical, where the most significant percentage of the evaluated risks is found. It tends to overestimate the occupational accident risks to the upper end of the scale. This happens because this method only offers four classification levels to quantify the necessary variables to reach the intervention level calculation. In the forestry industry, where the consequences of occupational accidents are for the most part severe, it is easy to fit the variables into the highest classifications when the evaluation method is not rectified for it.

More levels would help to better categorize and differentiate the risk evaluation through this method. Taking a closer look only at the intervention level I risks (Table 15), it is possible to see that motor-manual felling, motor-manual processing, both types of extraction and mechanized loading and transport are the processes with more contemplated cases in this level.

This is an expected outcome regarding the motor-manual processes, since contact with machines such as chainsaws is proven to be a task of great concern, as shown in Figure 6.

Both types of extraction present similar results in this analysis, indicating the lack of ability of this method to differentiate the risks deemed of higher importance. The highest number of risks for intervention level I belongs to the mechanized loading and transport. This process involves the hauling of logs and operation of trucks that transport them. Logs and trucks were hazards also identified in the literature review (Bonauto et al., 2019; Conway et al., 2017; Corella justavino et al., 2015; Danilović et al., 2016; Enez & Nalbantoğlu, 2019; Garland et al., 2019; Ghaffariyan, 2016; Jankovský, Allman, & Allmanová, 2019a; Jankovský, Allman, Allmanová, et al., 2019; Kim et al., 2017; Lagerstrom, Magzamen, Brazile, et al., 2019; Laschi et al., 2016; Melemez, 2015; Menegon Bristot et al., 2019; Newman et al., 2018; Nkomo et al., 2018; Rosecrance et al., 2017; Soranso et al., 2019; Yovi & Prajawati, 2015; Yovi & Yamad, 2019).

Table 15 - NTP 330, intervention level I risks

Intervention level I		
Felling	Motor-manual	9
	Mechanized	3
Processing	Motor-manual	5
	Mechanized	2
Extraction (ground based)	Semi-mechanized/mechanized ground-based extraction	6
Extraction (suspended cable)	Semi-mechanized	7
Loading and transport	Mechanized	10
Total number of risks for intervention level I		**42**

4.2 Results and discussion for WTF method

The WTF method provides not only a risk classification (Table 16) but also a categorization of the risks into justifiable or not justifiable interventions to correct the presented occupational accident risks (Table 17).

Table 16 - WTF risk classification

Risk classification	Action	Number of risks	%
Extreme	Immediate stop	5	6%
Very high	Requires immediate correction	0	0%
High	Requires correction	1	1%
Medium	Requires attention and possible correction	13	15%
Low	Acceptable in current situation	68	78%

Table 17 - WTF justification

Justification	Number of risks	%
Justified	43	49%
Not justified	44	51%

Right away, it can be seen that the WTF method seems to under-evaluate the occupational accident risks contemplated in the given examples. This method would require a big amount of past records in order to correctly ascertain the probability and consequence variables, which is rarely the case in the forestry industry (Bonauto et al., 2019; Danilović et al., 2016; Garland et al., 2019; Ghaffariyan, 2016; Iftime et al., 2020; Jankovský, Allman, & Allmanová, 2019b; Jankovský, Allman, Allmanová, et al., 2019; Laschi et al., 2016; Nkomo et al., 2018), and still its accuracy would be doubtful especially for the rarer occurrences. Prices and equipment change over time, adding up to different values in damages.

Since 78% of the cases are classified as low, meaning they are considered acceptable according to this method, it seems that an adaptation to the values would be necessary. Further explanation on how the method reached the presented reference values would also be key for the evaluator to follow the same steps.

Other difficulties were noted while evaluating the occupational accident risks through this method. On the variable "Exposure" this method does not contemplate daily non continuous activities, leading to the over estimation of this particular variable to "continuous - several times a day". Also noteworthy was the difficulty of estimating the cost factor, where a range of values must be chosen to quantify this variable. Prices will vary depending on the region or even on the company's financial capacity, making this variable very subjective(Colim et al., 2019). Nevertheless, an attempt was made to choose the most appropriate values.

About half of the risks presented on the matrix were deemed justified for correction and the other half not.

Table 18 - WTF, very high and extreme risks

Risk classification - Very High + Extreme		
Felling	Motor-manual	1
	Mechanized	0
Processing	Motor-manual	2
	Mechanized	0
Extraction (ground based)	Semi-mechanized/mechanized ground-based extraction	0
Extraction (suspended cable)	Semi-mechanized	0
Loading and transport	Mechanized	2
Total number of risks very high and extreme		**5**

An analysis on the "very high" and "extreme" risks allotted by processes reveals that motor-manual felling, motor-manual processing, and loading and transport are the contemplated processes for these classifications (Table 18).

Table 19 - WTF justified risks for correction

Justified corrections		
Felling	Motor-manual	8
	Mechanized	3
Processing	Motor-manual	8
	Mechanized	1
Extraction (ground based)	Semi-mechanized/mechanized ground-based extraction	6
Extraction (suspended cable)	Semi-mechanized	7
Loading and transport	Mechanized	10
Total number of risks for justified correction		**43**

Out of the 43 justified risks for corrections, they cluster around the motor-manual and semi-mechanized processes with special mention to loading and transport, which is a mechanized process but takes the lead on the justified risks for correction (Table 19).

4.3 Results and discussion for the IRMM

The IRMM provides a balanced distribution of the categories of risk, where both extremities (1 - Low, and 5 - Extreme) represent a low number of cases, and in the middle (2 - Medium, 3 - High, and 4 - Very High). The three remaining categories represent, together, 85% of the evaluated cases. More cases tend towards the higher side of risk categorization, "Very High" is the most populated category with 40% of the cases (Table 20).

Regarding the method itself, it appears that the variable "performance of the prevention and control systems" (PPC) contemplates the performance of the prevention systems but fails to do the same consideration for personal protective equipment. It only mentions its use.

Another remark is the lack of a variable that contemplates the probability of occurrence of the evaluated occupational accident risk. This is especially evident and important when we are considering risks with very severe consequences. Another option to solve this problem would be to adapt the PPC variable giving it more levels and/or different values to further attenuate the extremes which come from the risk level equation presented in this method.

Table 20 - IRMM risk category

Risk category	Number of risks	%
1 – Low	9	10%
2 - Medium	14	16%
3 - High	25	29%
4 – Very High	35	40%
5 - Extreme	4	5%

A selected examination of the occupational accident risks categorized as "Very High" and "Extreme" reveals that the most populated processes are the semi-mechanized suspended cable extraction, the mechanized loading and transport, followed by motor-manual felling and processing.

Felling and processing trees are activities subject of scrutiny by the scientific community (Bonauto et al., 2019; Corella justavino et al., 2015; Enez & Nalbantoğlu, 2019; Garland et al., 2019; Ghaffariyan, 2016; Jankovský, Allman, & Allmanová, 2019a; Kim et al., 2017; Lagerstrom, Magzamen, Brazile, et al., 2019; Landekic et al., 2019; Laschi et al., 2016; Lima et al., 2020; Marchi et al., 2017; Melemez, 2015; Newman et al., 2018; Nkomo et al., 2018; Poje et al., 2019; Rosecrance et al., 2017; Soranso et al., 2019; Yovi & Prajawati, 2015; Yovi & Yamad, 2019; Yovi & Yamada, 2015) as it can be seen on Figure 6. Moreover, the most used tool in the forestry industry for motor-manual processes is the chainsaw, which is the number one associated hazard in the forestry industry confirmed by the literature review (Bonauto et al., 2019; Cheţa et al., 2018; Conway et al., 2017; Corella justavino et al., 2015; Danilović et al., 2016; Enez & Nalbantoğlu, 2019; Fonseca et al., 2015; Garland et al., 2019; Ghaffariyan, 2016; Iftime et al., n.d.; Jankovský, Allman, & Allmanová, 2019a; Kim et al., 2017; Lagerstrom, Magzamen, Brazile, et al., 2019; Landekic et al., 2019; Laschi et al., 2016; Marchi et al., 2017; Melemez, 2015; Newman et al., 2018; Nkomo et al., 2018; Rosecrance et al., 2017; Soranso et al., 2019; Yovi & Prajawati, 2015; Yovi & Yamad, 2019; Yovi & Yamada,

2015) presented on Figure 5. Therefore, it is possible to deduce a certain degree of accuracy when the IRMM method classifies the occupational accident risks born from motor-manual processes as very high or extreme. The same reasoning can be applied to justify the number of risks classified as very high or extreme on the loading and transport process. The literature review identifies trucks and logs on Figure 5 as important hazards approached in the reviewed articles, which can be directly linked to this process. Furthermore, "loading and transport" is identified on Figure 6 (Bonauto et al., 2019; Danilović et al., 2016; Enez & Nalbantoğlu, 2019; Ghaffariyan, 2016; Jankovský, Allman, & Allmanová, 2019a; Jankovský, Allman, Allmanová, et al., 2019; Lagerstrom, Magzamen, Brazile, et al., 2019; Laschi et al., 2016; Lima et al., 2020; Melemez, 2015; Rosecrance et al., 2017; Soranso et al., 2019; Yovi & Yamad, 2019). The extraction by suspended cable is also featured in Table 21. This can be explained by the "cable yarding timber extraction" task presented on Figure 6 and also by the possible over-estimation that the IRMM method is subjecting this process to. Most of the risks listed for extraction by suspended cable, although severe, have a low probability of occurrence due to the working protocols and safety measures in place. The IRMM does not account properly to this factor for the reasons explained previously.

Table 21 - IRMM, very high and extreme risks

Risk categories - Very High + Extreme		
Felling	Motor-manual	6
	Mechanized	3
Processing	Motor-manual	6
	Mechanized	1
Extraction (ground based)	Semi-mechanized/mechanized ground-based extraction	3
Extraction (suspended cable)	Semi-mechanized	10
Loading and transport	Mechanized	10
Total number of risks for very high and extreme		**39**

This method continues to categorize the risks into levels of priority for corrective/preventive intervention. Here, the distribution is scarce in the extreme categories on both ends and grows towards the middle category.

Table 22 - IRMM priority category

Priority category	Number of risks	%
1 – Low priority	8	9%
2 – Medium priority	13	15%
3 – High priority	37	43%
4 – Very High priority	26	30%
5 – Urgent situations	3	3%

Looking at just the "very high" and "urgent" risks, it is possible to see the predominance of cases on both motor-manual felling and motor-manual processing.

Table 23 - IRMM, very high and urgent priority categories

Priority categories - Very High + Urgent		
Felling	Motor-manual	8
	Mechanized	4
Processing	Motor-manual	6
	Mechanized	2
Extraction (ground based)	Semi-mechanized/mechanized ground-based extraction	4
Extraction (suspended cable)	Semi-mechanized	1
Loading and transport	Mechanized	4
Total number of risks for very high and urgent priority		**29**

4.4 Results and comparison of the three methods

The three methods present very different distributions in terms of the overall classification of the evaluated occupational accident risks. NTP 330 overestimates tending heavily towards urgent and critical end of the spectrum. The WTF method does the exact opposite, tending towards the low and acceptable situations. While the IRMM provides a more balanced and spread evaluation out of the three methods, presenting low numbers on the extremities and concentrating the majority of the risks in the three middle levels.

Since these methods were not adapted to the forestry industry, some incompatibilities were expected. The Table 24 explores possible causes for these incompatibilities in the form of advantages and disadvantages identified for each method.

Table 24 - Advantages and disadvantages comparison table

Method	Advantages	Disadvantages
NTP 330	- Easy to apply.	- Four levels of risk categorization is not enough to differentiate high and severe risks in the forestry industry. - Does not provide any feedback on the justification or prioritization of interventions.
WTF	- 5 level risk categorizations. - Identifies which risks are justified for an intervention.	- Requires big amounts of past records and databases to accurately ascertain probability and consequence variables. - Exposure variable does not contemplate daily non continuous activities. - Cost factor is subjective to interpretation. - Does not prioritize risk interventions.
IRMM	- 5 level risk categorizations. - Identifies and prioritizes risks regarding interventions.	- Does not contemplate the performance of the PPE's, only its existence. - Probability of occurrence of a given occupational accident risk is not considered.

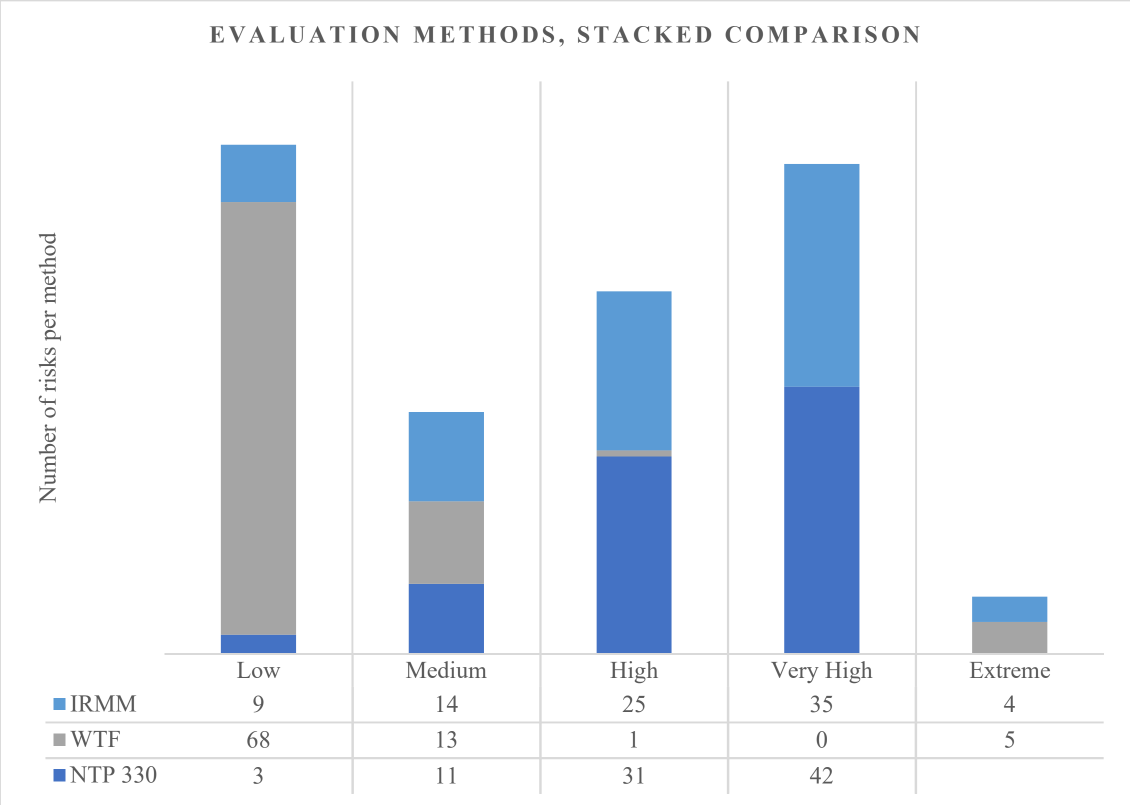

Figure 20 - Stacked column chart of the three evaluation methods

Figure 20 represents the distribution of the number of risks per method in the different risk categories. This is meant as an aid to visualize their behaviour. Since the NTP 330 only has four category levels, a truthful joint comparison is not possible with the other two methods. There are occupational accident risks evaluated by NTP 330 which will be allocated above or below the five category levels given by WTF and IRMM, not allowing a better discernment of the obtained occupational accident risks.

There are three processes within the occupational accident risks identified as very high or extreme that are repeatedly highlighted in all of the three methods (Table 15, Table 18, and Table 21). The featured processes are motor-manual felling, motor-manual processing as well as loading and transport. These processes match the most referenced tasks identified on Figure 6 from the literature review, namely “chainsaw operations”, “tree felling and cutting”, and “wood loading and transport”. This proves the OHS relevance of these activities in the productive cycle of the forestry industry.

Extraction by suspended cable is also highlighted in IRMM (Table 21), but it appears lower on the literature review tasks on Figure 6. This can be explained by the exacerbation of the risks resulting from high variables from the risk level (RL) calculation in this process and a misadjusted PPC value to mitigate the overestimation.

As for the priority on corrective and prevention measures to be taken, both WTF and IRMM agree to some extent on the intervention on motor-manual felling and motor-manual processing as it can be seen on Table 19, Table 23 and appendix 3. WTF justifies most of the occupational accident risks for “extracting by suspended cable” and “loading and transport”. The IRMM does not qualify the priority on corrective and preventive measures on those processes as very high or urgent. This is due to the different ways on how these two methods rate their cost and complexity. In this regard, the IRMM offers an important hierarchy of prioritization that the WTF does not.

It is concluded that there is a need to adapt the IRMM to the context of the forest industry while taking into account all of the existing sub-processes.

4.5 Limitations

Unfortunately, due to COVID-19, it was not possible to collect data directly from a company operating in the forestry industry. Specifically, the photographic survey which produced the risks for the risk matrix. Instead, these photographs were collected from the internet.

5 CONCLUSIONS

This dissertation provides an accident risk assessment tool in the form of a risk matrix based on the characterization of the whole productive cycle of the forestry industry. The matrix is a tool that can be used individually in different countries where, after adapting the occupational accident risks to their local conditions, it can be used to evaluate them.

The matrix is easy to apply to different scenarios of harvesting operations where adaptability is key. It also enables the systematization of all information in order to reduce the risk of the evaluation being dependent on the technician who performs it. If all of the information is clear, different technicians can conduct the risk assessment in the same manner.

Furthermore, it enables a full view of which sub-processes require more intervention, which is also helpful for risk management.

In this work, 87 occupational accident risks were characterized and analysed through three different methods. Although these methods are not fine-tuned for the forestry industry, they produced interesting results such as identifying the most urgent or critical processes and sub-processes.

The processes and sub-processes where there were more cases of critical and urgent occupational accidents in all methods were:

- the motor-manual felling process, including navigating through rough and potentially active terrain, planning the felling, felling the tree, retreat from the falling tree area sub-processes;
- motor-manual processing, presenting navigating through rough and potentially active terrain, debranching the tree, crosscutting the tree, chainsaw operation as the featured sub-processes;
- loading and transport, highlighting preparing and positioning the truck, loading, loading the cargo, securing load, transport, organizing landing area.

The extraction process, especially the cable-suspended extraction, is also featured in IRMM evaluation method with a high number of occupational accident risks classified as very high or extreme, namely the following sub-processes: Move loads and materials, hauling materials to the landing area, receiving materials in the landing area.

The IRMM produced the most balanced and promising results out of the three used methods. Future work will most likely include adapting this method to better suit the forestry industry's occupational accident risk assessment by including a probability parameter associated with severity, as well as adjusting the valuation of each parameter.

In order to validate the revised method a significant number of OSH technicians should apply it independently, given the same risk analysis information. The method's consistency and reliability will be determined by aggregating the results.

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APPENDIX 1 - SUMMARIZED LITERATURE REVIEW TABLE

AUTHORS, YEAR	TITLE	OPERATION/TASK	HAZARDS	RISKS	MAIN FINDINGS/RESULTS	PROTECTIVE/PREVENTIVE MEASURES	MAIN CONCLUSIONS

Conway., et al. (2017)	A Qualitative Assessment of Safe Work Practices in Logging in the Southern United States	Chainsaw operation; maintenance/repair	Biohazards; chainsaw; chemicals; trucks	**Accident risks:** falls machine rollover, securing cargo, slips, struck by/against trips. O**ccupational disease risk:** diesel exhaust exposure, incorrect and repetitive postures/movements, noise exposure, physical overexertion, saw dust exposure; heat exhaustion, **Psychosocial risk:** work stress/production pace	Identification of risk sources and factors.	NM	Participants were motivated to work in a safe environment, but underestimated risks in the workplace; divergent levels of confidence in co-workers.

Menegon., et al (2019)	Preparation of a Matrix of Occupational Health and Safety Risks in a Wood Company	Reception/unloading raw material; processing raw material, maintenance and cleaning of machines and equipment; chainsaw operation, operation, storage, and delivery of processed wood.	Harvester, hazardous, chemicals, logs, performer, saws, thickener, trimmer, trucks, tupia, unspecified logging machinery	**Accident risks**: cuts, death, falls, heat exhaustion, limb amputation, machine rollover, securing cargo, slips, struck by/against, trips, unspecified physical injury, venomous animals. **Occupational disease risk**: diesel exhaust exposure, incorrect postures/movements, noise exposure, physical overexertion, saw dust exposure.	Risk assessment according to BS OHSAS 18001: 2007.	Delimitate/signal hazardous areas; emergency stop system on machines; checklist for periodic maintenance of equipment and material, provide new CPE; training for the appropriate usage of CPE an PPE; training for the appropriate usage of the PPE.	Easy and low-cost steps can be taken to boost the workers quality of life as well as their productivity.

Nkomo., (2018)	Effectiveness of Health and Safety Training in Reducing Occupational Injuries Among Harvesting Forestry Contractors in KwaZulu-Natal	Cable yarding timber extraction; chainsaw operation; driving short haul vehicles; felling and cutting trees	Chainsaw, logs	**Accident risks**: falls, slips, struck by/against, trips. O**ccupational disease risk:** physical overexertion. **Psychosocial risk:** work stress / production pace.	Male workers, younger in age, under production pressure and with less experience, translates into a higher risk or occupational injury.	Health and safety training	Training to accident prevention, proper awareness, and attitude to safety.1

Kim, et al. (2017)	Occupational Safety and Health Concerns in Logging: A Cross-Sectional Assessment in Virginia	Chainsaw operation, driving short haul vehicles, felling and cutting trees, processing raw material, reception/unloading raw material, unspecified machine operation.	Chainsaw, logs, unspecified logging machinery	**Accident risks**: falls, machine rollover, slips, struck by/against, trips, unspecified physical injury. occupational disease risk: diesel exhaust exposure, ergonomic risk (incorrect postures), physical overexertion. **Psychosocial risk**: work stress / production pace.	Machine operation related risks.	OSH training; awareness of diesel exhaust exposures; awareness of the risk of MSD's, maintenance of machines, proactive proximity detection in the logging machines, provide safer and more ergonomic logging machines; adequate PPE, training for the appropriate usage PPE.	Three focus areas were identified: struck-by/against hazards, situational awareness during logging and visibility hazards.

Rodriguez., et al. (2019)	Work-Related Musculoskeletal Symptoms among Loggers in the Ark-La-Tex Region	Unspecified machine operation	Unspecified logging machinery	**Occupational disease risk:** ergonomic risk (incorrect postures), ergonomic risk (repetitive movements), physical overexertion. **Psychosocial risk**: work stress/ production pace.	Work-related Musculoskeletal symptoms interactions with work variables, environmental factors, and personal risk factors.	NM	Future interventional studies to encourage the removal of undesirable musculoskeletal consequences, on the following topics: job rotation, strategic rest breaks, machinery ergonomics, quantitative studies on physical exposures, larger sample studies.

Lima., et al. (2020)	Wood-logging process management in Eastern Amazonia (Brazil)	Crosscutting top trees/bases/logs and obstacles, cubage and stacking, felling and cutting trees, infrastructure construction, loading and transport, skidding, skidding planning	NM	NM	Logging companies' workflow, best practices.	provide safer and more ergonomic logging machines	The use of specialized equipment fitted with protective measures and articulated grappling forestry tractors in the tree skidding process is important to reduce the vulnerability of workers to the risk of occupational accidents. It was observed that safety equipment was not always used, making it hard for safety engineers, who often had to double-check the worker's use of safety equipment.

Lagerstrom., et al. (2019)	Determinants of safety climate in the professional logging industry	NM	NM	NM	The value of assessing the safety climate rather than injury reports is the opportunity to foresee and face risks before an injury or fatality happens.	NM	Worksite's safety climate is not consistent but differs greatly based on determinants such as socio-demographic variables.

Bonauto., et al. (2019)	Injury Rate Comparisons for Nonmechanized and Mechanized Logging Operations, Washington State, 2005-2014	cable yarding timber extraction, felling and cutting, loading and transport, skidding, skidding planning,	biohazards, chainsaw, hazardous chemicals, logs, unspecified logging machinery	**Accident risks:** cuts, falls, fractures, machine rollover, securing cargo, slips, struck by/against, trips. **occupational disease risk**: repetitive movements, noise, physical overexertion.	Mechanized logging offers a considerable safety advantage over nonmechanized logging operations.	Introduce more mechanization in the logging operations	Non-mechanized logging operations are far more hazardous than mechanized logging operations.

AUTHORS, YEAR	TITLE	OPERATION/TASK	HAZARDS	RISKS	MAIN FINDINGS/RESULTS	PROTECTIVE/PREVENTIVE MEASURES	MAIN CONCLUSIONS

Landekic, et al. (2019)	Assessment and Comparison of Machine Operators' Working Posture in Forest Thinning	chainsaw operation, crosscutting top trees/bases/logs and obstacles, driving short haul vehicles, felling, and cutting trees, harvester operation	Chainsaw, forwarder, harvester	**Occupational disease risk**: incorrect postures	Chainsaw operator work was riskier than the work of the harvester and forwarder operators.	NM	Application and implementation of the achievements of the international best OSH practice.

Soranso., et al. (2019)	Risk Analysis in a Tropical Forest Wood Exploration and Processing System in Mato Grosso State, Brazil	Chainsaw operation, crosscutting, cubage and stacking, driving short haul vehicles, felling, and cutting trees, loading and transport, processing/reception/unloading raw material, skidding, storage and delivery	chainsaw, saws, tractor, trucks, unspecified logging machinery	**Accident risks:** heat exhaustion occupational disease risk: noise, vibration	Unhealthy up to intolerable levels were detected in some activities.	NM	Need to implement corrective measures to heat exposure and control measures to noise and vibrations exposure.

Iftime., et al., (2020)	Chainsaw operators' exposure to occupational risk factors and incidence of professional diseases specific to the forestry field	Chainsaw operation	Chainsaw	**Occupational disease risk**: diesel exhaust exposure, incorrect posture, microclimate/macroclimate, noise e, saw dust, vibration	Values that largely exceeded the reference limits provided by legislation.	Improve awareness of the risk of MSD's, organized breaks, reduction of working time, provide adequate PPE	Measures are proposed to mitigate the exposure and reduce the impact of these risks on the workers' health.

Cremasco., et al. (2019)	Risk assessment for musculoskeletal disorders in forestry: A comparison between RULA and REBA in the manual feeding of a wood-chipper	Wood chipper operation	Wood-chipper	**Occupational disease risk**: incorrect postures, repetitive movements	None of the tasks reported a score referable to a negligible or low risk as well as a very high-risk level that would require an immediate intervention.	Improve awareness of the risk of MSD's, training on the mechanics of the operated machines	RULA method is more suitable than the REBA method for the evaluation of postural overload in the human–machine interaction related to a manually fed wood-chipper.

Spinelli., et al., (2017)	Postural risk assessment of mechanized firewood processing	Wood chipper operation	Wood-chipper	**Occupational disease risk**: incorrect postures, repetitive movements	Simple, manually operated new machines incur a higher postural risk compared with semi- or fully automatic machines.	Improve design or upgrade machines to newer models	In all cases, attention should be paid to postural risk that may occur during blockage resolution.

Cheţa., et al. (2018)	Workload, exposure to noise, and risk of musculoskeletal disorders: A case study of motor-manual tree feeling and processing in poplar clear cuts	Chainsaw operation, crosscutting top trees/bases/logs and obstacles, driving short haul vehicles, skidding, skidding planning	Chainsaw	**Occupational disease risk:** incorrect postures, noise exposure, physical overexertion	Evaluate the postural risk indexes, automatic procedures, and tools.	Organized breaks, provide adequate PPE	Motor-manual tree felling, and processing of flatland popular forests is heavy and hazardous work which loads the operators with heavy strains, exposes them to unacceptable noise levels and increased risks of musculoskeletal disorders.

Enez., et al. (2019)	Comparison of ergonomic risk assessment outputs from OWAS and REBA in forestry timber harvesting	Chainsaw operation, crosscutting top trees/bases/logs and obstacles, felling, and cutting trees, loading and transport, skidding	Chainsaw, logs, tractor, trucks	**Occupational disease risk**: incorrect postures, physical overexertion	OWAS was a statistically significant difference between logging and skidding and between loading and skidding. REBA was statistically significant between logging and skidding, logging, and loading, and skidding and loading.	NM	Ergonomic working principles can be applied to labor under open air conditions. These methods should now be applied to other forestry works to define the OSH risks of typical work postures in forestry, especially in terms of MSDs.

Garland., et al. (2019)	Safety in steep slope logging operations	Chainsaw op., crosscutting top trees/bases/logs and obstacles, felling, and cutting trees, maintenance of machines and equipment, manual timber cutting, walking in the woods	Chainsaw, logs, steep slopes, unspecified logging machinery	**Accident risks:** cuts, falls, machine rollover, slips, struck by/against, trips, **Occupational disease risk**: microclimate/macroclimate exposure, noise, physical overexertion, vibration	The productivity of the new technologies of steep slope logging also reduces the number of workers exposed to the hazardous tasks in felling and yarding.	Provide safer and more ergonomic logging machines, Introduce more mechanization in the logging operations	There is a reduction in exposure to hazards and a reduction in workers exposed to the most serious work in logging, felling, and working on cable operations on steep slopes.

Rosecrance., et al. (2017)	Job factors associated with occupational injuries and deaths in the United States forestry industry	cable yarding timber extraction, chainsaw operation, crosscutting top trees/bases/logs and obstacles, felling, and cutting trees, loading and transport, reception/unloading raw material, skidding	chainsaw, logs, steep slopes, trucks	**Accident risks:** cuts, death, falls, securing cargo, slips, struck by/against **Occupational disease risk**: incorrect postures, microclimate/macroclimate, physical overexertion	For some workers (fellers and hookers) the work is physically demanding throughout the work shift, while for others (machine operators, truck drivers) it can involve several hours of sustained sitting with intermittent periods of high forceful lifting and securing of equipment and loads.	Emergency first aid training, health, and safety training	Work conditions (extreme cold temperatures, steep incline of mountain slope), as well as job factors (felling and cutting trees, skyline skidding, driving logging trucks) contributing to increased risk for occupational related injury and death.

Danilović., et al. (2016)	Forestry work-related injuries in forest estate "sremska mitrovica" in Serbia	Chainsaw operation, loading and transport, manual timber cutting, unspecified machine operation	chainsaw, logs, tractor, trucks, unspecified logging machinery	**Accident risks**: falls, struck by/against, physical injury	Discussion of the relationship between injuries and experience/worktime/time of day, etc.	NM	Create new injury reports forms to facilitate this type of analysis and future work.

AUTHORS, YEAR	TITLE	OPERATION/TASK	HAZARDS	RISKS	MAIN FINDINGS/RESULTS	PROTECTIVE/PREVENTIVE MEASURES	MAIN CONCLUSIONS

Jankovský., et al. 2019	Is timber haulage safe? A ten-year study of occupational accidents	Loading and transport, maintenance and cleaning of machines and equipment, reception/unloading raw material	Trucks	**Accident risks:** falls, securing cargo, slips, struck by/against, trips, unspecified physical injury **Psychosocial risk**: work stress / production pace	Timber haulage was found to be a relatively safe occupation, regarding the number of occupational accidents.	Health and safety training, improve design or upgrade machines to newer models	The results showed that from the view of vehicle ergonomics and safety, the conditions improved significantly for the employees and the investments of the company's renewal of its fleet paid off.

Yovi., et al. (2018)	An occupational ergonomics in the Indonesian state mandatory sustainable forest management instrument: A review	NM	NM	NM	Forestry workers still showing poor OSH knowledge on hazards, sources of hazards, risk, and injured or losing party when an incident occurred.	NM	This paper offers a new approach in studying gap implementation and formulated policy recommendation on Indonesia's mandatory SFM instrument.

Yovi., et al. (2019)	Addressing occupational ergonomics issues in Indonesian forestry: Laborers, operators, or equivalent workers	Chainsaw operation, Cubage and stacking, felling, and cutting trees, loading and transport, manual timber cutting, processing/reception/unloading raw material, skidding	Chainsaw, logs, tractor, trucks, unspecified logging machinery	**Accident risks**: cuts, falls, machine rollover, securing cargo, slips, struck by/against, trips, venomous animals **Occupational disease risk**: ergonomic risk (incorrect postures), physical overexertion	Labor-intensive and semi- mechanized harvesting still plays a role as the back- bone of forest operations in Indonesia.	Health and safety training, increase wages, provide safer and more ergonomic logging machines	Increase wage rate, improve workers knowledge of OSH.

Jankovský., et al. (2019)	What are the occupational risks in forestry? Results of a long-term study in Slovakia	Chainsaw operation, driving short haul vehicles, felling, and cutting trees, loading and transport, maintenance, and cleaning of machine/equipment, processing raw material, reception/unloading raw material, skidding, unspecified machine maintenance/repair, walking in the woods	Biohazards, chainsaw, logs, steep slopes, unspecified logging machinery	**Accident risks:** cuts, death, falls, fractures, limb amputation, slips, struck by/against, trips, unspecified physical injury; **occupational disease risk**: diesel exhaust, microclimate/macroclimate, noise, physical overexertion, vibration.	The high share of accidents occurring to young workers points to the industry's underperformance in safety training. Time period observations concerning occupational accidents.	Enforcing safety measures	More mechanizing procedures: safe practices at work and incentivizing them to work safely.

Ghaffariyan., et al.(2016)	Analysis of forestry work accidents in five Australian forest companies for the period 2004 to 2014	Cable yarding timber extraction, felling and cutting trees, loading and transport, unspecified machine operation	Chainsaw, logs, trucks, unspecified logging machinery	**Accident risks:** cuts, falls, fractures, slips, struck by/against, trips, unspecified physical injury **occupational disease risk:** ergonomic risk (incorrect postures), noise exposure	Detailed analysis of the compiled data from the accident reports.	Health and safety training, improve awareness of the risk of MSD's, provide adequate PPE	The incident reporting system should be improved to capture details of working accidents for the purposes of better work safety management; Personal errors such as lack of PPE, operator error, poor body position and poor techniques applied. OSH training could be delivered to forestry workers.

Laschi., et al. (2016)	Identifying causes, dynamics, and consequences of work accidents in forest operations in an alpine context	Cubage and stacking, felling, and cutting trees, infrastructure construction, loading and transport, reception/unloading raw material, unspecified machine operation, walking in the woods	Biohazards, chainsaw, logs, steep slopes, unspecified logging machinery	**Accident risks:** death, falls, slips, struck by/against, trips, venomous animals	Motor- manual 'felling and processing' is the most dangerous phase. Distribution of injuries during the week is not consistent with other studies, thus suggesting the needs of further analysis of this aspect.	Better distribution of assignments	Archiving work accidents in forestry separated from agricultural ones. Archiving information regarding work accidents would permit to develop survey at larger scale, involving a high number of injuries.

Eroglu, et al. (2015)	A Study on Determining the Physical Workload of the Forest Harvesting and Nursery-Afforestation Workers	chainsaw operation, harvester operation, Nursery-afforestation	NM	Psychosocial risk: work stress / production pace	both positions were classified as medium-weight work, although harvesting workers presented higher values during activity.	Better distribution of assignments, organized breaks, health checks	Proper work plan to avoid peaks, work assigned according to aerobic capacities.

Yovi, et al. (2015)	Strategy to disseminate occupational safety and health information to forestry workers: The felling safety game information to forestry workers: the felling safety game	cable yarding timber extraction, chainsaw operation, felling and cutting trees	bio-hazards, chainsaw, uneven/slippery surfaces, dead branches/twigs and other obstacles	Accident risks: unspecified physical injury Occupational disease risk: ergonomic risk (incorrect postures), microclimate/macroclimate exposure, physical overexertion Psychosocial risk: work stress / production pace	It was considered that the workers and supervisors ha insufficient OSH knowledge which was due to limited access to information and the cost of training.	Health and safety training; provide workers with training for the appropriate usage of the personal protection equipment	the developed game met the requirements set by the author to improve OSH knowledge for the activity of manual/motor tree harvesting.

Melemez, Kenan. (2015)	Risk factor analysis of fatal forest harvesting accidents: A case study in Turkey	driving short haul vehicles, felling and cutting trees, loading and transport, skidding.	chainsaw, logs, tractor, trucks	Accident risks: death, securing cargo, struck by/against. Occupational disease risk: physical overexertion. Psychosocial risk: work stress / production pace.	The two most important causes of accidents were personal factors as well as organizational factors, the major sub-factors were also identified.	Enforcing safety measures, health and safety training, training on the mechanics of the operated machines, provide workers with training for the appropriate usage of the collective protection equipment, provide adequate PPE, provide workers with training for the appropriate usage of the personal protection equipment.	Prevention of fatal accidents during forestry operations is a challenging task with a wide range of factors to be considered.

AUTHORS, YEAR	TITLE	OPERATION/TASK	HAZARDS	RISKS	MAIN FINDINGS/RESULTS	PROTECTIVE/PREVENTIVE MEASURES	MAIN CONCLUSIONS

Newman, et al. (2018)	Human Factors Affecting Logging Injury Incidents in Idaho and the Potential for Real-Time Location-Sharing Technology to Improve Safety	cable yarding timber extraction, chainsaw operation, felling and cutting trees, maintenance and cleaning of machines and equipment	chainsaw, logs, steep slopes, unspecified logging machinery, dead branches/twigs and other obstacles	Accident risks: cuts, falls, machine rollover, slips, struck by/against	Production pressure, inexperience and fatigue are among the main factors identified by the workers as catalysts for logging injuries	NM	Limitations for the location-sharing technology are the cost and the distracting potential

Yovi, et al. (2015)	High Risk Posture on Motor-Manual Short Wood Logging System in Acacia mangium Plantation	chainsaw operation, crosscutting top trees/bases/logs and obstacles, felling and cutting trees, processing raw material, manual hauling	chainsaw, logs	Occupational disease risk: ergonomic risk (incorrect postures), physical overexertion	High/very high risk levels of MSD´s were detected through REBA, in felling, bucking and manual hauling	Health and safety training	The increase of OSH knowledge among workers would influence the safe behaviour

Marchi, et al. (2017)	Analysis of dust exposure during chainsaw forest operations	chainsaw operation, crosscutting top trees/bases/logs and obstacles, felling and cutting trees,	chainsaw, steep slopes	Occupational disease risk: diesel exhaust exposure, noise exposure, saw dust exposure, vibration exposure	The type of fuel did not affect the cutting performance, the exposure to wood dust was usually lower than the operational exposure limit set for this country only 2 samples exceeded this limit.	NM	The current European operating exposure levels for wood dust might not be taking into account variables present in field operations

Poje, et al. (2016)	A Case Study of the Impact of Skidding Distance on Tractor Operator Exposure to Noise	driving short haul vehicles, skidding, skidding planning,	tractor, unspecified logging machinery	Occupational disease risk: diesel exhaust exposure, noise exposure, physical overexertion, saw dust exposure, vibration exposure	The exposure of a tractor operator to noise increases with skidding distance	Better distribution of assignments	Other factors should be taken into consideration to evaluate the exposure to noise, this study is only focused on skidding distance. Proper work planning would decresase noise exposure.

Corella justavino, et al. (2015)	The use of OWAS in forest operations postural assessment: advantages and limitations	chainsaw operation, crosscutting top trees/bases/logs and obstacles, felling and cutting trees, manual hauling	chainsaw, logs, uneven/slippery surfaces, dead branches/twigs and other obstacles	Occupational disease risk: ergonomic risk (incorrect postures)	There are some specific situations where careful analyses is needed.	NM	Video recording and implementing the OWAS method has a lot of potential to successfully assess physical workload in forest operations

Fonseca, et al. (2015)	Effect of noise emitted by forestry equipment on workers hearing capacity	NM	chainsaw, forwarder, harvester, saws	Occupational disease risk: noise exposure	The years of exposure to noise from forestry equipment can adversely affect hearing. Workers with hearing protection equipment had lower threshold.	NM	Protective hearing equipment was found to reduce hearing loss particularly in higher frequencies. A similar research with more participants would increase the reliability of these findings

Poje, et al. (2019)	Operator Exposure to Noise and Whole-Body Vibration in a Fully Mechanized CTL Forest Harvesting System in Karst Terrain	driving short haul vehicles, felling and cutting trees, forwarder operation, harvester operation, skidding	forwarder, harvester	Occupational disease risk: noise exposure, vibration exposure	Exposure to noise does not exceed the limits imposed by European directives but the whole-body vibrations levels do.	Improve design or upgrade machines to newer models	Technical improvements on the machines are necessary to improve the registered levels.

Lagerstrom, et al. (2019)	Active Surveillance of Musculoskeletal Disorder Symptoms in the Development of Safety Interventions for Professional Loggers	chainsaw operation, driving short haul vehicles, felling and cutting trees, forwarder operation, harvester operation, loading and transport, processing raw material, reception/unloading raw material, skidding	chainsaw, forwarder, harvester, logs, steep slopes, tractor, trucks , uneven/slippery surfaces	Accident risks: cuts, death, falls, fractures, heat exhaustion, securing cargo, slips, struck by/against, trips, unspecified physical injury, Occupational disease risk: diesel exhaust exposure, ergonomic risk (incorrect postures), microclimate/macroclimate exposure, noise exposure, physical overexertion, vibration exposure Psychosocial risk: work stress / production pace	The mechanized harvesting operations are safer than the conventional harvesting operations	Introduce more mechanization in the logging operations	Quantifying the symptom prevalence on the current logging population helps to identify opportunities for improvements

Iftime, et al. (2020)	An investigation on major physical hazard exposures and health effects of forestry vehicle operators performing wood logging processes	driving short haul vehicles, skidding, unspecified machine operation	tractor, unspecified logging machinery	Occupational disease risk: diesel exhaust exposure, microclimate/macroclimate exposure, noise exposure, vibration exposure	Noise and whole-body vibrations are likely to exceed the permissible limits. 90% of the operators were diagnosed with occupational pathologies.	Better distribution of assignments, improve awareness of the risk of MSD's , training on the the mechanics of the operated machines, Introduce more mechanization in the logging operations, health checks	The cumulative effect of microclimate, physical exertion and vibrations increases the risk of occupational illnesses

APPENDIX 2 - COMPLETE LITERATURE REVIEW TABLE

This can be found in the attached Excel document with the name “Appendix 2_Complete literature review table”.

APPENDIX 3 - RISK MATRIX

This can be found in the attached Excel document with the name “Appendix 3_Risk Matrix”.

ATTACHMENT 1 – IRMM METHOD

The adopted model of this method, IRMM (Integrated Risk Management Method), is illustrated here.

Evaluation parameters	Description	Value
Severity of the event (S)	Events that can cause death Events that can cause serious injuries, or injury with absolute permanent disability for ordinary work and for all work	16
	Events that can cause serious injuries with absolute temporary disability >30 days, or absolute permanent disability not included in the previous point	8
	Events that can cause minor injuries with partial temporary disability or absolute temporary disability <30 days	4
	Events that can cause minor injuries without any type of associated disability	2
	Events that can cause an incident without any type of associated injury	1
Extension of the impact (E)	Event affecting more than 5 workers	5
	Event affecting 4 workers	4
	Event affecting 3 workers	3
	Event affecting 2 workers	2
	Event affecting 1 worker	1
Frequency of occurrence of the event (F)	Continuous occurrence, daily periodicity	5
	Occurs not continuously during the day, 3 or more days per week	4
	1 or 2 times per week	3
	Reduced occurrence, up to 3 times per month	2
	Isolated occurrences, associated to maintenance, emergency, accidental events	1

From these three parameters comes the following equation that presents the risk level parameter:

$$Risk\ level\ (RL) = S\ \times E\ \times F$$

Evaluation parameters	Description	Value
Performance of the prevention and control systems (PPC)	There is no prevention and control system implemented	0,5
	There is no prevention system implemented and the safety practices are limited to the occasional use of PPE	0,75
	No prevention management system implemented but functional safety procedures in place	1
	There is a prevention management system in place but no objective evidence of its adequate functionality	1,1
	There is an implemented system of continuous improvement interlinked to the safety management system	1,25

$$Weighted\ risk\ level\ (WRL) = \frac{RL}{PPC}$$

Risk category	Scoring
1 – Low	≤ 8
2 - Medium	8 ≤ RI ≤ 24
3 - High	24 ≤ RI ≤ 64
4 – Very High	64 ≤ RI ≤ 160
5 - Extreme	≥ 160

Evaluation parameters	Description	Value
Costs and technical complexity of the preventive/corrective measures for the event (CPC)	Prevention measures of low investment and basic technical complexity (solved with operating and working instructions)	400
	Prevention/correction measures with low investment and reduced technical complexity (simple intervention, small changes in equipment, PPE, training, ...)	72
	Prevention/correction measures of medium investment and medium technical complexity (Hiring OSH technician, occasional changes in equipment or processes...)	48
	Prevention/correction methodology with high investment and technical complexity (Collective protections, minor process changes, ...)	12
	Prevention/correction methodology with high investment and technical complexity (New technologies, new processes, Lay-out changes, Hiring external experts)	1

$$Priority\ Level\ (PL) = WRL\ \times CPC$$

Priority category	Scoring
1 – Low priority	≤ 800
2 – Medium priority	800 ≤ RI ≤ 2.500
3 – High priority	2.500 ≤ RI ≤ 15.000
4 – Very High priority	15.000 ≤ RI ≤ 50.000
5 – Urgent situations	≥ 50.000

ATTACHMENT 2 - NTP 330 METHOD

The NTP 330 is a simplified accident risk assessment system developed by the Spanish Institute for Occupational Safety and Hygiene.
This methodology allows the quantification of the magnitude of the existing risks coded as (NR) and rank the corrective measures. In the first phase, the probability level coded as (NP) is obtained as a function of the deficiency level (ND) and the exposure level (NE).

$$NP = ND \times NE$$

Deficiency Level (ND): is the magnitude of the expected relationship between the set of risk factors considered and their direct causal relationship with the possible accident

Deficiency Level	ND	Meaning
Very Deficient (MD)	10	Significant risk factors were detected that determine as very possible the occurrence of failures. The existing preventive measures regarding the identified risk are ineffective or non-existent.
Deficient (D)	6	Some significant risk factors have been detected that need to be corrected. The effectiveness of the existing set of preventive measures is poor.
Improvable (M)	2	Risk factors of minor importance. There is some effectiveness of the set of preventive measures regarding risk.
Acceptable (A)	-	No anomalies have been detected. The risk is under control.

When the ND is considered acceptable, there is no further evaluation to be done downstream.
Exposure Level (NE) is a measure of the frequency of exposure to risk and is estimated according to the length of stay in work areas, machine operations, etc.

Exposure level	NE	Meaning
Continued (EC)	4	Continuously. Several times during the workday and with prolonged time.
Frequent (EF)	3	Several times in the working day, with short times.
Occasional (2)	2	Sometimes during the working day, with short times.
Sporadic (EE)	1	Irregular.

The result of the multiplication of both levels allows us to place the probability level in one of four categories displayed in the table.

Probability level	NP	Meaning
Very high (MA)	Between 24 and 40	Deficient situation with continued exposure, or very deficient with frequent exposure. Typically the materialization of the risk occurs frequently.
High (A)	Between 10 and 20	A deficient situation with frequent or occasional exposure or a very deficient situation with occasional or sporadic exposure. The materialization of the risk is possible several times in the working life cycle.
Medium (M)	Between 6 and 8	Impaired situation with sporadic exposure, or improvable situation with continued or frequent exposure. It is possible that the damage will materialize at some point.
Low (B)	Between 2 and 4	Improvable situation with occasional or sporadic exposure. Risk is not expected to materialize.

This method then proceeds to quantify the risk level (NR) as a function of the probability level (NP) and the consequence level coded as (NC) through the equation:

$$NR = NP \times NC$$

Consequence Level (NC): classifies the human and material damage of a potential accident.

Consequence level	NC	Meaning (Human Harm)	Material Damage
Deadly or catastrophic (M)	100	1 dead or more	Total destruction of the system.
Very Serious (MG)	60	Serious injuries that may be irreparable	Partial System Destruction Financially and technically complex repair.
Serious (G)	25	Temporary Disabling Injuries	Requires stopping the process to make the repair
Light (L)	10	Minor injuries that do not require hospitalization	Reparable without stopping the process.

With the NR value, this method provides a table where it suggests 4 different levels of preventive or preventive action.

Intervention level	NR	Meaning
I	4000-600	Situation critical and requires urgent correction
II	500-150	Correct and implement control measures
III	120-40	Improve if it is possible. It would be convenient to justify the intervention and its cost-effectiveness
IV	20	There is no need to intervene, except if other more demanding analysis justifies it.

ATTACHMENT 3 - WILLIAM T. FINE METHOD

The method relies on the characterization of the risk level based on three variables:

- Consequences (C) - the most likely outcome of a potential accident;
- Exposure (E) - the frequency with which the risk situation occurs;
- Probability (P) - representing the probability associated with the occurrence of the accident.

Based on these variables it is then possible to obtain the risk level defined as (R).

$$R = C \times E \times P$$

The principles outlined in the following table can be used to define action based on the level of recognized and measured risk:

Risk	Risk classification	Action
≥ 400	Extreme	Immediate stop
250 ≤ R ≤400	Very high	Requires immediate correction
200 ≤ R ≤ 250	High	Requires correction
85 ≤ R ≤ 200	Medium	Requires attention and possible correction
< 85	Low	Acceptable in current situation

Quantification of the C, E and P variables:

Consequences (C)

Classification	Numerical attribute	Interpretation
Multiple fatalities or damage of up to 600.000€	100	Catastrophe
Fatalities or damages over 300.000€	40	Disaster
Fatalities or damages over 120.000€	15	Very serious
Permanent injuries or damages over 60.000€	7	Severe
Injury of a temporary nature or damage greater than 6000€	3	Very important
First Aid or damage greater than 600€	1	Notable

Exposure (E)

Classification	Numerical attribute	Interpretation
Continuously - several times a day	10	Very high
Often - about once a day	6	High
Occasionally - once or twice a week	3	Medium
Unusually - once or twice a month	2	Low
Rarely - once or twice a year	1	Very low
Very unlikely - not recorded in years but possible	0,5	Uncertain

Probability (P)

Classification	Numerical attribute	Interpretation
Consists of the most likely and expected outcome if the risk situation occurs - it occurs frequently.	10	Expectable
Is perfectly possible and not at all improbable - probability value of about 50%	6	Could occur

Corresponds to a rare sequence or coincidence, it is not expected to occur - probability value about 10%	3	Rare but possible
Corresponds to a sequence remotely possible. It is known it has already been registered - probability about 1%	1	Unusual
Never occurred in many years of exposure. May occur.	0,5	Conceivable but unlikely
It is practically impossible that it will occur - probability of about one in a million	0,2	Impossible

Based on the previously defined parameters this method continues to introduce the "justification" formula which can be used to estimate whether the cost of the corrective action is justified.

$$Justification\ (J) = \frac{R}{CF\ \times DC}$$

(R) – Risk level previously defined
(CF) – Cost factor, expected cost of the intervention
(DC) – Degree of correction, how much the implemented measure is expected to reduce the value of the risk

Cost factor (CF)

Estimated cost (€)	**Score**
Over 30000	10
Between 15000 and 30000	6
Between 6000 and 15000	4
Between 3000 and 6000	3
Between 600 and 3000	2
Between 300 and 600	1
Under 300	0,5

Degree of correction (DC)

Correction, expected effectiveness	**Score**
100%	1
75%	2
Between 50% and 75%	3
Between 25% and 50%	4
Under 25%	6

After determining the value for the justification, the following limits are suggested:
J >10 Justified
J < 10 Not justified