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TAMPERE UNIVERSITY OF TECHNOLOGY

HENRIIKKA TUOMINEN

THE MODERNIZATION OF SAFEGUARDS TO IMPROVE THE SAFETY OF THE MACHINERY

Master of Science Thesis

Examiner: prof. Jouni Kivistö-Rahnasto
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ABSTRACT

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The safety of machinery influences the health and safety of numerous workers globally. Clearly, the safety of machinery is not at required level since machinery-related accidents still take place. Due to the poor design of the safety of machinery the workers are exposed to hazards. The design of machinery should be improved in order to prevent accidents. In the first place, the machinery should be designed to be inherently safe. One way to improve the safety of an existing machine is to modernize the machine.

This thesis analyzed the safety of a machine which was operated by Ahlstrom-Munksjö Tampere Oy. The research provided information on safety modernization of the machine, concentrating on one area of the machine which has been rather difficult to improve. The research method combined a constructive approach and a risk assessment method presented by the standard ISO 12100 Safety of Machinery and it was supplemented by the technical report ISO/TR 14121-2 Safety of Machinery aiming at finding the problems and corresponding solutions.

Safety deficiencies and hazards were occurring especially within the rotating elements of the machinery. The proposed solutions to reduce the risks related to the hazards included improving safeguards, mainly guards which deny access to the hazardous zone. Almost all the risks were eliminated or reduced by proposed solutions.

The research studied only one limited area of the machine and investigation of the whole machine was not on the scope. The implementation of proposed solutions was also excluded from the scope. The effectiveness of the solutions in reality should be assessed after the implementation.

The research provided a method to combine several different aspects and to conduct relevant information regarding design of machinery in modernization. It made sure that task based hazards are assessed systematically. This method was transferable to other plants, industries and machineries where human–machine interface existed.

TIIVISTELMÄ

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Koneiden turvallisuus vaikuttaa lukuisten työntekijöiden terveyteen ja työturvallisuuteen maailmanlaajuisesti. Koneiden turvallisuus ei ole riittävällä tasolla, sillä koneista johtuvia tapaturmia tapahtuu edelleen. Työntekijät altistuvat koneiden vaaroille koneiden puutteellisen turvallisuussuunnittelun takia. Tapaturmien ehkäisemiseksi koneiden suunnittelua on parannettava. Ensisijaisesti koneet olisi suunniteltava luontaisesti turvallisiksi. Koneen modernisointi on yksi tapa parantaa olemassa olevan koneen turvallisuutta.

Diplomityö tutki Ahlstrom-Munksjö Tampere Oy:n tuotantokoneen turvallisuutta. Työ tuotti tarvittavaa tietoa koneen turvallisuusmodernisointia varten keskittyen koneen osaan, jota on ollut erityisen hankala kehittää. Tutkimusmenetelmä yhdisti konstruktiivista lähestymistapaa ja ISO 12100 -koneturvallisuusstandardin esittelemää riskienarviointia, jota täydennettiin koneturvallisuuden ISO/TR 14121-2 -teknisen raportin tiedoilla. Tutkimusmenetelmä tähtäsi ongelmien ja niihin soveltuvien ratkaisujen löytämiseen.

Turvallisuuspuutteita ja vaaroja esiintyi erityisesti koneen pyöriviin osiin liittyen. Ehdotetut ratkaisut riskien vähentämiseen sisälsivät suojausteknisiä toimenpiteitä, pääasiassa suojuksia, jotka estävät pääsyn vaara-alueelle. Ratkaisut poistivat tai vähensivät lähes kaikki tunnistetut riskit.

Diplomityö tutki vain yhtä rajallista aluetta, eikä konetta tutkittu kokonaisuutena. Diplomityö ei myöskään ulottunut ehdotettujen ratkaisujen toteutukseen. Ratkaisujen vaikuttavuutta käytännössä pitäisi tutkia niiden toteutuksen jälkeen.

Diplomityö esitteli tavan yhdistää useita erilaisia näkökulmia ja tarpeita ja muodostaa niistä tarvittavaa tietoa koneen modernisoinnin suunnitteluun. Tällä tavalla työtehtäviin liittyvät vaarat voitiin arvioida järjestelmällisesti. Metodi toimii myös muille tehtaille, teollisuuden aloille ja koneille, joissa on ihminen–kone -vuorovaikutus.

PREFACE

Ahlstrom-Munksjö Tampere Oy, especially Safety Manager Sami Vähätalo, who gave practical guidance for this thesis, and Plant Manager Nicolas Evrard made this wonderful opportunity for me to write a Master's thesis on such an inspiring topic possible. Users of the analyzed machine gave their significant contribution to help my work, and I received great support from the whole personnel of the company. I am grateful, thank you all!

I would like to thank Professor Jouni Kivistö-Rahnasto for directing and examining this thesis. Also, I would like to thank Juliette Coirier, the fellow students and friends of the SaFir club and all the other people who helped me during this work. And of course, a special thank you belongs to my dear husband.

In Tampere, Finland, on 30 July 2017

Henriikka Tuominen

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ABBREVIATIONS

EEA	European Economic Area
ERP	Enterprise Resources Planning
EU	European Union
FMEA	Failure Modes and Effects Analysis
HAZOP	Hazard and Operability study
ISO	International Standardisation Organisation
JSA	Job Safety Analysis
LOTO	Lock Out/Tag Out procedure
OSH	Occupational Safety and Health
PPE	Personal Protective Equipment
SPE	Sensitive Protective Equipment
SWIFT	Structured What-If Technique

1. INTRODUCTION

The safety of machinery influences the health of numerous workers globally. On average, more than 6’000 workers die every day due to the work they are doing (Hämäläinen 2010). Even though the minority of these fatalities originates from machines, machinery-related accidents in industry cause remarkable and negative consequences on people’s health (Backström & Döös 1997; Jocelyn et al. 2016). In addition, occupational accidents have an impact on organizations and societies by decreasing productivity (Hämäläinen 2010) and increasing costs (Schulte et al. 2008; Aaltonen et al. 1996). By legislation many countries try to decrease the occupational injuries and their negative effects and guarantee safe work places for workers. In spite of the binding legislation, there are machines in use in the work places which do not reach the required level of safety (Malm & Hämäläinen 2006) and cause fatal accidents (Kivistö-Rahnasto 2009) or severe non-fatal accidents (Lind 2008). At least in the member states of the European Union (EU), it is the employers’ responsibility to ensure that machines in use comply with the legislation of today (D 89/391/EEC). In the first place, machines should be designed to be safe (SFS-EN ISO 12100:2010) but once it is not possible anymore for an old machine, one way to improve the safety of an existing machine is to modernize the machine (Malm & Hämäläinen 2006).

This thesis is made in cooperation with Ahlstrom-Munksjö Tampere Oy. The company operates a machine which produces nonwoven with a wet-laid technique. The machine is almost 4 decades old, therefore, old age sets demands for upgrading and modernizing it from time to time. Many parts of the machine have been updated through the years; yet its purpose of use has remained the same. The modernization of the machine is necessary again, especially in one area of the machine which has been rather difficult to improve. A recent safety audit confirmed issues in the safeguarding and an action plan was set. One relevant aspect to be improved is the safety of the machine, as the development of technology enables safer solutions than in the past (Malm & Hämäläinen 2006). Also, Ahlstrom-Munksjö Oyj, to which Ahlstrom-Munksjö Tampere Oy belongs, has globally been focusing on unifying the practices of its factories regarding the safety and safeguards of the machinery during the latest years.

This thesis provides information to Ahlstrom-Munksjö Tampere Oy regarding the safety modernization of the machine. The scope of this thesis is the safety of machinery focusing on safety modernization and safeguards. The objectives of the thesis are (1) to identify safety requirements, regarding the modernization of the chosen area of the machine, especially concentrating on safeguards, (2) to identify deficiencies and hazards related to the safety of this area of the machine and (3) to propose solutions to meet these requirements and reduce the risks related to the hazards. The objectives will be achieved by a mixed research strategy combining a constructive approach with a risk assessment method presented by the standard ISO 12100 Safety of Machinery and supplemented by the technical report ISO/TR 14121-2 Safety of Machinery. The analyzed machine is located in Finland; consequently, the statutory requirements for the machine are based on Finnish legislation. The modernization of the work equipment, which is in use, is under the Government Decree (12.6.2008/403), which provides requirements on safe use and inspection of work equipment, and a CE marking normally required for machines is not applicable since the machine has been commissioned before the year 1995 (A 12.6.2008/400).

The results of this thesis make sure that risks related to task based hazards in the chosen area of the machine are systematically assessed and they will be used as a basis for safety modernization. The results help the company to further improve the safety of the machine and of the working environment, which is also part of the company's continual improvement process. The chosen area of the machine is especially complex when it comes to integrating usage of the machine, safeguarding, variation of different products and all the requirements these issues set. Therefore, the requirements of operations of the machine are an important aspect to be taken into account while modernizing the machine and users of the machine play a big role as a source of information.

There are some limitations in this research. It studies only one limited area of the machine and investigation of the whole machine is not on the scope. The technical design and implementation of proposed solutions and safeguards are excluded, too. However, the results of the thesis are verified by comparing them to possible technical design and execution which were outsourced of this thesis. The reassessment of risks related to the machine and its working environment will be carried out only after the implementation of the results and safeguards. The company will continue utilizing the results later on.

The framework for this thesis is provided in Chapter 2. Chapter 3 represents Object and Execution of the Research and demonstrates step by step the phases of the research. The results of the research are gathered and analyzed in Chapter 4 about each phase of the research. A discussion is presented in Chapter 5. Chapter 6 is the Conclusion of the thesis. Lastly, Appendix A shows an Open Questionnaire for Personnel used within this thesis, and Appendixes B and C includes Tables for Applicable Safety Requirements of the Government Decree (12.6.2008/403) and Risk Assessment.

2. FRAMEWORK

2.1 Hazards and Safety of Machinery

Machineries cause hazards to multiple people: to those who use them, to those who are not using them but are nearby for different work-related reasons and even to those external people who have nothing to do with the machinery but just happen to be close by. Hazards of machinery should be minimized and machineries should be designed and made safe in order to reduce negative effects which machinery can cause. "Safety of machinery" can be seen as an ability of a machine to carry out safely all the functions that the machine is designed to carry out during its life cycle. It presumes that risks related to the hazards of the machine are reduced adequately. (SFS-EN ISO 12100:2010)

Hazards especially related to machineries are divided into different categories, such as mechanical, electrical, thermal, noise, vibration, radiation, material, ergonomic hazards, and hazards associated with the environment in which the machine is used. Additionally, different kinds of combinations of these hazards are always possible as well. *Hazard* is defined as a "potential source of harm" and *harm* as a "physical injury or damage to health" in the standard of Safety of Machinery. With each hazard, there is a hazardous zone. When a person or a body part of a person is in the hazardous zone, hazardous situations and hazardous events can occur and the person is exposed to the hazard. This may lead to harm. It can either happen suddenly, such as an accident, or in case of a long-term exposure, such as a loss of hearing which gradually appears. Hazards and hazardous zones can exist permanently somewhere or they can appear occasionally, which might complicate discovering them and increase the possibility of harm. (SFS-EN ISO 12100:2010) Several definitions of what *risk* is can be found, however, usually probability of potential consequences of some activity and severity of these consequences are involved in the definition of risk. Potential consequences can, for instance, mean harm to a person's health. (Aven 2008; SFS-EN ISO 12100:2010; Gauthier & Charron 2002)

A poor design of machines causes accidents (Driscoll et al. 2008; Chinniah 2015) and the design of machines should be improved in order to prevent accidents (Bluff 2014; Backström & Döös 1997). Safety aspects of the machinery should be taken into account during the design phase (Gauthier & Charron 2002). Designing a machinery to be inherently safe is the most efficient way to develop the safety of machinery (SFS-EN ISO 12100:2010; Aven 2008). However, producing safe machinery is not an unambiguous issue. Gathering information about experiences of using machines and related accidents would be a good feedback in order to improve the design of machines but gathering such information has proven to be rather difficult (Jocelyn et al. 2016). Accidents take place regardless of safeguards and other safety measures (Chinniah 2015; Backström & Döös 2000; Aneziris et al. 2013). In Chinniah's study (2015) the major reason for accidents related to machines was that moving parts were accessible; for instance there were problems with safeguarding and a lack of them. Bluff's study (2014) revealed that most of the studied manufacturers of machinery either failed to inform the users of the machine about related hazards or had not pledged safe design and construction of their machineries.

Lind (2008) reckoned that machine safety design might have advanced even though accidents still occur while working at running processes. Backström & Döös (2000) considered that, in spite of the improvement of safety of automated installations, accidents come up with machine movements especially. The users of the machinery can be exposed to the movements of the machine either while the machine is ON or while the machine is turned OFF and it suddenly starts unexpectedly (Aneziris et al. 2013). Various reasons might cause unexpected and unintended start-ups, for example a failure of start command or a release of energy that was stored into the machinery after an interruption. The design of the machinery has an effect on and can prevent unexpected start-ups (SFS-EN ISO 12100:2010) but also safe working methods and procedures are important with the machinery. The user of the machinery, too, has chances to make the usage of the machinery safer: unintended start-ups can be prevented by using the Lock Out/Tag Out (LOTO) procedure when maintaining the machine. With the LOTO procedure, the disconnection of energies from the machine is guaranteed by isolating the energies and physically locking isolating devices. (Aneziris et al. 2013)

Chinniah (2015) proposed key actions to prevent accidents: to carry out a risk assessment, to use guards to protect hazardous zones, to ensure that the lockout procedure is used, to train employees properly and to prevent the bypassing of safeguards. According to Aneziris et al. (2013) the most efficient way to prevent fatality risk is by the functioning emergency stop switch and for non-fatal injuries the efficient prevention action is to respect the hazardous zone around the moving parts of the machinery. If the machinery was designed so that it is impossible for people to access the hazardous zone, it could prevent accidents: no exposure to hazard, no harm. Still, accidents can occur in several phases of the life cycle of the machine, and all these phases should also be taken into account while designing the machine. (SFS-EN ISO 12100:2010) However, possibilities to influence the safety of already existing machines are limited: it is only during the designing phase of a machine that all possibilities to make changes exist and that one can design the machine to be inherently safe (Aven 2008).

To improve and maintain the safety of an existing machine, it is possible to modernize the machine. Modernization means remodeling or reforming the machinery so that its life cycle continues without changing its purpose of use. The modernization can for instance focus on improving the quality, the safety, the reliability of a system or on increasing its capacity and productivity. Naturally, a modernization should never weaken the safety level of the machinery. (Malm & Hämäläinen 2006) When designing the modernization for a machine in EU member states, the best available safety level and technology, “state of art”, has to be known and taken into account (D 89/391/EEC). The standard ISO 12100 regarding the safety of machinery and other harmonized standards help to meet an up-to-date level of the machinery safety (Työsuojeluhallinto 2009). Moreover, a successful modernization of machinery requires proper information on the characteristics of the machine, its use, working methods and requirements set by operations and environment. One of the major reasons causing unsuccessful projects related to modernization of machinery has been inadequate requirement specification. (Malm & Hämäläinen 2006)

The European Union provides the legislation regarding the machinery and safety of machinery for its Member States (European Commission 2017a). In addition to the EU, other countries such as the USA have set law and standards to assure and develop occupational safety, including the safety of machinery (Occupational Safety and Health Administration 2017). These different kinds of legislation and standards are provided by a legislator, however, they are not direct findings of researches. Manufacturers and other agents who operate on the markets covered by the legislation have to comply with them. It is mandatory to follow binding legislation. (Occupational Safety and Health Administration 2017; European Commission 2017a) Nevertheless, it is not always easy to completely comply with the rules. The designer of a machine is obliged to design the machine to be safe both within its intended use and foreseeable misuse (D 2006/42/EC) but it can be very difficult for the designer to foresee all the possible circumstances that can effect on the use and safety of the machine: circumstances vary. Also, people do not always comply with the guidance and instructions. The users of the machinery might even defeat or remove safeguards if it makes their work easier. (Backström & Döös 2000) That is why it is essential to try to anticipate the misuse of a machine. As long as there is human–machine interface, there is a possibility for human-based error that might lead to unsafe circumstances. Therefore, one remarkable issue within the human–machine interface which has to be understood is the human performance and its cognitive aspects (Hallbert et al. 2010) as well as stress-related and ergonomic aspects (SFS-EN ISO 12100:2010).

2.2 On Risk Management of Technical Systems

Operational risks are one of the main categories of risk management. Operational risks impact on normal operational situations in organizations or enterprises and might be endangering them. Among other things, accidental events, failures, quality deviations, sabotage and loss of key personnel are operational risks. These are essential issues to be managed within technical systems, in which accidental events might include potential for great loss. The risk management consists of multiple elements. Some of the elements are drawn in the Figure 1. To manage risks successfully, organizations need strategies and activities on various levels. Roles and responsibilities should be established. The risk assessment includes different phases such as a risk analysis and a risk evaluation. The risk treatment comes after the risk assessment, when risks are known and it is possible to implement the required measures to modify the risks. Modifying can include for instance avoiding, reducing, transferring or retaining risks. (Aven 2008)

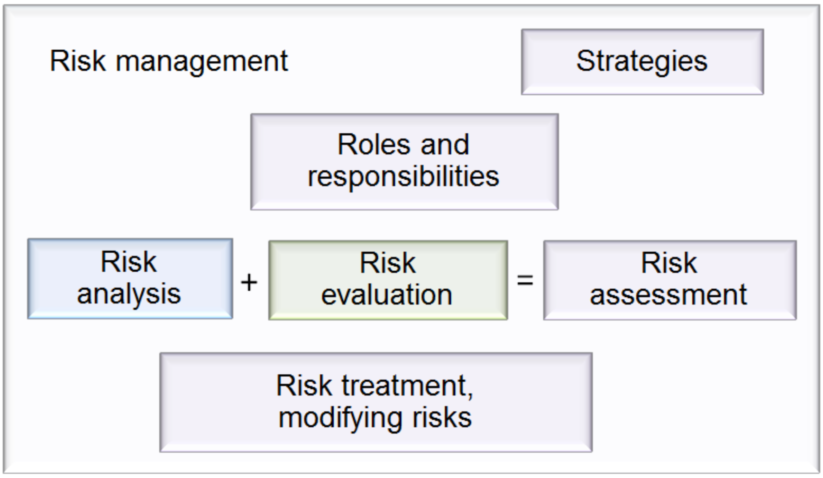

Figure 1. *Multiple Elements of Risk Management (Aven 2008)*

The risk analysis is a useful and usually essential part of the risk management. By way of the risk analysis, organizations can conduct information to support decision-making during the whole life cycle of a system. For instance decisions on costs and investments in relation to safety might ask for such information that a risk analysis can provide. Risk analyses are useful to compile risks related to systems, recognize different and critical factors, conditions, activities and components effecting on risks, and assess the effects of different measures on risks. This will help to choose from different alternatives of design, measures or solutions to achieve an eligible conclusion within considered issues. (Aven 2008)

The risk analysis can help decrease costs regarding the design and redesign of a system. Once the system, such as a production facility or a machine, is on a planning phase, there still are multiple options available and flexibility to change the plans for execution. In this phase the risk analysis will provide valuable information. For instance, some considered solutions might include higher costs or a wider range of safety hazards than another solution. During the planning phase it is less costly to make these decisions or redesign than in the construction phase, not to mention the operational phase, during which it may not even be possible to make changes anymore. The possibilities to affect to the design are lesser once the system is already constructed. (Aven 2008)

The aim of the risk analysis is to identify and describe possible risks. To be able to identify risks, the hazards that can lead to these risks have to be known. The hazard identification is a basis for that. There are various methods to be used for the hazard identification, such as Failure Modes and Effects Analysis (FMEA), Hazard and Operability (HAZOP) studies, Structured What-If Technique (SWIFT), Fault tree analysis, Event tree analysis, Bayesian networks and Monte Carlo simulation. The objectives of the risk analysis have an effect on the choice of the method. Each method demands for some input and source data that can be for example general experience, inspections, databases and assumptions. The outcome of the hazard identification is a list of undesirable events, hazardous events which can finally lead to the realization of risk. Causal and consequence analyses are used to supplement situations as a whole. To achieve a comprehensive list of risks it is critical to perform the analysis systematically in a structured way and, also, to ensure that the people involved are qualified enough in knowing the assessed system. To describe and estimate possible risks, their probabilities and values are assessed. There are several ways to assess them. It is essential to notice that one hazard or hazardous event might lead to multiple different consequences. It depends on the chosen method, if multiple consequences are assessed. (Aven 2008)

There are multiple dimensions used in different methods. The probability of an undesirable event and the possible consequences of that event are often used dimensions. To state dimensions, terms are used, such as “there is a certain percentage probability that event occurs within 5 years”, or consequences will cause “a first aid injury for one person”. It is better to use precise terms rather than too general terms that can be understood widely, such as the probability for occurrence of some event is “often”. (Aven 2008)

Risk analysis methods can either adopt a forward or backward approach (Aven 2008). In a forward approach, also called a bottom-up approach, the risks are assessed from a starting point or hazard to the undesired event or harm. A backward approach, also called a top-down approach, studies risks the other way around: from the undesired event or harm to their starting points, trying to find all the reasons that can cause these undesired events or harm. Usually, checklists are used within the backward approach, which might cause situation in which some hazards stay unidentified due to an incomplete checklist. This can be avoided by thinking creatively outside of checklists (SFS-EN ISO 12100:2010) and by gathering a team that is experienced and has competence over objects of the risk analysis. Forward approach is more comprehensive than the backward approach but also more time-consuming. (Aven 2008)

2.3 Legislation of Safety of Machinery in the European Union

The European Union provides legislation for its Member States. Part of the set legislation is binding for all Member States, for instance regulations and directives. (European Union 2017a) Regarding the safety of machinery the European Union has set a Machinery Directive (2006/42/EC) to harmonize health and safety requirements for machineries in the European Union (European Commission 2017a) and in the European Economic Area (EEA) (European Commission 2017b). The EU obligates all Member States to comply with the Directive and to implement it into a national legislation (European Union 2015).

The aims of the Directive are to guarantee a high level protection against hazards caused by machinery for European Union citizens and workers and to advance the free movement of machinery on the EU market. The Machinery Directive is set by the European Parliament and the Council, and its latest version became applicable in 2009. (European Commission 2017a) The Machinery Directive regulates machines when they are first put on the market or commissioned for the first time, which means usually manufacturing new machines and modifying already commissioned machines so that their purpose of use changes. Manufacturers, importers and other organs providing machines on the EU market or modifying machines are liable for guaranteeing that all the requirements of the Machinery Directive are fulfilled. (European Commission 2010)

In general, the assembly that includes a drive system and that consists of linked parts, of which at least one is moving, is defined as machinery (D 2006/42/EC). For example machine tools, packaging machines, agricultural machinery and conveyor belts are defined as machineries (European Commission 2016). However, there are exceptions to machineries being in the scope of the Directive. Among other exceptions, weapons, audio and video equipment and seagoing vessels are excluded from the scope. Some of these excluded machineries are regulated by other legislations. The Machinery Directive regulates topics such as the control systems of machinery, required characteristics of guards and protective devices and maintenance. There are supplementary health and safety requirements for certain categories of machinery, like foodstuffs machinery, in the Directive, too. (D 2006/42/EC)

Guidance documents to help comply with the Machinery Directive have been published with the endorsement of the Machinery Committee Working Group. For instance there are Guidance documents for Emergency Stop Devices, Equipment used for lifting persons and, above all, the Guide to application of the Machinery Directive. (European Commission 2017a) It has been translated into various languages of the Member States (European Commission 2017c).

The Machinery Directive is so called “New Approach”, which means that in addition to the mandatory Machinery Directive, there are voluntary harmonized standards (European Commission 2017a). The Machinery Directive only instructs the general guidelines for essential health and safety requirements, and harmonized standards offer detailed technical specifications for various machineries and topics. In designing a machine by complying with the applicable standards, it can be confirmed that the machinery meets the requirements of the Directive. (European Union 2011)

The Machinery Directive imposes a requirement on the conformity of machines. It presumes that the machinery meets the essential health and safety requirements of the Machinery Directive. There is a CE conformity marking in use to prove the conformity and to allow a free movement for machines on the EU market. (D 2006/42/EC) The CE marking must be added on the machine before it is set on the market. However, it does not mean that the EU or another authority has proved the machine to be safe but it is affixed by the manufacturer, the importer or the distributor of the machine after their own assessment. (European Commission 2017b) In order to affix the CE marking on the machine, the machinery must have been designed and constructed according to the requirements of the Directive, a conformity assessment must have been executed and documented, and a technical file for the machinery must have been compiled. With some particular machines there are different procedures on how to prove the conformity of the machines in the Directive. It is not allowed to affix CE marking to those products which are not regulated by the legislation related to CE marking. Figure 2 shows the form for the initials that the CE marking must always consists of. (D 2006/42/EC)

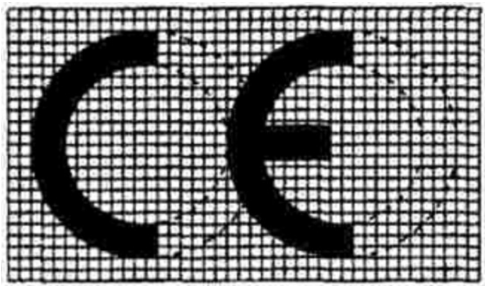

Figure 2. *The Form for the CE Conformity Marking Initials (D 2006/42/EC)*

The Machinery Directive regulates not only the design of the machinery but also the design of the safety of all other life cycle phases of the machinery. Once they are planned to comply with the essential health and safety requirements, it can decrease the amount of risks, accidents and costs that are caused by the accidents related to machinery. The installation and maintenance, too, have a role in machine safety. It is important to guarantee that the installation is made appropriately and that the maintenance of the machinery is designed to be safe. (D 2006/42/EC) The Directive regulates that after a commissioning of a machine, the employer is responsible of ensuring that the conformity and the safety level of the machine remain adequate through the life cycle of the machine. Improving actions for the machinery might be necessary if technical solutions are not adequate enough for safe work anymore, for example, a decade after the commissioning of the machine. If an employer connects a machine to an assembly of machines, the employer is responsible of the safety of the whole assembly and its conformity with the essential health and safety requirements of the Directive. (European Commission 2010)

In addition to the Machinery Directive, there are other directives of the European Union providing requirements for the use of machines in work places in terms of the occupational safety of workers in work places. The European Union has provided a Council Directive on the introduction of measures to encourage improvements in the safety and health of workers at work (89/391/EEC). It is also called a European Framework Directive on Safety and Health at Work, OSH Framework Directive for short, in which "OSH" stands for "occupational safety and health" (EU-OSHA 2017). It emphasizes preventative actions and provides a general framework about minimum requirements for workplaces to ensure the health and safety of workers and to improve working environments (D 89/391/EEC). Based on the Framework Directive more than 25 other individual directives have been established for various fields (Kraatz 2016). One of them is a Council Directive regarding the minimum safety and health requirements for the workplace (89/654/EEC) and it provides more details for workplaces than the Framework Directive. The directive regarding the minimum safety and health requirements for the use of work equipment by workers at work (2009/104/EC), too, is an individual directive providing more requirements focusing on the work equipment, including machines. All these directives provide requirements that have an effect on the occupational safety and, in their own way, on the safety of the machinery aiming to protect workers from risks resulting from the use of machines and other work equipment (D 89/391/EEC; D 89/654/EEC; D 2009/104/EC). Moreover, depending on the type of machinery there might be more directives to comply with, such as the Directive (2014/35/EU) regulating the electrical equipment designed for use within certain voltage limits.

2.4 Legislation of Safety of Machinery in Finland

In Finland, the legislation regarding the safety of machinery is mainly divided into two sections. Firstly, there is the legislation about designing and manufacturing machinery and it regards companies and organs that operate as manufacturers and importers of machines (L 26.11.2004/1016; A 12.6.2008/400). Then, there is the legislation concentrating on occupational aspects related to the safety of machines and other work equipment for employers who operate the use of machines (L 23.8.2002/738; A 12.6.2008/403). These legislations consist of laws and decrees, as seen in Figure 3. The decrees comply with the applicable European Directives, too. (L 23.8.2002/738; L 26.11.2004/1016; A 12.6.2008/403; A 12.6.2008/403) As a Member State of the European Union, Finland (European Union 2017b) is under the obligation of complying with the EU legislation (European Union 2015). The same standards and guidance are beneficial and practical in any case since they provide guidance and recommendations to apply regulations (Työsuojeluhallinto 2009).

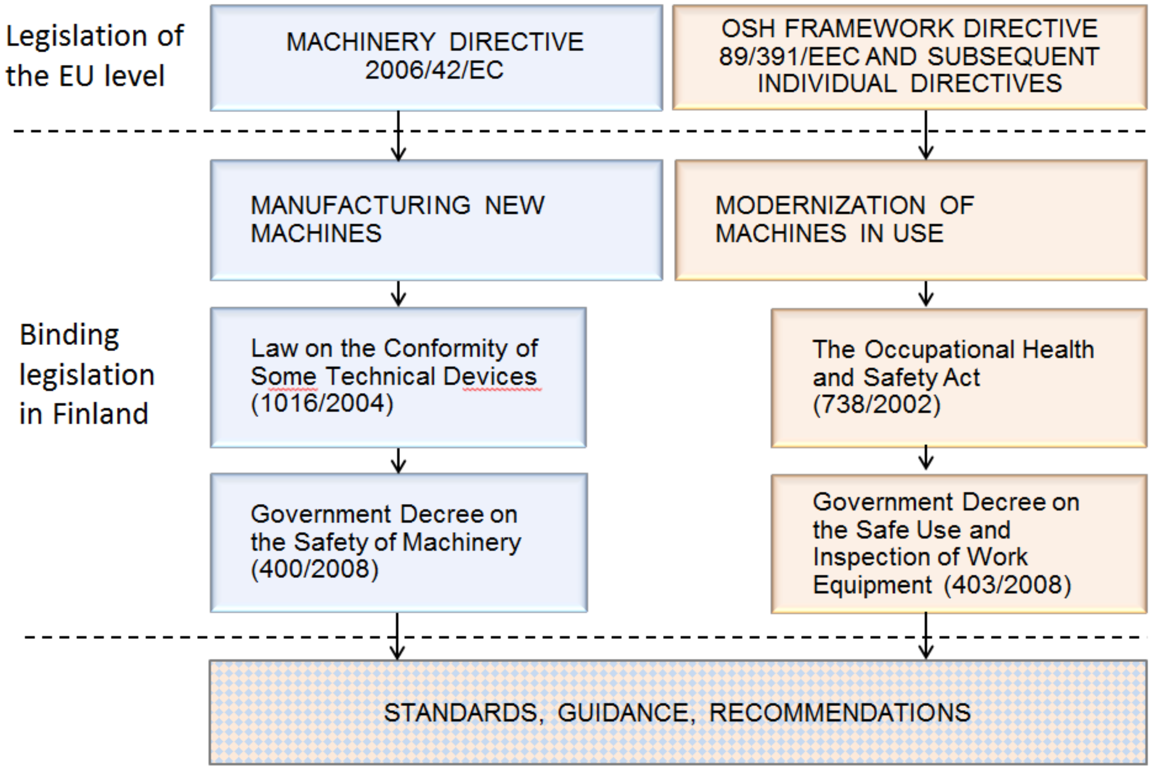

Figure 3. *Machinery Safety Regulations in Finland (Malm & Hämäläinen 2006; L 23.8.2002/738; L 26.11.2004/1016; A 12.6.2008/400; A 12.6.2008/403)*

To provide regulations for designing and manufacturing machines, usually new machines, there are a Law *Laki eräiden teknisten laitteiden vaatimustenmukaisuudesta (26.11.2004/1016)* and a Decree *Valtioneuvoston asetus koneiden turvallisuudesta (12.6.2008/400)*. The Decree is enacted by the Law but mainly the legislation in the European Union level has impacted the Decree. Regarding the machinery safety legislation, a Machinery Directive (2006/42/EC) is a directive that the Member States of the EU implement into a national legislation of their own. (European Union 2015) In Finland the Machinery Directive is implemented into the Decree (12.6.2008/400). It is a government decree on the safety of machinery, so called "Machinery Decree" (Tukes 2013).

To provide regulations for occupational health and safety and safe use of machines in work places where machines are operated and in use, there are an Act *Työturvallisuuslaki (23.8.2002/738)* and a Decree *Valtioneuvoston asetus työvälineiden turvallisesta käytöstä ja tarkastamisesta (12.6.2008/403)*. The Decree is prescribed by the Act and the Decree implements, too, the Directive regarding the minimum safety and health requirements for the use of work equipment by workers at work (2009/104/EC) of the EU legislation. The European Framework Directive on Safety and Health at Work (89/391/EEC) is implemented into a Finnish legislation in the Act. Also, other regulations of the EU level have had an impact on the Act; including the Council Directive regarding the minimum safety and health requirements for the workplace (89/654/EEC).

The objectives of the legislation regarding the designing and manufacturing of machines are to ensure that all machines produced comply with the requirements of conformity, they are alienable for the market and they do not cause any hazard of accident or harm to health. This legislation covers manufacturing new machines, assemblies of machinery and modifying new or old machines or an assembly of machinery so that its purpose of use changes. (L 26.11.2004/1016; A 12.6.2008/400) But then, once a machine or an assembly of machinery is in use and the employer wants to modernize an old machine or an assembly of machinery without changing its purpose of use, the legislation to comply with is the legislation concentrating on the occupational safety aspects of machines. The objectives of this legislation are to guarantee a safe working environment and conditions, including machines and work equipment for employees and to prevent accidents and harms to health originating from work. Also, the legislation of occupational safety requires that the employer takes into account the development of technology to improve working conditions, including machines. (L 23.8.2002/738; A 12.6.2008/403)

Essential health and safety requirements of both legislations can be ensured by applying the same standards, guidance and recommendations. In general, the required level of safety increases when the level of technology develops. The standards describe what an achievable level of safety nowadays is, which prevents the solutions that are not up-to-date anymore, especially when modernizing machinery or work equipment. (Työsuojeluhallinto 2009)

More accurately, the Figure 4 illustrates how the safety procedure and documentation to comply with should be chosen in cases of a demand for a new machine and of a modernization of an old machine. When manufacturing a totally new machine or a new machine by reusing old parts of an existing machine, the safety procedure and documentation should follow the Machinery Decree (12.6.2008/400). In this case, the CE marking is always required. (Malm & Hämäläinen 2006; A 12.6.2008/400)

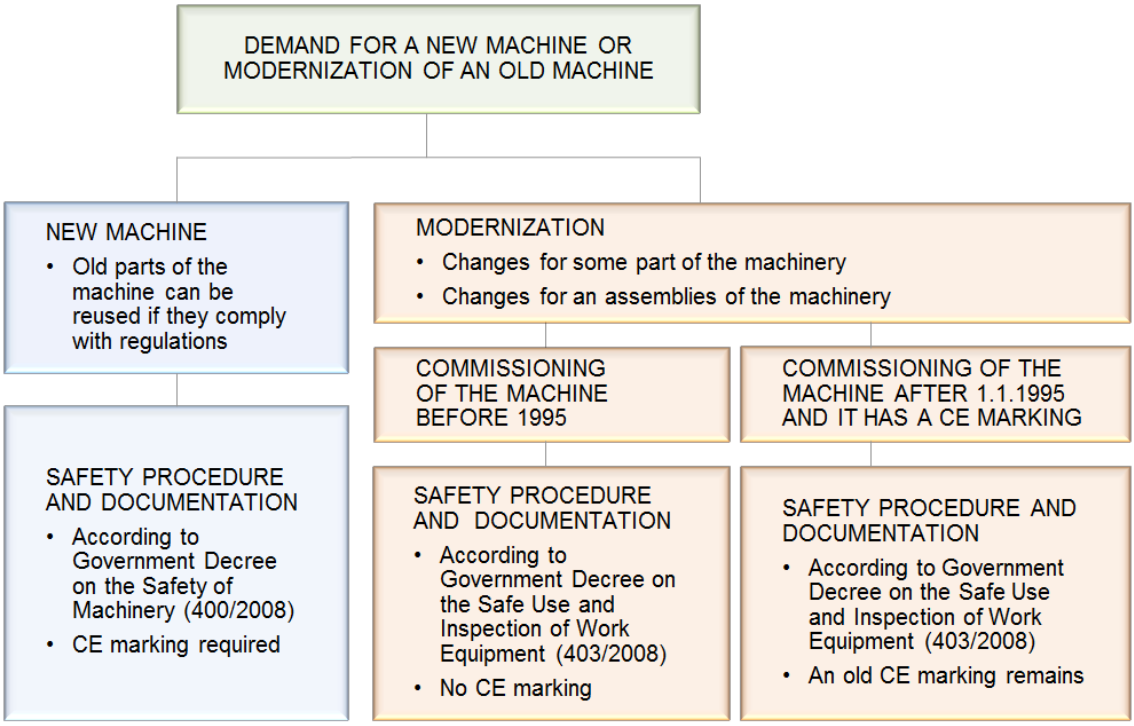

Figure 4. *Safety Procedure and Documentation for Machines in Finland (Malm & Hämäläinen 2006; A 12.6.2008/400; A 12.6.2008/403)*

Regarding the Figure 4 and the modernization of an old machine, “old” means that the machine or an assembly of machinery has already been commissioned before its modernization. When modernizing an old machine or an assembly of machinery, the safety procedure and documentation to comply with will be chosen according to the occasion of commissioning of the machine. If the occasion has been before the year 1995, there will be no CE marking on the machine after the modernization. Machines commissioned after 1.1.1995 should already have a CE marking so the old CE marking remains, too, after the modernization. Regardless, the safety procedure and documentation needs to follow the Decree (12.6.2008/403), which provides requirements on safe use and inspection of work equipment. The Decree (12.6.2008/403) does not provide any requirements regarding the CE marking. (Malm & Hämäläinen 2006; A 12.6.2008/403) The year 1995 is the limit for the occasion of commissioning of the machine because on 1.1.1995 Finland joined the European Union and was obligated to implement the rules and regulations of the EU. The Machinery Directive was implemented and the old legislation was repealed. (European Union 2017b)

What is common for these Decrees is that they both require that the manufacturer of the machine or employer who is operating the machine executes an assessment to reveal and manage possible hazards and risks caused by using the machine. With the assessment it is possible to show deficiencies of safety and by improving and performing corrective actions it is possible to reduce the risks related to the machinery. (A 12.6.2008/400; A 12.6.2008/403) The Machinery Decree demands for “risk assessment” (A 12.6.2008/400) and the Government Decree demands for “hazard assessment” (A

12.6.2008/403), however, they provide basically the same requirement and the outcomes of the assessments are similar to each other.

2.5 On Design of Safety of Machinery

2.5.1 Harmonized Standards of Safety of Machinery

The European Union uses different kinds of standards to support its legislation. The standards, which are made to apply to the legislation of harmonization and are provided by the European standardization organizations CEN, CENELEC or ETSI, are called "harmonized standards". (Suomen Standardisoimisliitto SFS ry 2017a) The European standardization organizations are requested by the European Commission to provide these standards (European Union 2011). Letters "EN" in the reference of the standard show that it is a European standard and it has been confirmed by CEN. Letters "ISO" in the reference of the standard means that it has been confirmed by the International Organization for Standardization (ISO) and it is an international standard. When standards are confirmed in Finland, they are marked with letters "SFS". Standards can be confirmed by more than one organization, in which case there is more than one of these marks in the reference of the standard. (Suomen Standardisoimisliitto SFS ry 2017b)

Harmonized standards regarding the safety of machinery are based on the Machinery Directive (2006/42/EC) of the European Union. The Directive provides the general requirements whereas the standards instruct detailed information on technical specifications on health and safety requirements for machinery. Following the standards is voluntary but by manufacturing the machine in conformity with them and using applicable standards, the requirements are achievable systematically, and the authorities are liable for admitting that the machine fulfills the essential health and safety requirements of the Machinery Directive. (European Union 2011) The CE marking is used to prove the conformity with those requirements and, once the CE marking is affixed to the machine, it means the machine is eligible for a free movement in the EU market (D 2006/42/EC).

Harmonized standards regarding the safety of machinery are divided into three categories: type-A, type-B and type-C standards. Type-A standards are basic safety standards, which give instructions for basic concepts, general aspects and design principles applicable to the machinery. (SFS-EN ISO 12100:2010) The application of type-A standards alone is not enough to ensure a full presumption of conformity (European Commission 2016). Type-B standards are generic safety standards focusing on specific aspects or specific types of safeguards which can be used across a wide range of machineries. They are divided into type-B1 and type-B2 standards. Type-B1 standards deal with specific safety aspects, such as safety distances, and type-B2 deals with specific safeguards, such as interlocking devices. (SFS-EN ISO 12100:2010) The application of type-B standards alone does not confer a presumption of conformity, except for the safety components which are independently placed on the market, but in relation to type-C standard or a manufacturer's risk assessment, type-B standard and its specifications can confer the presumption of conformity (European Commission 2016). Type-C standards are machine safety standards which provide detailed safety requirements for a given category of machinery (SFS-EN ISO 12100:2010). The application of type-C standards confers a presumption of conformity in relation to a manufacturer's risk assessment (European Commission 2016). The requirements of type-C standards always take precedence to the requirements of type-B standard (Suomen standardisoimisliitto SFS ry 2015).

The standard EN ISO 12100 Safety of Machinery is a type-A standard that provides general principles for design, risk assessment and risk reduction. Risk assessment methodologies confirmed to be suitable for machinery are described in the standard. (SFS-EN ISO 12100:2010) In addition, the technical report ISO/TR 12141-2 is an informative report about the safety of machinery and risk assessment. It is in line with the standard EN ISO 12100 and provides practical guidance and examples of the presented methods. These are useful standards for all designers and manufacturers of machines. (SFS-ISO/TR 14121-2:2012) There are hundreds of type-B and type-C standards published. The table 1 shows some examples of harmonized standards, their reference numbers and names. (European Commission 2016)

Table 1. List of a Certain Harmonized Standards (European Commission 2016)

Reference	Title of the standard
EN ISO 12100	Safety of machinery – General principles for design
EN 614-1 + A1	Safety of machinery – Ergonomic design principles – Part 1
EN 547-1 + A1	Safety of machinery – Human body measurements – Part 1
EN 1037 + A1	Safety of machinery – Prevention of unexpected start-up
EN ISO 13850	Safety of machinery – Emergency stop function
EN ISO 14119	Safety of machinery – Interlocking devices associated with guards
EN ISO 14120	Safety of machinery – Guards
EN ISO 14122	Safety of machinery – Permanent means of access to machinery – Parts 1–4

Some of the harmonized standards are divided into parts. Standard related to permanent means of access to machinery is divided into 4 parts. Part 1 provides help about choice of fixed means and general requirements of access, whereas second part handles working platforms and walkways. Part 3 is for stairs, stepladders and guard-rails and part 4 handles fixed ladders. (European Commission 2016) Standards provide very detailed and technical specifications on the topics (European Union 2011).

2.5.2 Principles for Risk Assessment of Machinery

The Machinery Directive (2006/42/EC) requires that a risk assessment has to be carried out when designing and manufacturing machinery on the EU market. The process of risk assessment related to design of the safety of machinery is introduced in both the Machinery Directive and the standard ISO 12100 Safety of Machinery. The process of risk assessment comprises a determination of limits of the machinery, a hazard identification, a risk estimation, and a risk evaluation. The risk management includes also the risk reduction following this process. (D 2006/42/EC; SFS-EN ISO 12100:2010)

The determination of limits of machinery is the first step of risk assessment of the machinery. In order to make a successful risk assessment for the machine, the limits of the machinery must be determined. The aim of the determination of limits of machinery is to identify and gather all the necessary information about the machine, its characteristics, functions, intended use and environment of use, and also reasonably foreseeable misuse. (SFS-ISO/TR 14121-2:2012) The limits consist of different characteristics and performances of the machine and the related people, environment and products. The limits can be divided into use limits, space limits, time limits, and other limits. Use limits not only include an intended use but also a reasonably foreseeable misuse. Also, the different modes of the machines, use of the machine, interventions of the users, knowledge and other qualities of the users, and exposure of other people are aspects to consider. Space limits mean the range of movement of the machine, the space that users need when interacting with the machine during operations and maintenance, operator–machine interface and machine–power supply interface. Time limits take into account the life cycle of the machine and its components, and recommended periods of service. Other limits might include properties of the materials to be processed, housekeeping including the level of cleanliness required and environment. (SFS-EN ISO 12100:2010)

The second step of the risk assessment is a systematic hazard identification. An identification of hazards and hazardous situations should cover the whole life cycle of the machine, and every situation including continuously appearing hazards and unexpectedly appearing hazards. A task identification is a useful tool to take into account all human interaction with the machine. Tasks can be for example setting, start-up, all modes of operation, feeding the machine, removal of product from machine, stopping the machine intentionally and in case of emergency, recovery of operation from blockage, troubleshooting, and preventive and corrective maintenance. After the tasks are identified, all reasonably foreseeable hazards related to them shall be identified. Hazards and hazardous situations can also appear in different states of the machine, when the machine functions normally or with unintended functions. Moreover, reasonably foreseeable misuse of the machine should be surveyed, since misuse resulting from human performance with its cognitive aspects, such as a lack of concentration, fatigue, carelessness, reflex behavior in case of a malfunction or incident, could cause hazards. Among other things, a misuse can also include actions caused by pressure to keep the machine running or loss of control of the machine. (SFS-EN ISO 12100:2010)

The third step of the risk assessment is the risk estimation. Risks resulting from hazardous situations identified in the second step of the risk assessment need to be estimated. (SFS-EN ISO 12100:2010) There are several different methods to estimate risks. A risk estimation can be carried out by a qualitative or quantitative assessment. (Aven 2008)

The standard ISO 12100 represents a qualitative risk estimation. The technical report ISO/TR 14121-2 represents several styles, which are suitable when estimating risks related to the machinery (SFS-ISO/TR 14121-2:2012).

When following the standard SFS-EN ISO 12100, there are different elements of risk regarding the safety of machinery, as can be seen in the Figure 5. The standard SFS-EN ISO 12100 (2010) presents that the *risk* related to the considered hazard is a combination of *severity of harm* that can result from the considered hazard and *probability of occurrence* of that harm, which is a combination of three elements: *exposure of persons to the hazard*, *the occurrence of a hazardous event* and *the possibility to avoid or limit the harm*. It is possible to estimate the severity of harm by the severity of injuries and the extent of harm. When considering the exposure of persons to the hazard, especially, the need of users to access the hazard zone and time spent in there, the nature of the access, the amount of persons, and frequency of accesses have an impact on it. The occurrence of a hazardous event can originate from a human or technical source, and statistical data and history about accidents and damages to health help to estimate it. The possibility to avoid or limit the harm should be estimated by considering how skilled persons exposed to the hazard are, how quickly a hazardous event can escalate into an incident, the awareness of risk, and the human ability to avoid or limit harm. (SFS-EN ISO 12100:2010) It is essential to notice that one hazard can possibly cause more than one risk thus a same hazard might require several estimations (SFS-ISO/TR 14121-2:2012).

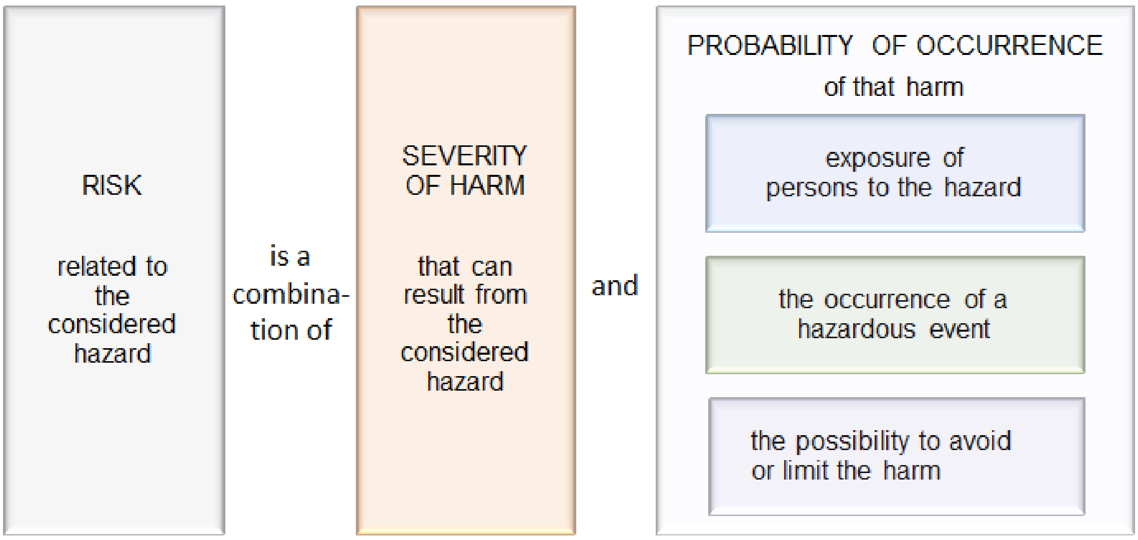

Figure 5. *Elements of the Risk (SFS-EN ISO 12100:2010)*

The risk evaluation is the forth step of the risk assessment. The aim of the risk evaluation is to decide which risks need to be reduced. Appropriate protective measures need to be chosen to reduce the risk that cannot be accepted. After applying the measures, it has to be reviewed that they do not cause any new hazards, or if they do, the risk assessment has to be repeated for them. The risk reduction based on the risk evaluation is adequate enough once all operations, their conditions, tasks and interventions required from users have been observed, all hazards and risks have been removed or reduced to acceptable level, residual risks are notified to users, and also possibility and consequences of using the machine in non-industrial or other non-designed context have been considered. In general, residual risk means the risk that remains after risk reduction has been done. Moreover, it has to be observed that the protective measures do not have a negative effect on the usability of the machine or the working conditions of the user. (SFS-EN ISO 12100:2010)

Regarding the risk reduction, the principle for the design of the safety of machinery and protective measures is a tripartite method required by the Machine Directive and presented in the standard SFS-EN ISO 12100 Safety of Machinery. The first and most important step is to eliminate the hazards or reduce the risks by applying inherently safe design measures. It means by changing the design of the feature of the machine or changing the user–machine interaction. Features of the machine to be taken into account are, for instance, physical aspects, choice of appropriate technology, applying principle of positive mechanical action, or provisions for stability. Secondly, safeguarding and complementary protective measures are used to eliminate or reduce the risks remaining in the machine. Safeguarding means guards and safety devices, and protective measures are for example emergency stop devices and walkways. Thirdly, the information for use about the hazards and risks remaining despite the design and safety measures is provided either in the instruction handbook of the machine or, primarily, on the machine, in form of warning signs, signals, or warning devices. (SFS-EN ISO 12100:2010; Suomen Standardisoimisliitto SFS ry 2015)

The risk assessment should be carried out by a team rather than by one person only. It can be more efficient and comprehensive when the team is made up of multiple persons and their knowledge affects the results. People attending the risk assessment can vary depending on what the risk assessment is like. However, a wide range of knowledge on the topic in question should be guaranteed in order to perform a reliable risk assessment. Also, the team needs a team leader who takes care of the risk assessment in its entirety. (SFS-ISO/TR 14121-2:2012)

2.5.3 Safeguards and Complementary Protective Measures

Safeguards and complementary protective measures are the second step of the principle for the design of the safety of machinery, aiming at eliminating the hazards and reducing the risks that remain after the designer has applied the inherently safe design measures. Safeguards and complementary protective measures include guards, safety devices, safeguards for reducing emissions, and complementary protective measures. When choosing a safeguard for a certain machine, the choice has to be based on the risk assessment. (SFS-EN ISO 12100:2010)

The main functions of guards are to prevent the access of persons to the space or hazard zone of the machine, and to prevent the access of different materials, such as workpieces, chips, liquids or emissions, to the outside of the intended space. Protective devices are devices connected to the control system of the machine, and the chosen devices must meet the requirements of the particular product standard. The design of guards and protective devices should be done so that they are not easily defeated. Complementary protective measures are used in addition to the inherently safe design measures, safeguarding and information for use, and they contain for example components to achieve emergency stop function, measures for the escape and rescue of trapped persons, measures for isolation and energy dissipation, and measures for safe access to machinery. (SFS-EN ISO 12100:2010)

Properties and hazards related to safeguards and complementary protective devices should be taken into account when designing them for the machinery. Safeguards and complementary protective devices should be suitable into the working environment where the machinery will be used. The required properties of safeguards and complementary protective devices include them to be robust enough by their construction and to be located far enough from the hazardous zone. Safeguards and protective devices should never cause any additional hazard and they should not be bypassed or defeated easily. The observation and view for operations of production should not be prevented or blocked by safeguards or protective devices. When possible, safeguards and protective devices should be designed to allow access to the area required by essential tasks of maintenance so that there is no need to remove safeguards or protective device and the tasks can be performed safely. (SFS-EN ISO 12100:2010) The intended use and foreseeable misuse of the machinery are essential information when choosing and designing safety measures for the machinery. If the usage of the machine is difficult or if it changes to be more difficult than normally on some occasion, it may entice the operator to defeat safeguards or protective equipment to make the machine easier to use, which might cause significant hazards. The possibilities for this kind of behavior should be eliminated within the design of the machine. (SFS-EN ISO 14120:2015)

The selection of guards is wide, and characteristics of guards vary. The applicable guard is chosen by depending on the need of access to the hazard zone: whether the access is needed during normal operations or not, or if the access is needed for machine setting, faultfinding, cleaning or maintenance. If there is no need for access to the hazard zone of the machine during normal operation, the type of the chosen safeguard should be a fixed guard, an interlocking guard with or without guard locking, a self-closing guard, or a sensitive protective equipment, for example an electrosensitive protective equipment or pressure-sensitive protective devices. When the guard needs to allow the access to the hazard zone regularly during normal operation, the safeguard should be an interlocking guard with or without guard locking, a sensitive protective equipment, for example an electrosensitive protective equipment, an adjustable guard, a self-closing guard, two-hand control devices, or an interlocking guard with a start function, also called a control guard. The design of the machine should take into account, in addition to normal operations, the operations such as machine setting, teaching, faultfinding, cleaning or maintenance that require access to the hazard zone; the safeguards should provide protection for every user operating the machine throughout the life cycle of the machine. (SFS-EN ISO 12100:2010) However, every guard has their own problems, so choosing safeguards should be carried out cautiously (Backström & Döös 2000).

Fixed guards are guards that are affixed so permanently that they can be removed or opened only by using tools. Suitable ways for affixing are for instance screws, nuts and welding. (SFS-EN ISO 12100:2010) The tools for opening fixed guard can be for example a key or a wrench. Implements, that are not designed to open and close a fastener, are not perceived as a tool, for example coin or nail-file. (SFS-EN ISO 14120:2015)

Interlocking guards are guards that are connected to an interlocking device and control system of a machine. The aim of an interlocking is to prevent the machine from executing hazardous functions as long as the guard is open, to stop the machine if the guard is opened during hazardous functions and to allow the machine to operate hazardous functions when the guard is closed but, however, closing the guard should not start the functions by itself. The interlocking can be implemented with or without guard locking. With a guard locking, the interlocking guard has to be not only closed but also locked in order to allow performing the hazardous function that it is guarding. Interlocking guards with a start function are a special type of interlocking guards. They are also called control guards. A control guard starts the hazardous function of the machine without using any separate start control after the guard is closed. (SFS-EN ISO 12100:2010)

Self-closing guards are movable guards which allow operated workpiece to pass and then they close automatically. The workpiece can also be fastened by a part of the machining jig and then the machining jig passes the opening of the self-closing guard. The returning of the self-closing guard can be carried out by gravity, spring or another external power. (SFS-EN ISO 14120:2015)

Adjustable guards are guards that are either wholly adjustable or partly adjustable. Partly adjustable guards feature parts of which at least one is adjustable. An adjustable guard can be a fixed or a movable guard. (SFS-EN ISO 12100:2010) The adjustment can also be made manually. In this case, the adjustment stays fixed while the machine is performing certain operations. (SFS-EN ISO 14120:2015)

A sensitive protective equipment (SPE) is an equipment to detect a person or a body part of person within the certain area and to send a signal to the control system of the machinery. Usually the signal starts the wanted function. The aim is to reduce the possible risk that threatens the person who entered the area. The tripping of the signal can be caused by crossing a certain limit or by a presence sensing in a certain area. Examples of a SPE are an electrosensitive and pressure-sensitive protective equipment. When there is no need to access the hazard zone during normal operations, pressure-sensitive protective devices are suitable for guarding the hazard zone. (SFS-EN ISO 12100:2010)

Two-hand control devices are control devices that require the user to actuate with both hands simultaneously. Actuating with two hands allows the machine to perform the hazardous function that is otherwise non-functional. The protective measure that a two-hand control device provides is directed only at the person who is actuating the control device. (SFS-EN ISO 12100:2010)

Multiple standards can be helpful when designing safeguards and complementary protective devices. For instance, standards ISO 13855 and ISO 13857 provide information related to the positioning of safeguards. ISO 13855 advises “positioning of safeguards with respect to the approach speeds of parts of the human body”. ISO 13857 advises “safety distances to prevent hazard zone being reached by upper and lower limbs”. Standards ISO 14119 and ISO 14120 provide information related to guards. ISO 14119 advises “interlocking devices associated with guards, principles for design and selection”. ISO 14120 advises “general requirements for the design and construction of fixed and movable guards”. Also, once a machine includes built-in platforms or stairs, they have to be designed acknowledging safeguards and protective devices. Such information is provided by the standard ISO 14122 for permanent means of access to the machinery. (European Commission 2016)

2.5.4 Information For Use

The information for use is the third and final step of principle for the design of the safety of machinery. After the designer has applied the inherently safe design measures and eliminated hazards and reduced risks by designing safeguards and complementary protective devices, the residual risks remaining within the machine are made clear to the user of the machine with the information for use. The information for use is affixed to the machine or written in the instruction handbook of the machine. It can also be provided both ways. The information affixed to the machine can consist, for instance, of warning signs, warning signals or warning devices. In the instruction handbook there might be, for example, texts, symbols or charts. (SFS-EN ISO 12100:2010)

The designer of the machine needs to provide the information for use in order to reduce the risks remaining within the machine. However, these provided protective measures have to be taken under the control of the user, so that they become effective. The information for use is aimed at each user of the machine, no matter if the user is a professional or a non-professional. Hence, the information for use has to be easily understandable and to cover all possible and intended operation modes. The information for use should provide all the instructions required to use the machine safely and to provide information about the residual risks of the machine, so that the user is aware of them and knows how to avoid them. When necessary, the information for use should provide requirements concerning the training of the user, the use of personal protective equipment and possible additional safeguards. Also, the information for use should cover all hazards and associated risks which could occur during the life cycle of the machine, including assembling, installation, commissioning of the machine, among other things. (SFS-EN ISO 12100:2010)

The positioning of the information for use depends on the risk, the time when it is needed and the physical structure of the machine. Visual and audible signals within the machine, such as flashing lights and sirens, are useful ways to warn of hazardous events. They need to be executed before the hazardous event happens. Also, the signals need to be unequivocal so that they are easily noticed and not mixed up with other used signals. (SFS-EN ISO 12100:2010)

There has to be markings on the machine providing some information at least about the series or type of the machine, its manufacturer, markings to prove that the machine complies with the mandatory requirements and all the necessary information so that the machine can be used safely. Such information might be, among other things, the maximum speed of rotating parts, the mass of the machine, the maximum working load or the need to wear personal protective equipment. Of course, the permanent markings affixed to the machine should always be readable during the whole life cycle of the machine. Other ways to add the information for use on the machine include signs, pictograms, symbols and written warnings. The culture where the machine is to be used affects the markings that can be affixed to the machine; symbols and pictograms in signs are essential to be easily understandable. (SFS-EN ISO 12100:2010)

The written instructions given on the machine or the instruction handbook of the machine include detailed information on the machine. Such information should cover for example the instructions for handling the machine, how to store and install the machine, the information on the machine itself, its use and maintenance, and instructions in case of emergency situations associated with the machine. The operator should know applicable operating methods if an accident or a breakdown occur. (SFS-EN ISO 12100:2010)

3. OBJECT AND EXECUTION OF THE RESEARCH

3.1 Ahlstrom-Munksjö and Object of the Research

Ahlstrom-Munksjö is a public company that provides fiber-based materials globally for industrial applications and end user products. Ahlstrom-Munksjö was formed on April 1st, 2017 when Ahlstrom Corporation and Munksjö Oyj merged. After the merger the net sales of the company increased to about 2.15 billion euros. The company has 6,000 employees. Spread over 14 countries Ahlstrom-Munksjö has 41 sites for production and converting. The share of Ahlstrom-Munksjö is listed on the Nasdaq Helsinki and Stockholm. (Ahlstrom-Munksjö 2017)

Ahlstrom-Munksjö has 4 business areas which are Decor, Filtration and Performance, Industrial Solutions and Specialties. The business areas provide products such as nonwovens, electrotechnical paper, glass fiber materials, tapes, food packaging and labeling and medical fiber materials. The main customer segments of Ahlstrom-Munksjö are for instance the automotive, energy, printing, medical and diagnostics industries. In 2016, 60 percent of the company's net sales came from Europe, 24 percent from the Americas and 16 percent from the Asia-Pacific region. (Ahlstrom-Munksjö 2017)

This thesis inspects the production machine in Ahlstrom-Munksjö Tampere Oy, which is part of the business area of the Filtration and Performance. The machine originates from about 4 decades ago. Naturally, many parts of the machine have been updated through the years; still, the purpose of its use has not changed. Since the machine has been commissioned before the year 1995, the legislation does not require CE marking for it but to comply with the legislation providing requirements regarding occupational safety aspects and use of machines (A 12.6.2008/400; A 12.6.2008/403).

The analyzed machine is a machine producing nonwovens with a wet-laid technique. The study was limited to a particular area of the machine, which starts at the end of a forming fabric and continues until the end of a conveyor wire after the first drying section. The other parts of the machine in this area are a pick-up felt, a dryer and an under wire. The analyzed area is comparable to a paper making machine. Other areas of the machine were left out of the study due to prioritizing this area. A schematic diagram of the machine is shown in Figure 6.

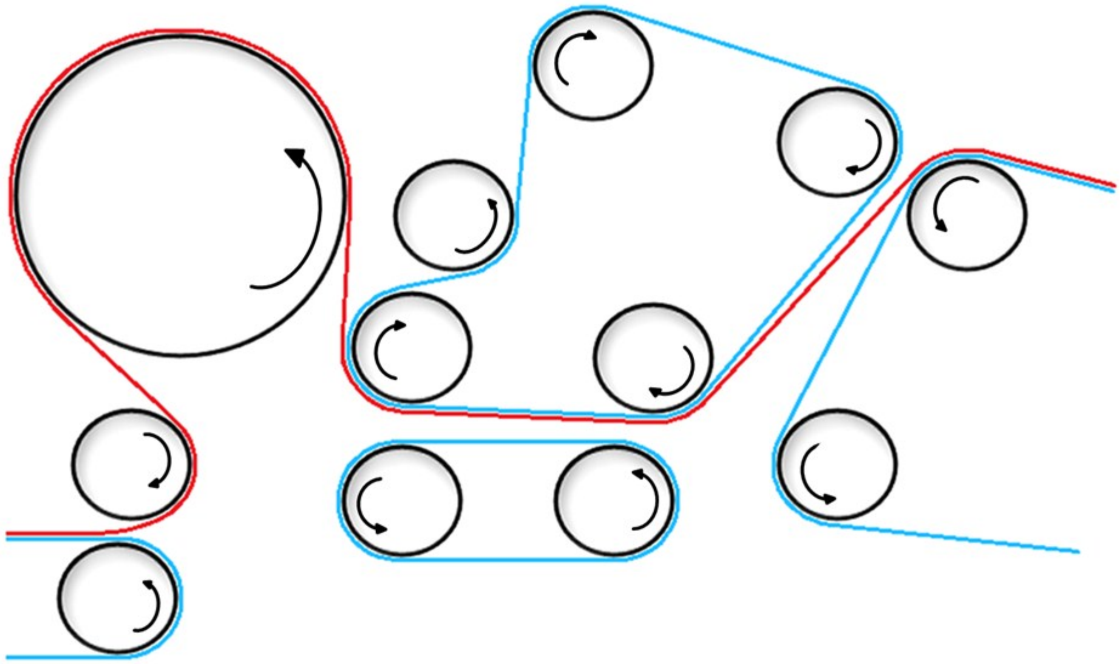

Figure 6. *Schematic Diagram of the Analyzed Area of the Machine*

The Figure 6 is an approximate sketch of the analyzed area of the machine. It does not include all parts of the machine. However, it reflects what kind of machine is in question. There are moving parts consisting of several rollers and wires in the analyzed area.

3.2 Execution of the Research

This thesis provides information regarding the safety modernization of the machine. This thesis featured applied research by its nature and its objectives were (1) to identify the safety requirements, regarding the modernization of the chosen area of the machine, especially concentrating on safeguards, (2) to identify deficiencies and hazards related to the safety of this area of the machine and (3) to propose solutions to meet these requirements and reduce the risks related to the hazards. The mixed research strategy to achieve these objectives combines a constructive approach and a risk assessment method presented by the standard ISO 12100 Safety of Machinery. The method was supplemented with a matrix of risk estimation presented by the technical report ISO/TR 14121-2 Safety of Machinery, and due to the matrix, the definition of risk and its elements was sharpened. The aspects of the constructive approach were that the need for the research originated from the reality and a new reality was constructed with the solutions that were invented and developed, not only found (Lukka 2001). The constructive research is featured in the field of the applied research (Järvinen & Järvinen 2011, 103). The results of this thesis were used as a basis for the safety modernization of the machine to improve its safety and the safety of the working environment.

The risk assessment method based on the standard ISO 12100 was selected for this study since it was purpose-built and valid for the machine, even though the possibilities to improve the safety of an already built and existing machine are limited. Inherently safe design measures can only be applied efficiently during the designing phase of the machine; after that, the focus to improve the safety and eliminate the risks associated with the machine is put on safeguarding and complementary protective measures (SFS-EN ISO 12100:2010). That is why the study concentrated on the safeguarding of the machine. The matrix of risk estimation presented by the technical report ISO/TR 14121-2 was included to further supplement the risk estimation. The research was executed by the phases presented in Figure 7.

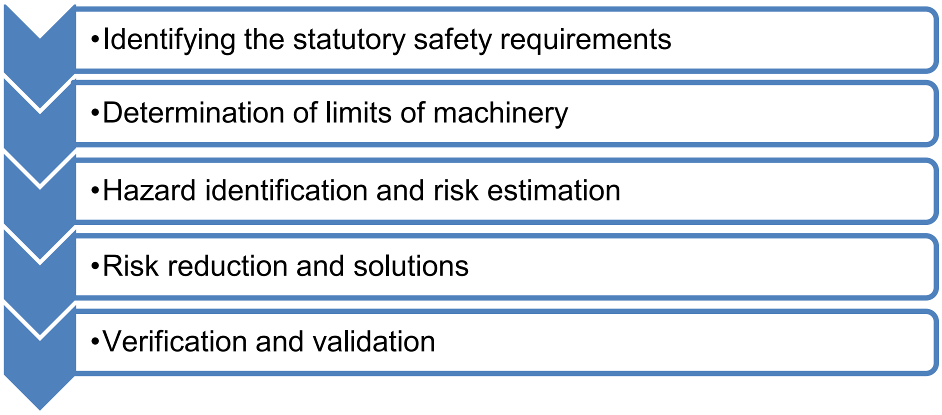

***Figure** 7. The Phases of the Research*

First, statutory safety requirements were identified and it was noted if they were met. Secondly, the limits of the machinery were determined, including the tasks performed within the machine. The limits of the machinery are an essential base for the later phases of the research. Then a hazard identification was carried out to identify deficiencies and hazards related to the safety of this area of the machine, and a risk estimation was conducted for identified potential consequences or harms. In the phase of the risk reduction, corrective actions were considered and solutions were proposed to meet the requirements, reduce the hazards and achieve an acceptable level of safety. The last phase of the research was a verification and a validation of the proposed solutions. Each phase is described in more details in the following chapters.

The proposed solutions consisted of information and actions to modernize the safety of the machine and what should be taken into account when designing modernization and improving safeguards. The plan and modernization of the machine were about to be conducted in the near future after the thesis was ready, however, the implementation and commissioning of the plan were not in the scope of this thesis. The commissioning was not available within the time limits set for this thesis.

3.3 Identifying the Statutory Safety Requirements

The analyzed machine is an assembly of machines as defined in the Machinery Decree (12.6.2008/400). However, since the machine has been commissioned before the year

1995 in Finland, and its purpose of use has not changed after its commissioning, it does not belong to the scope of the Machinery Decree (Malm & Hämäläinen 2006; A 12.6.2008/400; A 12.6.2008/403). This study answers the need for improving the machine, hence, what is in question is a modernization of the machine. Then, the statutory safety requirements for the modernization are provided by the Government Decree (12.6.2008/403), which regulates safe use and inspection of work equipment. The machine is "work equipment" as defined in the Government Decree (12.6.2008/403).

Statutory safety requirements of the Government Decree (12.6.2008/403) on the safe use and inspection of work equipment were identified and gathered into a table from the Decree by paragraphs. At the table, it was mentioned whether the requirements are fully or partly complied with or not. For the closer inspection of unfulfilled requirements, there were reference comments for risk assessment where the subject is handled more. Mostly requirements in one subsection of the Decree are closely combined with each other; therefore, they were placed together as one requirement at the table. The determination of requirements was executed by way of a discussion with the process manager, the maintenance specialist and the safety manager. They had required knowledge and competence to assess statutory safety requirements regarding the machine and work place.

Only applicable requirements for the analyzed area of the machine were taken into account. Mostly, they were under the chapter 1 General provisions. Section 1 provided the scope of application for the Decree and there were no clear requirements in that section. Sections 2–12 regulated applicable topics such as instructions for use of work equipment, assessment and elimination of risks, ensuring the functional condition of work equipment. Section 13 regulated hazards originating from weather conditions, and since the machine was located inside of a building, this section was not applicable. Section 14 regulated special competence requirements, of which only the requirement for "drivers of devices for lifting persons" was applicable and taken into account. Chapters 2, 3, and 5 regulated supplementary provisions on mobile work equipment, supplementary provisions applicable to lifting machinery, and "initial and periodic inspections, and a condition monitoring system", and they were not applicable. In chapter 4, which provided safety requirements for work at height, applicable sections were section 26 regulating guard structures and equipment preventing falls and section 30 regulating use and placing of ladders. Other parts of the chapter 4 concentrated on scaffolding and working the help of rope access, and they were not applicable.

3.4 Determination of Limits of Machinery

The uses of the machinery regarding the limits of the machinery were determined mainly with the task based approach. The task identification was carried out to identify all tasks performed by the operators of the machine and the maintenance personnel within the analyzed area of the machine. The task identification determines use limits: both intended use and foreseeable misuse. The main sources of the task identification were an open questionnaire for operators and maintenance personnel, a Job Safety Analyses (JSA) that have been made for this area of the machine, and inquisitive discussions with the operators and maintenance personnel in question. Some information was supplemented from the lists of orientation for new personnel.

The form used for the open questionnaire of task identification is in Appendix A (in Finnish), and its main function was to gather, as specifically as possible, the tasks performed within the machine. Also, it included columns to ask how often a certain task is carried out, if there is any particular needs for the task, for example the need for work equipment, space, light, or visibility, and whether the task is performed while the machine is ON or OFF. The production manager, backup crew and all 5 shifts of operators took part in the open questionnaire but the quality controllers were excluded, since they do not have the experience of the analyzed area of the machine. Answering the questionnaires for operators was organized in group sessions with time to discuss together but also each operator had the opportunity to answer it as an individual. Each shift answered the questionnaire within its own group. Absent operators answered the questionnaire later individually. The first time the operators saw the questionnaires happened outside of normal working hours, so that they were able to concentrate on it better than during the work shift. In addition to that, they had the possibility to supplement their answers during the next work shifts. The maintenance personnel who answered the questionnaire included the maintenance specialist, the internal maintenance personnel and the most regular external workers. Due to the nature of the maintenance work, the maintenance personnel answered the questionnaire individually. They had time to supplement the answers later during the next work shifts.

The inquisitive discussions were carried out informally during the work shifts while the operators and maintenance personnel were performing their tasks. The main function of the discussions was to supplement and define further the task identification. To ease the operators in summoning up all possible tasks, certain questions were used. Such questions asked about tasks within normal and abnormal conditions, observing situations, maintenance and most commonly maintained places, places for cleaning and fault-finding. The operators and maintenance personnel were encouraged to think about how they would improve the analyzed area of the machine in order for it to be safer and easier to work with. Additionally, some requirements were drawn onto photography images of specific places that had requirements for visibility inside the machine and an access or space requirement. This made the limits of the machine more concrete and explicit than words. The operators of every shift and maintenance personnel were able to add their point of view by drawing different areas onto the image.

Tail threading is a specific task that operators perform during every start-up and product change, and the number and frequency of tail threading are essential information on use limits and time limits. The number of tail threading was determined by the number of web breakages. The number and frequency of web breakages were gathered from the devices connected to the Enterprise Resources Planning (ERP) system. Web breakages include every stop caused by different reasons, for example product changes, planned cleaning and maintenance, and unplanned malfunctions. The information was determined from the latest three years 2014–2016. The frequency was estimated as an average value: the average in a month and in a day.

The space limits of the machine were asked in the same open questionnaire that was carried out for the operators and maintenance personnel about the task identification. The space limits were supplemented by observation and inquisitive discussions while operators and maintenance personnel were performing their work tasks. For instance, one particular task, which sets limits for the space needed around the machine, is tail threading. The aim of the observation was to systematically identify the required space limits. Also, the ergonomics of working positions were observed and if there are any requirements for the tasks due to ergonomics. The observation was executed by standing by and monitoring the performance of the tasks. The inquisitive discussions were carried out after the observed task, so that the performance of the task was not influenced by the observation or the discussions. The questions asked during the discussions were generally related to the opinions of the operators and information about the tasks. The observation and discussions were executed with every shift of operators.

Mostly the information and knowledge regarding the operating environment and other limits were gathered and accumulated during the observation, the inquisitive discussions and unofficial talks. These were carried out with the operators, maintenance personnel and other people, such as managers and specialists. The operating environment and other limits were for instance information about driving speed of the machine and possible impacts of different products.

3.5 Hazard Identification and Risk Estimation

There are hazards and hazardous situations or events associated with the tasks performed within the machine. The hazard identification was made based on the task identification that was carried out within the determination of limits of machinery. For each task, all different possible hazards involved were identified. The origin of the hazard and the hazardous situation or event, which occur when a person exposes to the hazard, were first to be identified. Secondly, potential consequences or harm related to the hazardous situation or events were assessed. Moreover, hazards were identified with the checklists provided by the standard ISO 12100 Safety of machinery. The checklists included different types of hazards that might appear within the machinery.

During the first subpart of this study, statutory safety requirements of the Government Decree (12.6.2008/403) were identified. Unfulfilled and partly fulfilled requirements were reviewed during the hazard identification: equivalent requirements were picked up from the Machinery Decree (12.6.2008/400) and the kind of hazards which are related to these were reviewed as well. The Machinery Decree provides more specific information for the same requirements than the Government Decree and that way it is possible to assess the requirements in a wider range than with the requirements of the Government Decree. Unfortunately, there was no English translation of the Machinery Decree available, therefore, to avoid mistakes caused by an unprofessional translation, the requirements were cited literally. This means they are cited in Finnish. Some of these requirements already came up within identified tasks and hazards related to them, so they were not recorded twice.

Before the hazard identification, it was decided that some assumptions would be taken into account, as assumptions can be an input for a risk assessment (Aven 2008). It was decided that only the "worst case scenario" of potential consequences was to be recorded and assessed. Often, the most likely consequence or harm was not as serious as "the worst case scenario" but risks were intended to assess in a way that really shows hazardous events. The company decided that the assumptions for the hazard identification were that there are no unexpected people in the production facilities other than its own personnel, including external workers, and guided visitors, and that the personnel uses the mandatory personal protective equipment (PPE) and follows the given instructions. Also, the fulfilled statutory safety requirements were noticed as assumptions for the risk assessment. However, the behavior against the basic instruction was partly included in the foreseeable misuse that was reported and assessed regarding the applicable tasks. Also, it was assumed that the requirements of statutory safety requirements, such as technical requirements, were as assessed earlier.

A method to gather the information about hazards involved in the identified tasks was observation. The operators were observed while they were performing their tasks. The aim of the observation was to systematically acknowledge the possible hazards and situations and events related to them. The observation was executed by standing by and monitoring the performance of the tasks. With the checklists, the hazard identification was supplemented by inquisitive discussions with the operators. The discussions were carried out after the observed task, so that the performance of the task was not influenced by the observation or the discussions. The questions asked during the discussions were connected to the observation of the operators and information about the tasks and known hazards. The observation and the discussions were executed with every shift of the operators.

A risk estimation was carried out for each potential consequences or harm that were identified within the hazard identification. The risk estimation started with a discussion about the identified hazard, whether all possible hazards were identified or were there more hazards within the analyzed area of the machine. The aim of the risk estimation was to classify the risks related to the hazards in order to determine which ones have to be minimized and reduced. The risk estimation was performed as a work group. Attendees of the group were the safety manager, the production manager, the process manager, the maintenance specialist, the machine tender and two other operators. The attendees were chosen so that the group consisted of employees from multiple grades. Gathering such a group aimed to achieve a team with a diverse range of skills and experience of the machine and tasks performed within the machine. Both the operational and the maintenance party were represented. The team consisted of 3 individuals who were qualified to tend the machine: the actual machine tender, the other one of the two operators was a member of the backup crew and thus qualified as machine tender, as well as the production manager. The risk estimation meeting was to last 3 hours. The risk estimation was led by the safety trainee who also acted as a secretary of the meeting.

Regarding the risk estimation, the risk assessment method presented by the standard ISO 12100 was supplemented with a matrix of risk estimation presented by the technical report ISO/TR 14121-2 Safety of machinery. The company had used this matrix of risk estimation in the earlier risk assessments and safety audits. It was natural to choose it for this study too due to the earlier practices. The matrix provides a slightly different definition for the *risk* and its elements from the standard ISO 12100, so they were changed and sharpened to be almost the same definitions as in the matrix.

The risk estimation was executed with the risk matrix (Figure 8), which has four elements to form the risk. One aspect, the probability of occurrence of harm is marked as a “Class” in Figure 8. It is composed of three of the elements, which are *frequency and duration of exposure of persons to the hazard*, *probability of occurrence of a hazardous event* and *possibility of avoiding or limiting harm*. The values of these three elements were added up to form the value for “Class”. The fourth element is *severity of harm*.

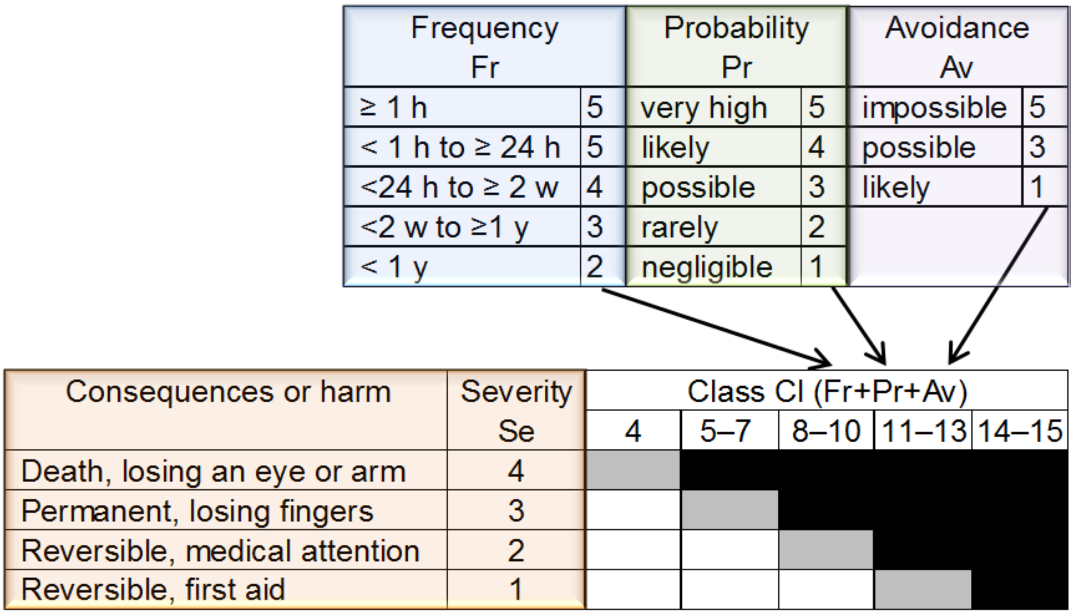

Figure 8. *Risk Estimation Matrix (SFS-ISO/TR 14121-2:2012)*

Frequency and duration of exposure of persons to the hazard was rated on a scale of 2 to 5, where the lowest value 2 means “happens less frequently than once a year” and the highest value 5 means “happens once an hour or more frequently”. The probability of occurrence of a hazardous event was rated on a scale of 1 to 5, where the lowest value 1 means negligible probability and the highest value 5 means very high probability. The possibility of avoiding or limiting harm was rated by the values 1 “likely”, 3 “possible” or 5 “impossible”. The severity of harm was rated on a scale of 1 to 4, where values 1 and 2 represent harm or consequences that are reversible injuries and values 3 and 4 harm or consequences that are permanent injuries.

On the risk matrix (Figure 8), where the severity and the probability of occurrence of harm, “Class”, cross, the risk estimation gives classification for the harms identified. The estimated risks can have three values: white, grey or black, as can be seen in the risk matrix. White risk means that it is a low and acceptable risk. The color grey stands for a medium risk, which means that safety measures are recommended. Correspondingly, the color black represents a high risk and in that case safety measures are required.

Figure 9 shows instructions on estimating risk elements within the table, which gathers together the results of earlier parts of the risk assessment. There are columns for “task”, “origin of hazard”, “hazardous event” and “potential consequences, harm”. These columns are essential for the risk estimation: the values for the elements of risk are selected due to information provided in these columns. The task in question defines how often the frequency and duration of exposure can happen. Some of the tasks are divided into phases. When valuing the frequency and duration of exposure, checking the column of the origin of hazard is also needed. How often some hazard occurs within the task varies and one task might include more than one hazard. In addition to that, one phase of the task might include more than one hazard. The identified hazard can cause a hazardous event, which is written in the next column. The probability of occurrence of a hazardous event is assessed with the information of this column. A column of “potential consequences, harm” provides information on what kind of harm can potentially occur, and it is used when assessing the severity of harm and the possibility of avoiding or limiting harm.

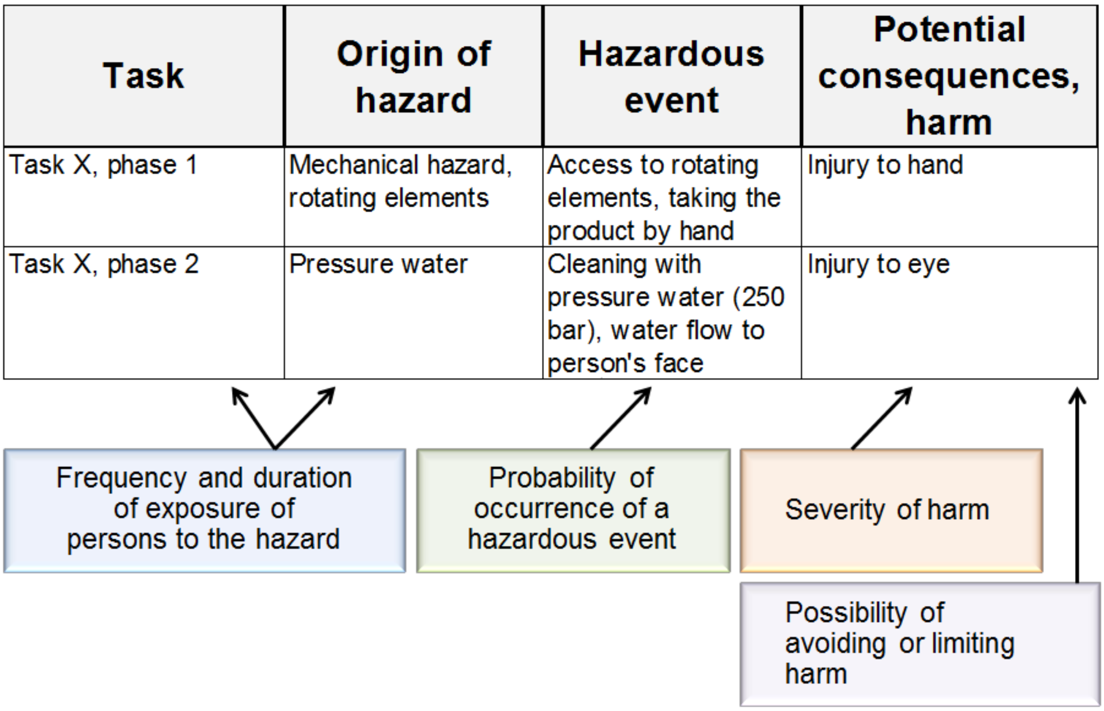

Figure 9. *Instructions on Estimating Risk Elements*

Some of the hazards and risks were identified and estimated in the earlier risk assessments and safety audits outside this study. Applicable hazards and risk estimations of these earlier assessments were filled in the risk assessment table before the group work event. Added hazards and risks were discussed if they still occur within the same dimensions and risks nowadays.

3.6 Risk Reduction and Solutions

A risk reduction was carried out for the estimated risks. The aim of the risk reduction was to consider and find solutions to minimize and reduce the risks that are not on an acceptable level. The risk reduction and finding solutions were carried out for the risks that were estimated as “safety measures are recommended” and “safety measures are required”. Also, acceptable risks were reviewed in order to see if there would be any easy solutions to reduce the risks, for instance including them within the solutions for other risks. Figure 10 visualizes which parts of the risk assessment table are essential for risk reduction and solutions. While planning the risk reduction, the hazardous event, the potential consequences and harm, the requirements of the task and the risk have to be taken into account. The proposed solutions and actions required were written down lastly.

Hazardous event	Potential consequences, harm	Require-ments of the task	Assessment						Proposed solution/ Action required
			Se	Fr	Pr	Av	Cl	Risk	
Access to rotating elements, taking the product by hand	Injury to hand	Task requires access and visibility to the area	2	3	3	1	7	Acceptable	Action X
Access to rotating elements, taking the product by hand	Injury to hand		2	3	3	3	9	Safety measures recommended	Access should be denied with guards

Risk Reduction and Solutions

Figure 10. *Instructions on Risk Reduction and Solutions*

Also, solutions were proposed to meet the statutory safety requirements. Then, "literal citation" of the Decree and "hazard, hazardous event" were essential for proposing solutions. The solutions and required actions were recorded.

The risk reduction and proposed solutions were discussed with the machine tenders of all shifts and most of the operators. The machine tenders were the most critical operators to comment on them due to their knowledge. The aim of discussions was to share and review the ideas to process them further and to find the most practical solutions. After that, risk reduction and proposed solutions were reviewed by a group that consisted of the safety manager, the process manager, the production manager and the plant manager. The identified risks and proposed solutions were communicated together and action plans were discussed.

The operators brought up many ideas related to risk reduction already during the hazard identification. Typically, when a hazard was identified and discussed, possible corrective solutions were also formed. The ideas were gathered at the risk assessment table.

Primarily, solutions to eliminate the risks were considered. Secondly and most often, safeguards and complementary protective measures were considered and brainstormed further. Lastly, if it seemed that there was no solution to lower the risks to the acceptable level with safeguards or other safety measure, the information for use was mapped out, too. Despite the safeguards, sometimes the information for use was needed.

3.7 Verification and Validation

The proposed solutions and planned corrective actions that reduce risks were the results of the study, which were verified and validated. The planned corrective actions were designed by the technical designer and other personnel. The proposed solutions were handed over to the technical designer who designed the possible implementation of safeguards and other changes for the machine. Some of the proposed actions were not applicable or reasonable to be designed by the technical designer but to be executed by other personnel, such as the electrical and maintenance personnel.

The verification and validation were performed qualitatively by way of a discussion with a group that consisted of the technical designer, the safety manager, the process manager, the production manager, the maintenance specialist and the safety trainee. The group was gathered for its professional knowledge, and its members had taken part in earlier team work events regarding this study, except the technical designer. The group was familiar with the requirements and hazards of the machine.

The results were verified by comparing and assessing how they cover and fulfill the original demands: to eliminate and reduce the risks related to hazards and hazardous events. In addition to that, requirements of the tasks were taken into account since they effected on proposed actions. Figure 11 visualizes which parts of the risk assessment table are essential for the verification.

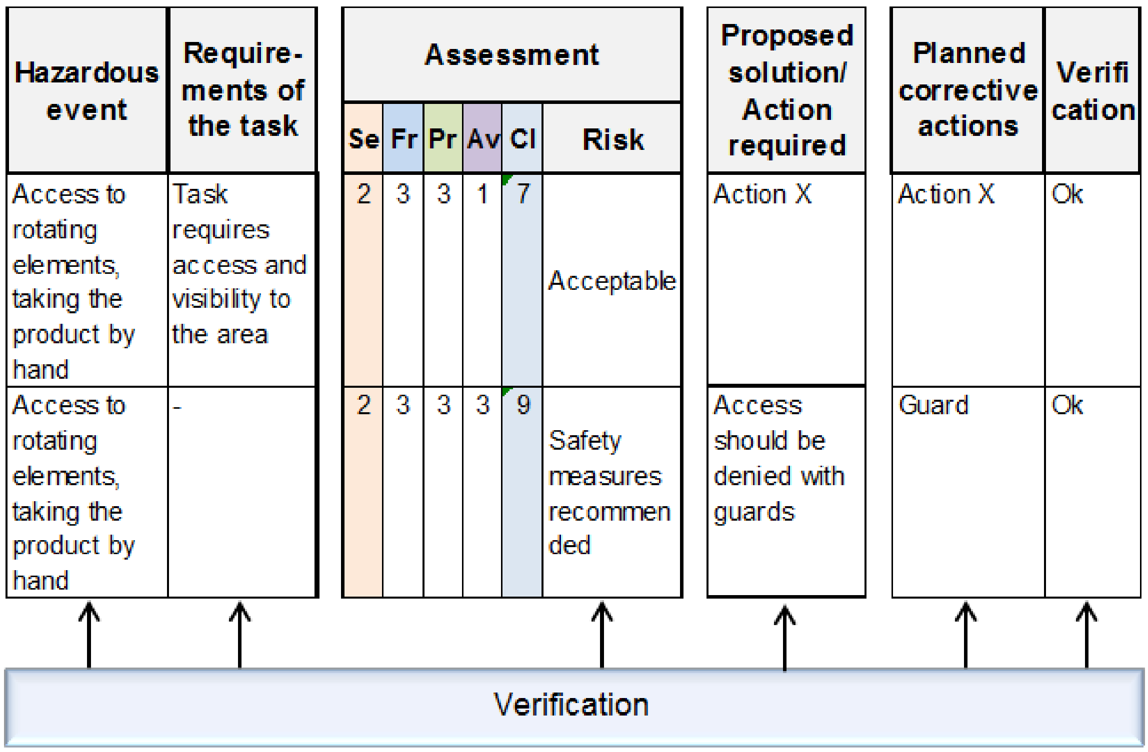

Figure 11. *Instructions on Verification*

The results were validated by assessing if the proposed actions and planned corrective actions were valid solutions in practice to eliminate and reduce the risks related to hazards and hazardous events. Again, the requirements of the tasks were taken into account since they affected the proposed actions. Figure 12 represents which parts of the risk assessment table are essential for the validation.

Hazardous event	Require-ments of the task	Assessment						Proposed solution/ Action required	Planned corrective actions	Valida tion
		Se	Fr	Pr	Av	Cl	Risk			
Access to rotating elements, taking the product by hand	Task requires access and visibility to the area	2	3	3	1	7	Acceptable	Action X	Action X	Ok
Access to rotating elements, taking the product by hand	-	2	3	3	3	9	Safety measures recommended	Access should be denied with guards	Guard	Ok

Validation

***Figure 12**. Instructions on Validation*

The verification and validation were made for all the tasks that included a high or medium risk and for each task that included some requirements so that the new actions would not have any unwanted effect, such as blocking an access to somewhere unnecessarily. The results of the verification were marked as “Ok” or “Not ok” in the column of verification. The results of the validation were marked correspondingly.

4. RESULTS

4.1 Identifying the Statutory Safety Requirements

The statutory safety requirements for the modernization of this machine consisted of the requirements provided by the Government Decree (12.6.2008/403), which regulates the safe use and inspection of work equipment. Applicable safety requirements of the Decree are gathered at a table (Appendix B). 74 percent of the requirements were fully complied with, and the 26 percent of the requirements left were partly complied with. None of the requirements were totally unfulfilled.

The partly fulfilled requirements were included in the risk assessment where they were more closely analyzed within the chosen area of the machine. The identified requirements that were partly fulfilled were under the topics such as “choosing work equipment, and its placement”, “instructions for use of work equipment”, “properties of guards and safety devices”, “warning devices and markings”, “stopping the work equipment, and emergency stop”, “guard structures and equipment preventing falls” and “use and placing of ladders”. However, the partly fulfilled requirements were largely fulfilled but only a few points of each one were not. For instance, there were sufficient amount of emergency stop devices on the tender side of the machine but doubts if the emergency stop devices were too widely positioned on the drive side of the machine. Among other partly fulfilled requirements, this kind of speculation was pondered in the risk assessment. Some of the requirements were noticed by the tasks of operators in the risk assessment, too, so they were included into the task based assessment.

Some requirements were fulfilled but, still, included into the risk assessment. For instance, in normal conditions, the work equipment is safe but then hazards caused by failure of some tasks might change the situation. Ensuring the functional condition of work equipment was one of these topics that were partly included and covered by the risk assessment.

4.2 Determination of Limits of Machinery

The results of task identification as a use limit are gathered at a table in the risk assessment (Appendix C). The same table includes both intended use and reasonably foreseeable misuse. The tasks that were identified composed the base for the risk assessment, as they were listed as a commencement for task based risk assessment. Tasks are divided into two sections: the tasks that are performed while the machine is ON and the ones while the machine is OFF. Some of the tasks could be done either way, hence, they are primarily positioned in the category while the machine is ON when there might be more hazards involved within the task. The tasks include both tasks performed by the operators and by the maintenance personnel.

Almost 50 tasks were identified. 54 % of them were tasks which are performed while the machine is ON. The other 46 % were performed while the machine is OFF. The most common tasks while the machine is ON were observing and cleaning of various targets. The most common tasks while the machine is OFF were cleaning and changing parts. Again, the targets of these tasks vary. Most of the identified tasks were performed on the tender side of the machine.

The identified tasks set requirements for the working environment around the machine. Space limits, including ergonomics, and other requirements for each identified task were analyzed and gathered at a table in the risk assessment as "requirements of the task". Limits were written down: if the task requires access to or visibility of the area or something else, for example stairs. The space limits were drawn onto photography images of the machine. The space limits were required for 50 % of the tasks which are performed while the machine is ON. Especially, the task of tail threading set the space limits needed around the machine. There was an access to the machine from two sides of the machine: the tender and the drive side. Clearly, a more frequent access was needed from the tender side of the machine. The determination of space limits concentrated more on the tasks that are performed while the machine is ON because the tasks, that can be carried out while the machine is OFF, are more flexible regarding for instance safeguarding. The guards can be removed while the machine is OFF since many hazards, for instance hazards of moving or rotating elements, do not exist.

The identified tasks set requirements for the visibility of the machine. These areas of required visibility were drawn onto photography images of the machine. 73 % of the identified tasks required a visibility of the machine while it is ON. It means that the analyzed area of the machine has to be easily on view while performing tasks. Moreover, the lightning of the machine arose as an issue within the task identification. More spotlights were required on certain areas of the machine while the machine is ON and tasks are performed. Of course, proper lightning was required during maintenance work, too, and other tasks that are mainly performed while the machine is OFF.

The other use limit, the number and frequency of web breakages, is gathered in Table 2. It represents the number and frequency of web breakages in the latest three years of 2014–2016. The frequency is shown as an average in a month and average in a day.

Table 2. The Number and Frequency of Web Breakages

Year	The number of web breakage	The frequency: average in a month	The frequency: average in a day
2016	851	70.9	2.3
2015	892	74.3	2.4
2014	906	75.5	2.5
average	883	73.6	2.4

The number of web breakage was 851 in 2016. The average of the number of web breakage in the latest three years of 2014–2016 was 883, so the number of 2016 is relatively close to the previous years, since it's only 4 % less than the average. The frequency of web breakage shows that there are 73.6 web breakages in one month on average. It means that there are 2.4 web breakages every day on average. Every time there is a web breakage, there is a tail threading, too. In other words, the operators of the machine are required to perform the tail threading many times a day, and the access to the machine has to be simple and undemanding within the places where the tail threading is performed.

The users of the machine are mainly 5-shift operators, the backup crew, and maintenance personnel. Every shift has its own machine tender in charge of the operations during the shift. The backup crew is qualified as a machine tender. The exposure of other people to the machine is possible: visitors and other workers walk on the walk way past the machine.

The machine is located indoors; therefore the operational and thermal environment remains the same. The driving speed of the machine is normally A m/min. The tail threading is performed within speed B m/min. The crawling speed is C m/min.

Other limits of the machine have an effect on time limits. The machine produces different kinds of nonwoven based materials, so the properties of the materials that are processed vary. While working the open questionnaire of the task identification, the operators brought up the information that there are different frequencies of some tasks depending on the different products. Producing different products does not significantly change necessary tasks but the recurrence interval of some tasks is quicker. Such tasks can be for example checking the cleanliness level and then cleaning when required, and tail threading. The properties of the products causing these additional repetitions of tasks are usually weight and thickness.

4.3 Hazard Identification and Risk Estimation

The results of hazard identification and risk estimation are gathered at the table in the risk assessment (Appendix C). The results are connected to the earlier tasks that were identified. For each task one or more hazards involved within the performance of the task were identified. Some tasks included more than one phase so the phases were recorded one by one when applicable. Some of the hazards were already known and reduced to an acceptable level. Nonetheless, they were gathered in the same risk assessment file to identify all possible hazardous events or situations related to the analyzed area of the machine.

The statutory safety requirements were included into the hazard identification. 11 topics were divided into 16 sections. For example one topic related to 3 different areas, which were assessed individually. The 16 sections of the statutory safety requirements were assessed if there were hazards related to them. In some cases hazardous events were assessed, too, just to make sure that there is note of the issues that caused corrective actions. The potential consequences and the risk estimation were not carried out, due to the statutory base of these requirements: it does not matter which kind of consequences there are, the requirements are mandatory to fulfill. In most cases, there were no identified hazards related to the requirements. This closer inspection for requirements, that were earlier assessed as partly fulfilled, were now noted to be fulfilled with new safeguarding, and it was also noted that the requirements just have to be remembered while designing guards or other safety measures. Yet, deficiencies were identified when stopping the machine. It is equipped with several emergency stops, however, now possible incapability to stop the machine in case of emergency on a certain place was discussed and the need for the emergency stop device was identified.

Around 60 task-based hazards were identified. Hazardous events and potential consequences and harms were assessed for each hazard. The most common origin of hazard was mechanical hazards. Working nearby rotating elements, access to rotating elements was assessed to be the hazardous event that was most frequently related to the tasks. It occurred several times within the tasks performed by operators. The most common potential consequence was assessed to be an injury to the hand. Several foreseeable misuse cases were identified. Mostly, they were connected to the situations and action that were done when a person is cognitively loaded, such as when a person behaves reflexively or is tired during the night shift.

Some of the tasks were divided into phases to be able to assess them in a very detailed way. Regarding one task more than 10 phases within different working areas and positions were identified. This led to a surprisingly large amount of identified hazards within the task, even though there was basically only one hazard, which remained the same during the task. If conclusions were made too straightforwardly due to the amount of identified hazards, it would not reflect the reality since the tasks were divided into phases this way just to reveal all limits and requirements of the tasks.

Figure 13 represents two examples of the tasks, the related hazards and estimated risks from the risk assessment table. Both situations are within the same task, task A, and within the same phase of the task, phase 2. First, there is the situation in which the task fails when the product sticks to the doctor blade. A mechanical hazard was identified, caused by rotating elements. If the operator performing the task uses additional working equipment to help the product pass the doctor blade, a hazardous event can occur because there is an access to the rotating elements and additional working equipment might stick to the rotating elements. Potential consequences are assessed to be an injury to the hand. On the other hand, the situation might go differently: the second situation is assessed as a foreseeable misuse. When the task A fails and the product sticks to the doctor blade, a foreseeable misuse can happen. In this case, the hazardous event occurs if the operator uses his hand thoughtlessly close to the machine and the hazardous zone, which consists of rotating elements. Taking the product by hand is not allowed but a reflexive action is possible especially when the operator is cognitively loaded, for instance tired. Again, as a potential consequence, there could be harm in form of an injury to the hand.

Task	Origin of hazard	Hazardous event	Potential consequences, harm	Assessment					
				Se	Fr	Pr	Av	Cl	Risk
Task A, phase 2 **failing**: the product sticks to the doctor blade	Mechanical hazard, rotating elements	Access and contact with rotating elements, helping the product by additional work equipment	Injury to hand	2	3	3	1	7	Acceptabl e
Foreseeable **misuse:** When task A, phase 2 is **failing,** it is possible that operator uses his hand thoughtlessly close to the machine	Mechanical hazard, rotating elements	Access and contact with rotating elements, taking the product by hand	Injury to hand	2	3	3	3	9	Safety measures recomme nded

Figure 13. *Examples of the Tasks, the Related Hazards and Estimated Risks*

The risk estimation for these situations is similar for both. The severity of harm was assessed to be a reversible injury to the hand, which requires medical attention at its worst. It got value 2 in both cases. The frequency and duration of exposure of persons to the hazard was the same since every time the task A and its phase 2 fails, the foreseeable misuse can also happen. The frequency and duration of exposure of persons to the hazard was assessed with value 2 which means it can happen once a year or more frequently, but not as often as once in 2 weeks. The probability of occurrence of a hazardous event was valued as possible, value 3, in both cases. But, the possibility of avoiding or limiting harm is where these situations vary from each other. In the first scenario, the possibility of avoiding or limiting harm was assessed to be likely, value 1. The operator performing the task can also choose not to use additional working equipment close to the rotating elements of the machine. In the second scenario, the possibility of avoiding or limiting harm was assessed to be possible, value 3. In this case, the operator can avoid harm but not as easily as in the other situation since he might be acting according to his instincts. These latest three elements were added up to form *probability of occurrence of harm*, which is marked as a "Cl" in Figure 13. For the first scenario, the probability of occurrence of harm was 7 and for the second one it was 9. This value and the value of the severity of harm leads to the classification of risk by using the risk estimation table. The risk of the first scenario was a low and acceptable risk. The risk of the second scenario was a medium risk, which means that safety measures are recommended. The risk estimation was carried out in a similar way for the other identified tasks and hazards.

In addition to the operators, the maintenance personnel were performing tasks related to the maintenance of the machine. During most of the maintenance tasks in the analyzed area of the machine, no hazards were identified. One assumption of the risk assessment was that the personnel follows given instructions. This has already reduced some risks such as an unexpected starting of the machine by using the Lock Out/Tag Out (LOTO) procedure. The maintenance tasks were mainly carried out when the machine is turned OFF, hence, the LOTO procedure is always used in these tasks. While access and working nearby to rotating elements was the most frequently occurring hazardous event within the tasks performed by the operators, one of the most often occurring hazardous events for maintenance personnel was access to and working nearby sharp edges. Injury to the hand and injury to the body were common potential consequences within the tasks of the maintenance personnel. Some of the tasks did not include any hazards but they were still left in the risk assessment table: they set requirements that have to be taken into account when designing safeguards.

4.4 Risk Reduction and Solutions

The results of risk reduction and finding solutions are gathered at the table in the risk assessment (Appendix C) under the title "Proposed solution/Action required". The results are connected to the earlier tasks and hazards that were identified. The risk reduction was assessed for most of the risks. Only some acceptable risks were left as they were without any risk reduction measures or finding other solution.

The most common proposed solution was guard. It means that as a required action there is need to improve existing guards, possibly make them to cover wider area of the machine and simply add more guards for some places. Some areas of the machine were lacking of guards, because they had earlier been estimated to include acceptable risks and they had not been assessed to be any priorities of actions. Now, the need for improvements of guards was revealed so clearly, and it is practical to cover those areas of acceptable risks too. Guards will deny access to many areas which include rotating elements. It was decided to remove already existing guards and rebuild them in connection with the new guards. This way guards can be made to be more continuous and uniform. The guards will, also, eliminate and reduce the risks related to foreseeable misuse. Some of the misuse cases were connected to situations when there is an access to the rotating elements. Once these areas are covered, the identified potential misuse is not possible anymore.

Both fixed and movable guards were assessed to be needed. Some areas clearly require fixed guards but some areas and tasks within these areas benefit from the guard with occasional access. In fact, some tasks are not possible to carry out without an access to the certain areas of the machine. Especially, operators are performing the task of tail threading many times a day, as the determination of limits of machine revealed, and some of the areas that are vital for tail threading require a movable guard. In principle, good solutions were found for these areas. However, finding solutions was not easy because of the multiple requirements of the tasks. The machine was not designed originally with guards, so adding more guards might complicate performing tasks. Of course, some of the tasks are practical to perform slightly differently but the performance of some tasks simply is forced to be made differently. There were solutions to ease the changes. It takes an effort from the operators and maintenance personnel to adapt to a new ways of performing the tasks. Even though, the personnel has been involved in this study providing information on their work, all the changes made for the machine has to be passed on and communicated to the personnel comprehensively.

The requirements of the tasks were taken into account when proposing solutions to reduce the risks. The requirement of visibility caused the proposed solution of a safeguard with visibility. In practice, it means that the guard cannot be made of non-transparent material. One solution was that the guard could be made of a network structure, in which case the operators and maintenance personnel could see through the holes. Of course, a guard with holes might not be sufficient enough to secure the personnel from flying objects. However, this machine does not produce any heavy products and it was not a foreseeable option that parts of heavy pieces could break off the machine. So, the network structure as a material for guards was assessed to be a safe choice. In general, the tasks required access, visibility, stairs or proper lightning to the machine. More specific requirements were identified, too.

The difference between the requirements of the tasks that are performed when the machine is ON and the tasks when it is OFF was noticed. While the machine is ON, the operators mostly require visibility on the machine. While it is OFF, the access is the most required demand. This was expected and is a natural result. The proposed solution for removing guards was that they be easily removed with one tool or as little tools as possible. For instance, the same size of tool for all the screws in the guards would be an easy solution for operators and maintenance personnel. Moreover, the guards should be made of more than one piece. Many small pieces allow for the guards to be removed only partly, without removing everything. This makes it practical if some tasks require access to a particular area only. Yet, the guards cannot be made from too many pieces: removing and affixing them cannot be like “playing a puzzle” every time a task requires access behind the guards. It is important to find a suitable balance for the size of the guards.

The ergonomics of the operators and maintenance personnel was one aspect of space limits to be taken into account. During the execution of the research, the performances of the tasks were assessed to be suitable for each operator and maintenance personnel regarding ergonomics. There were some requirements of the task due to the ergonomics, such as a need for stairs. Guards will change the situation at least regarding the task of removing the guards. New guards would probably be wider and larger pieces than the existing ones, hence, moving them has to be designed easy and safe in an ergonomic way. Moving them by hands requires that it is possible to hold on to them and carry them, and that the weight is appropriate for manual lifting.

Figure 14 represents the proposed solutions or required actions for the same tasks and risks that were already shown in Figure 13. The first situation was when task A and its phase 2 fails. The risk was acceptable. However, usage of additional work equipment within the task raised discussions which resulted in it needing to be safely handled, and certain actions were proposed regarding the safeguards. The other situation was when the same phase of the task fails and a foreseeable misuse occurs. The required action was identified: access to the hazardous zone should be denied with guards. When discussing about the risk reduction and finding solutions, it was ensured that there is no requirement of the task that needs this kind of access to the area which includes the hazardous zone.

Task	Assessment						Proposed solution/ Action required
	Se	Fr	Pr	Av	Cl	Risk	
Task A, phase 2 **failing**: the product sticks to the doctor blade	2	3	3	1	7	Acceptabl e	Usage of additional work equipment should be safe (action X needed concerning safeguards)
Foreseeable **misuse:** When task A, phase 2 is **failing,** it is possible that operator uses his hand thoughtlessly close to the machine	2	3	3	3	9	Safety measures recomme nded	Access should be denied with guards

Figure 14. *Examples of the Proposed Solutions as a Risk Reduction*

Foreseeable problems with guards are cleaning them. Guards made of a network structure might gather dirt. Fibers and pieces of products will probably cause guards to get partially dirty which will block the visibility. Operators would need to clean the guards when the machine is not producing. However, this is not a big change from the existing situation; cleaning is already a recurrent task for the operators.

The lightning of the area around the machine might need a reassessment after the guards are implemented. The guards might block the general light so that more spotlights are required to achieve a sufficient level of illumination. As for the lights and visibility through the guards, it would be good if a darker color than the one of the actual machine or parts of the machine behind the guards was chosen. This helps to see through and see the structures behind clearly.

9 near miss findings were reported while carrying out the risk assessment. Near miss findings was the company's way of reporting possible ideas for improvements or near miss cases that happened. These 9 findings were written down as required actions. They were reported soon after their identification so that these findings could be taken into action without waiting for the implementation of other results of this study. The findings included notes of malfunctions of some part of the machine, demands for cleaning some parts of the machine to make them work more sufficiently, ideas for simplifying something, ideas for improving the ergonomics of the personnel operating with the machine or similar types of findings.

Regarding the statutory safety requirements, the need for an emergency stop device was identified. The proposed solution was to add an emergency stop device to a certain place. As other near miss findings, it was reported so that the action could be taken into implementation without waiting for the completion of this study.

4.5 Verification and Validation

The results of verification and validation are gathered at the table in the risk assessment (Appendix C). The validation of the results was only performed by assessing the solutions in theory. The implementation of the results was excluded from the scope of the thesis due to the time limits of the thesis and assessing the solutions in practice was not possible.

Almost all of the verified proposed solutions and planned corrective actions were assessed to cover and fulfill the original demands. Some of the proposed solutions were lacking of final decisions of what was to be done to fulfill the requirements, or it was not clear if the demands were to be fulfilled. These issues were discussed and handled later on by the company.

All of the proposed solutions and planned corrective actions that were verified to cover and fulfill the original demands were, also, assessed to be valid solutions in practice to eliminate and reduce the risks related to hazards and hazardous events. Figure 15 represents that 91 percent of the validated results were assessed to be valid. However, 3 percent of the results were not applicable. These 3 percent were related to statutory safety requirements and any of the planned corrective action was not related to these requirements. However, if the verified solutions, of which the final decisions had not yet been made, would be related to these statutory safety requirements, they have to be taken into account.

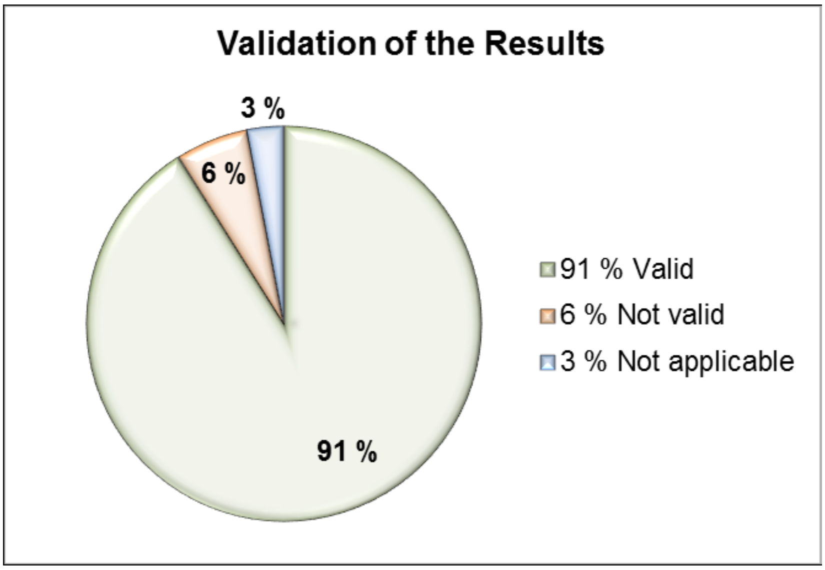

Figure 15. *Validation of the Results*

Figure 16 represents the verification and validation for the same tasks and risks that were already shown in Figures 13 and 14. Although the risk is acceptable in the first situation, where phase 2 of the task A was failing, required action was needed regarding safeguards. In the Figure 16 it can be seen that the same action regarding safeguards was a planned corrective action. Within the verification, it was verified that this action fulfilled the demands of the situation.

Task	Assessment						Proposed solution/ Action required	Planned corrective actions	Verification	Validation
	Se	Fr	Pr	Av	Cl	Risk				
Task A, phase 2 **failing**: the product sticks to the doctor blade	2	3	3	1	7	Acceptable	Usage of additional work equipment should be safe (action X needed concerning safeguards)	Action X	Ok	Ok
Foreseeable **misuse:** When task A, phase 2 is **failing,** it is possible that operator uses his hand thoughtlessly close to the machine	2	3	3	3	9	Safety measures recommended	Access should be denied with guards	Guard	Ok	Ok

Figure 16. *Examples of the Verification and Validation of the Results*

In the second situation, the foreseeable misuse was occurring during the same phase of the same task and the risk was medium. The proposed solutions suggested that the access should be denied with guards. To add a guard was also the planned corrective action. It was verified to be an applicable solution to eliminate the hazard. Both of these actions were assessed to be valid solutions in practice.

The verification and validation of the results showed that the majority of tasks (91 %) were achieved to be safe enough as aimed by implementing the proposed solutions and planned corrective actions. The results of the research were for the most part sufficient enough to meet the requirements set for proposed solutions and to eliminate or reduce risks adequately. A minority of the tasks (6 %) remained with the risks that will be managed by the company later on.

5. DISCUSSION

5.1 Analysis of the Results

The results of this research were used as a basis for safety modernization and they made sure that the risks related to the hazards within the chosen area of the machine were assessed systematically. The verification of the results confirmed that the majority of the results covered and fulfilled the original demands aiming at eliminating and reducing risks related to the hazards of the machine by conducting proposed solutions and planned corrective actions for the analyzed area of the machine. The validation of the results showed that 91 percent of the results were valid solutions in practice. 6 percent of the results that were not valid were proposed solutions lacking of a final decisions about what will be made. These issues remained with the risk, if there were any risks involved, and the company will decide later on what the solution will be.

Around 50 tasks were identified and around 60 hazards related to them. For some tasks there was more than one hazard related to the performance of the task. The risk reduction has taken this into account: different hazards within the same task had their own risk reduction measures. Dividing tasks into phases turned out to be a good solution since it contributed to identifying several hazards during different phases of the task.

The most common hazardous events related to the machine were working nearby rotating elements when there was an access to the rotating elements. This is in line with the findings other studies have revealed too: movements and moving parts of the machine and access to them are common reasons for accidents related to machinery (Chinniah 2015; Backström & Döös 2000). Potential consequences were most often assessed to be an injury to the hand. Sometimes access to moving parts is caused by a lack of safeguards or there are problems with them (Chinniah 2015). Also, in this research deficiencies with safeguards were identified. The safeguards did not cover all of the rotating elements, which enables for hazardous events, and further, possible accidents. As a result, the most common proposed solution was guard: existing guards need to be improved and extended to cover wider areas of the machine to make it safer. Guards are an efficient way to reduce risks related to the hazards of machinery, since they deny access to the hazardous zone (SFS-EN ISO 12100:2010). The proposed guards include both fixed and movable guards since access to certain areas is required during the operations.

In addition to guards, there were other proposed solutions to carry out within the machine, such as to add an emergency stop device in a certain place. Assessing through statutory safety requirements whether they were complied with or not revealed certain issues, such as sufficiency of the amount of emergency stop devices. When the proposed guards and other solutions are implemented, risks related to the hazards of the machine are reduced and the machine reaches a higher level of occupational safety.

The results of this research concentrated on guards for the most part. Guards feature safeguards and complementary safety measures which should always be the second step after applying inherently safe design measures to reduce risks and hazards of the machinery (SFS-EN ISO 12100:2010). In this case, inherently safe measures were not possible for an existing machine that is decades old and, hence, guards are a valid solution to improve the safety of the machinery. Moreover, safeguards are more efficient than applying only information for use that relies on informing the users and warning them of the hazards of the machinery (SFS-EN ISO 12100:2010). The proposed solutions of this thesis minimized the need for additional information for use. The solutions are simple enough to lower the risks without residual risks that remain within the solutions, and mainly, information for use is not required. This makes working with the machine relatively safe in that sense, since users do not have to keep in mind extra safety instructions while performing the tasks within the machine.

This research was based on the fact that the requirements of operations have to be taken into account while planning the safety modernization of the machine. It was important to gather all possible tasks related to the machine in order to be able to generate solutions and new guards so that they cover all critical and hazardous areas but allow performing the vital tasks of the operations. Clearly, implementing safety measures should not form any new hazards or complicate the ergonomics and usage of the machine. It would have been easy to eliminate most of the risks related to the hazards of the machine by simply adding a fixed wall of guards next to the machine, but, it would have not taken into account all variables and requirements of the operations. Some tasks are vital for production, hence, these tasks have to be carried out while the machine is ON and there has to be a safe way to carry them out. Building unpractical solutions could cause misuse and defeating safeguards (Backström & Döös 2000) and this was to be prevented by finding a practical solution which would match with the requirements.

The research was concentrated more on the tasks that are performed while the machine is ON than OFF. Thus, more hazards were identified within them. In reality, a wider range of hazards might be involved within the tasks that are performed while the machine is OFF since these tasks include so many ranges of different tasks. Nonetheless, the tasks performed while the machine is ON were the tasks that affected most on the requirements of safeguarding of the machine. By using other safety procedures, such as the LOTO procedure, safe working methods can be guaranteed for the tasks performed while the machine is OFF.

The first objective of the research was to identify safety requirements regarding the modernization of the chosen area of the machine, especially concentrating on safeguards. This objective produced the first two phases of the research: identifying statutory safety requirements and determination of limits of machinery to conduct the basic information for a later risk assessment. It was essential to gather detailed information in order to be able to carry out a successful project related to the modernization of the machinery (Malm & Hämäläinen 2006) based on the results of this research. The determination of limits of machinery included a task identification, and an identification of other limits such as space and time limits. The statutory safety requirements were identified from the applicable legislation in Finland, which in this case was the Government Decree (12.6.2008/403), which regulates safe use and inspection of work equipment. The partly fulfilled requirements were reviewed in the hazard identification based on the equivalent requirements from the Machinery Decree (12.6.2008/400). This enabled that requirements were assessed more closely with details since Machinery Decree provides more specific information for the same requirements than the Government Decree.

The second objective of the research was to identify deficiencies and hazards related to the safety of the chosen area of the machine. The third phase of the research was the hazard identification and risk estimation. The determination of limits of machinery and the hazard identification were carried out with a task based approach. If they were determined with the machine based approach instead of the task based, it might have resulted in different values for the hazard identification. Though, fewer hazards might have been revealed since not all of the hazardous situations were easily recognizable before the users of the machine were performing their work tasks. Moreover, the risk assessment method was a forward approach, which means assessing situations from hazard to harm. It was an applicable approach to be used since it revealed the hazards involved more comprehensively than the opposite approach, the backward approach, in which situations would have been assessed from harm to hazard (Aven 2008). Thus, these chosen approaches, the task based and forward approaches, were productive for this research.

The risk estimation was carried out by following a matrix of risk estimation provided the by technical report ISO/TR 14121-2 Safety of Machinery. It can be questioned if a numeral risk evaluation was needed: the other option, the qualitative assessment does not take as much time as the used numeral assessment and it might give a sufficiently detailed assessment of the issues requiring actions and improvements. The people qualified in assessing risks or experienced in executing risk assessments might be able to evaluate risks reliably without a numeral rating. Naturally, it may be easier to assess whether the actions taken have decreased the risks adequately, when using the numeral risk evaluation. On the other hand, the statutory requirements in Finland demand that the occupational conditions and hazards related to them are assessed (L 23.8.2002/738; A 12.6.2008/403) and the numeral risk evaluation as a part of the risk assessment certainly complies with this demand.

The third objective of the research was to propose solutions to meet the identified requirements and reduce the risks related to the hazards. This objective produced the forth phase of the research, which was the risk reduction and solutions. The last phase of the research was the verification and validation of the results. The research method included the risk assessment, as earlier studies have shown it to be a valuable tool for the safety of machinery (Chinniah 2015; Aven 2008). It led systematically to identifying deficiencies and hazards related to the machine and to reduce the risks related to the hazards by discussing and deciding the proposed solutions. Also, the risk assessment was a logical tool to verify if the results of the risk reduction were valid enough to eliminate the identified hazards and reduce the risks since all individual results were uniformly gathered into the same risk assessment table.

The objectives of the research can be considered fulfilled; the need for this research was to conduct information for the safety modernization of a machine and to propose solutions. The information about the requirements, the safety deficiencies and the solutions to meet them was conducted widely. The verification and validation of the results confirmed that most of the results were applicable to reduce the risks related to the hazards of the chosen area of the machine and valid in practice and, thus, fulfilled the objectives.

This research only concentrated on one chosen area of the machine. If the machine was investigated as a whole, it might have revealed different kinds of issues that now remained unidentified. However, the chosen area was particularly demanding and it was chosen in the scope of this thesis which enabled investigating it and risks related to its hazards thoroughly. By using the same method for a larger area of the machine, for the whole machine or for another machine, it is possible to extend the safety modernization and systematic risk assessment.

After an implementation of the results and the safety modernization, it is recommended that the company performs a reassessment of risks related to the machine and its working environment. The reassessment is a useful way of making sure the risks were really reduced in a planned way and any other risks were not created. The used risk assessment table already includes the reserved columns for the reassessment of each task and related hazards so executing should be simple. There were some proposed solutions lacking of final decisions. Once the decisions are made, the company can verify the decided solutions and, after an implementation, carry out the reassessment for them, too. Alternatively, another risk assessment method can be used, such as the Job Safety Analysis (JSA). Anyway, following the impacts of the implemented safety measures is important. It is recommended to update work instructions after the safety modernization. Moreover, all changes of the working environment and methods should be passed on and communicated to the personnel comprehensively.

5.2 Qualitative Rigor of the Research

5.2.1 Credibility

The credibility of the qualitative research is a similar element to what the internal validity is in a quantitative research. It is an essential aspect to be assessed in order to estimate the truth-value of the qualitative research. (Thomas & Magilvy 2011) In this research, there were aspects within the execution of the research which demonstrate its credibility.

The users of the analyzed machine played a major role as a source of information for the research. An open questionnaire, inquisitive discussions and observation were used for gathering the required information from the users. To achieve coherent understanding of the gathered information, the results were supplementing each other.

Open questionnaires were executed for each group of users, in this case meaning for each shift. The users had time to discuss together and form answers with a common understanding. Except the maintenance personnel who answered the questionnaire individually. Later, users had time to supplement their answers. Inquisitive discussions were carried out with helping questions and a possibility to discuss and supplement the earlier given answers. The users were able to define and correct their answers. Also, the observation that was executed for the users while they were performing the analyzed tasks and later discussions, after the observation, did supplement the gathered information. These methods were performed with each user of the machine as was defined within the research method.

The results were gathered together. It was easy due to the likeness of the answers of the different shifts. Very similar information regarding the limits of the machinery, tasks, requirements and hazards appeared. Lastly, after several phases of the research, the most qualified users of each shift, the machine tenders, were asked to ensure the results of the gathered information. This member checking added credibility to the research. Also, it showed that there was reflexivity in the research method once it responded to the actions of the participants: they were able to supplement and correct their answers.

5.2.2 Transferability

Transferability represents for the qualitative research the same element that external validity is for the quantitative research. It studies the applicability of research findings or methods to other contexts. (Thomas & Magilvy 2011) This research was estimated as transferable due to its high applicability to other contexts. The research method used in this thesis is functional and practical to other industries and machineries where human–machine interface exists. It means different types of machineries, production facilities and production lines globally.

However, if this research was conducted again in different cultures, the research may not be as easily performed as it was in this original context. It depends on the culture, both organizational and national, to what extent it is possible to rely on the answers received from the users of the machinery. For example, a high resistance to changes might lead users not to speak honestly about their working tasks and other limits of the machinery. Someone might think that, for a clearer example, the less guards there are the less the execution of the tasks is bothered. It is good to be aware of this kind of resistance while using this method for conducting information. Yet, the research method includes several ways to gather the information, such as the open questionnaire, observation and discussions, hence, these different ways can be weighted differently from what they were in this research, if it seems necessary in some other cultures and contexts. Executing, for instance, more observation instead of a questionnaire might lead to more comprehensive results in some occasions.

5.2.3 Dependability

The dependability represents the reliability of the qualitative research (Thomas & Magilvy 2011). This research achieved partially relative high dependability. The aim of this research and the research method were precisely described so that it is possible to them to be followed and reproducible. Describing the method included recounting the reasons for who was participating in the research, what the methods of gathering information were and how the relevant information was gathered together as results. The research was divided into small phases to make it easier for other researchers to follow in the future.

Some issues had effects on the dependability of the study. One phase of the research was the determination of limits of machinery which was a base for the rest of the study. It included task identification, in which information was gathered by way of an open questionnaire and inquisitive discussions with the users of the machine. The form of the open questionnaire was executed in Finnish due to the language skills of the users, yet, the specification of the research method clarifies the main clues of the questionnaire so that it can be reproduced.

But, the form used for the open questionnaire was not formal and professional. Now, as an unprofessional form, its strength was that it was easy to confront for the operators and maintenance personnel. They might have felt that their answers do not have to be “perfect” to be written down. However, the form of the open questionnaire could have been formulated in a more professional way. It was not totally neutral; it had leading questions that “suggested” answers to the people who were answering the questionnaire. For instance, there was a column in which it was asked if any possible tool or other requirement was needed for the task in question, and after that there were leading questions “such as space, light, visibility”. It is likely that this affected the answers collected from the questionnaire since these requirements were the most common requirements identified and answered within the tasks. However, these leading examples were clearly the most expected requirements involved in many tasks. It can be questioned if they would have come up in these numbers without having the leading questions. On the other hand, leading questions might have caused that people answering the questionnaire did not take into account other requirements after they identified these led examples to be involved within the task. That is one reason why the questionnaire was supplemented with inquisitive discussions: people were ushered to supplement their answers and to rethink also other possible answers.

Once this research was executed, it would change the working environment for the users of the machine. Due to this aspect, it has to be questioned if the users gave the information that completely reflects the reality. It is always possible that they were answering more requirements, such as access needed more often to certain places, than what real work requires. However, this was taken into account by executing the research for each group of users, for each shift, and reflecting their answers to each other. Of course, to achieve more accurate information of some requirements, such as the frequency of needed access to the machine, the performance of the tasks could have been recorded on tape and analyzed based on that.

Observation is a practical source of information when it comes to executing the tasks and hazards involved within. The observation was carried out every time only during the day and evening shifts. The performance of the tasks might vary during the night shift due to changes in the cognitive aspects of the users. Therefore, it was attempted to take into account the changes in the cognitive aspects by assessing a possible misuse caused by them. Also, it was justified that the observation occurred on every shift due to variable working methods: some of the users use different work positions and work tools might vary, too. For instance, some operators might use high pressure water instead of normal pressure water for cleaning the machine.

The dependability of the research depends strongly on the dependability of the risk assessment. Several phases of the risk assessment included team work, in which the dependability depends on the knowledge and skills of the participants. Therefore, it is essential to reflect whether the teams had required knowledge and skills concerning the investigated machinery.

The participants of the teams varied a little during the research. The users of the machine were strongly involved during the information gathering phase, in the hazard identification and the risk estimation. After that, they were not involved in the team discussions, however, the risk reduction measures were discussed with most of them individually and informally during their work shifts. The most qualified users, the machine tenders, were all participating in the risk reduction phase. Then again, the same individuals of managers' level were attending within the team work events, except the maintenance specialist who did not attend to the risk reduction meeting. Most of them had a long, comprehensive experience of working with the machine. All of them had years of experience with this machine. Both maintenance and operational sides were represented even though the maintenance specialist was absent once. Lastly, the results of the research were reviewed and verified with a team that took part in the team work events and execution of the research.

The risk assessment was based on the determined limits of machinery. The users of the machinery were providing information related to those limits. They know how the machine functions, what the situations occurring while performing tasks are and how variable products affect on the usage of the machine. In addition, other employees such as managers and specialists were sharing their knowledge of the machine. The combination of knowledge and skills of all attendees were extensive enough to fulfill the required qualification for a dependable risk assessment.

The reproduction of the research by another researcher following the descriptions of each phase of the research would very probably result in similar findings to this original research. However, as this was a qualitative research, the findings might have some variation in the risk assessment. The estimation of risks always depends on the attendees and their qualification and knowledge of the analyzed machinery.

5.2.4 Confirmability

The confirmability of the qualitative research is similar to what the objectivity is in the quantitative research. It occurs once all the other elements of qualitative rigor have been established. (Thomas & Magilvy 2011) The credibility, transferability and dependability of this research can be considered as established, and further, confirmability of the research.

There were some preconceptions while executing the research. It was pondered by the writer of the thesis what it would take to make sure that foreseeable misuse does not happen. Fortunately, it turned out to be relatively simple to eliminate some identified foreseeable misuse cases by guards. With the proposed guards, there is no need to load operators with instructions that are rarely applicable. In addition to that, the identified risks within the machine were pretty much the similar kinds of issues that were expected. However, new issues were revealed, too. Gathering together all possible hazards was highly practical in order to conduct the results. The unity of the results consisted of the knowledge and information of the participants of the research.

5.3 Scientific Contribution

This research confirmed the same findings of earlier studies: machinery is likely to include safety deficiencies, especially connected to guarding hazardous zone and moving parts of machinery or machine movements. Hazards can efficiently be reduced with safeguards and modernization, however, in this case, it will not compensate totally the lack of inherently safe design measures. This thesis provided one method on how to reveal safety deficiencies related to the usage of the machinery and conduct information for safety improvements through modernization. This method was used to bring up the experience and feedback from the users to the designing of the modernization. Retrospectively, it would be useful to study how effective the safety modernization really was regarding the safety of the machinery: were the safety of the machinery and its working conditions and environment improved and the hazards and risks reduced as verified beforehand.

Further studies could be related to the effectiveness of the safety modernizations of various types of machineries and how efficient these modernizations can be when compared to machineries, in which inherently safe design measures were applied in the first place. Are there any differences between the amounts or severities of accidents in modernized and non-modernized machines? It would be worth studying what kind of design issues especially lead users to defeat safeguarding. Also, it could be reviewed how experiences of users could more easily be brought to the designer of the machine, and how the designers of machineries could effectively be qualified to take safety aspects into account more accurately when designing machinery.

5.4 Practical Contribution

This thesis was carried out to conduct information for a safety modernization of a machine that is operated by Ahlstrom-Munksjö Tampere Oy. The results of this research conducted proposed solutions to eliminate and reduce risks related to the hazards that were identified within the chosen area of the machine. The company can implement the results and, thanks to them, carry out successfully the safety modernization and improve the safety of the machine and its working environment.

The research revealed safety deficiencies and hazards especially occurring within rotating parts of the machinery and how these areas can be made safer by improving safeguarding, furthermore, mainly with a combination of different types of guards. Earlier studies have revealed how important it is to take into account all the aspects that are affecting the design of machineries: users might defeat safeguarding if it makes their work easier even though it endangers their safety (Backström & Döös 2000). This research pointed out one method to do so. The used method is functional to achieve more comprehensive design for the modernization of machinery.

The research method combined a constructive approach and a risk assessment method aiming at finding the problems and corresponding solutions. The method used gathered together several issues to compose the proposed solutions, which included the proposed guards. The characteristics of the guards and other solutions were composed by information of the statutory safety requirements, the limits of the machine, the working environment and different usage of the machine including their multiple requirements, such as visibility of and access to the machine, the ergonomics and foreseeable misuse and problems. This method proved to be effective in combining several kinds of aspects to conduct the requested information, which was now used for the safety modernization of a machine. The method can be used to conduct information for various other situations when several aspects concerning machinery, its use and environment have to be taken into account.

The company can use the same method conducting information and assessing risks related to hazards of machineries in all its other locations and plants to harmonize the assessment methods. The method makes sure that the risks within the machinery are assessed systematically. Further follow-ups are recommended to assess how the use of the machine has really changed and how the proposed solutions and new actions that arose from the risk assessment affected the working methods and working environment. If some risks still occur with the machine, information for use, such as work instructions and warning signs, should be provided and risks communicated to the users of the machine.

The used research method is relatively simple, practical and relevant to other industries and machineries where human–machine interface exists. It can be used for different types of machineries and production facilities in other locations, factories and industries. It was used for an existing machinery in this research, yet, this method is also suitable for assessing occupational hazards and aspects proactively during the design phase of a machinery. But then, other assessments might be required, too. However, if there is no human–machine interface within the machinery, this method is not effective. The task based approach should be, at least, changed to a machine based approach in order to be applicable and effective with, for instance, automated machineries where the human–machine interface does not exist. Correspondingly, if the method is used to assess occupational risks without machines, it needs to be modified to fit for the intended use. For example the determination of limits of machinery could be changed to a determination of other aspects of the working environment. Of course, the task based hazard identification is valid for all kinds of occupational hazards. The risk estimation used in the method might be too complicated for hazards occurring within other than industrial environment. Then, instead of 4 elements of risk, 2 elements could be sufficient enough.

6. CONCLUSION

Machinery and usage of machinery cause accidents globally. Accidents have negative effects on organizations and societies, not to mention the individual who is injured in the accident. At work places, the employer is responsible to ensure that all the operating machineries comply with the safety requirement of the legislation. Primarily, machineries should be designed and produced to be safe during their whole life cycle. Once there is a machinery that does not comply with the safety requirements, it can be modernized to improve its safety.

This thesis analyzed the safety of a machine that was operated by Ahlstrom-Munksjö Tampere Oy. The machine has been commissioned decades ago and the safety modernization of the machine was timely again, especially regarding the safety of one particularly difficult area of the machine. The thesis combined together several relevant aspects to conduct required information for the safety modernization of the chosen area of the machine.

The research method combined a constructive approach and a risk assessment aiming at finding the problems and corresponding solutions. By dividing the research into phases, the objectives were achieved systematically. The phases studied through the statutory safety requirements, the limits of the machinery, the safety deficiencies and hazards, the risks related to the hazards, the risk reduction and finding solutions. Lastly, the results were verified and validated.

After the verification of the results, the validation of the results showed that 91 percent of them were valid in corresponding to objectives which aimed at eliminating and reducing the risks related to the hazards of the machine. The results concentrated mainly on proposing safeguards, which included both fixed and movable guards. The most common hazardous event was assessed to be working nearby and access to rotating elements. Guards deny the access to a hazardous zone of the machine and, hence, reduce hazards and risks efficiently. By implementing the results, the company can improve the safety of the machine and its working conditions and environment, and it is made sure that the risks are assessed systematically.

This research was limited to only one chosen area of the machine and an investigation as a whole machine was not on the scope. Different kinds of hazards might have been revealed if the research was extended to a larger area of the machine or to the whole machine. After the company executes the safety modernization, a reassessment of risks is recommended to estimate whether the proposed solutions were effective enough to reduce the risks in reality. It would be useful to carry out the same risk assessment for other machineries, also in different locations and plants of the company, to harmonize risk assessment methods and make sure that risks related to machineries are assessed systematically.

The research identified safety deficiencies and hazards occurring especially within rotating elements of the machinery. The solutions to make these areas safer were mainly to improve the safeguards. Earlier studies have revealed that users of the machine might even defeat safeguarding if it makes their work easier (Backström & Döös 2000), even though it can be extremely dangerous and harmful for their own and their colleagues' health. Therefore, it is important to take into account all aspects that can affect the design of working conditions and the safety of machinery. This research pointed out one method to combine several different aspects and conduct such information. The used method is useful in bringing up the experience from users and achieving a more comprehensive design for the modernization of the machinery. The method is transferable to other industries and machineries where human–machine interface exists.

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APPENDIX A: OPEN QUESTIONNAIRE FOR PERSONNEL

Kysely pick-up-huovan ja välikuljettimen välillä tehtävistä työtehtävistä

Päivämäärä:
Vastaaja: tuotanto / kunnossapito

Työtehtäviä kirjattaessa pohtikaa monipuolisesti normaaliin toimintaan, huoltoihin, häiriötilanteisiin ja muihin epätavallisiin tilanteisiin liittyviä tehtäviä.

Työtehtävä	Kuka/ketkä tekevät (konho, massamies, kunnossapito jne.)	Tehdäänkö työ päivittäin/ viikottain/ kuukausittain/ harvemmin	Tehtävän mahdollisesti vaatimat työkalut tai muu tarve (esim. oltava tilaa/valoa/ näkyvyyttä)	Tehdäänkö työ koneen käydessä vai kone sammutettuna

Kiitos vastauksista!

APPENDIX B: APPLICABLE SAFETY REQUIREMENTS OF THE GOVERNMENT DECREE (12.6.2008/403)

Section of the Decree	Requirement (citations from unofficial translation)	Are requirements complied with?
Section 2: Choosing work equipment, and its placement	Employers must, for the employees' use, choose safe work equipment that is suitable for the work and the working conditions. The dimensions and strength of work equipment must correspond to the demands of the work. Work equipment must not be burdened or stressed in a way that creates any hazard.	Partly. The analyzed machine complies with the requirements. Closer inspection for other possible and additional work equipment are included in risk assessment in Appendix C.
Section 2: Choosing work equipment, and its placement	While using work equipment, the working posture and location of employees using the equipment, as well as ergonomic principles, must be taken fully into account.	Yes.
Section 2: Choosing work equipment, and its placement	It must be especially ensured that there is space enough to use the work equipment, and that the energy or substance used or produced by the work equipment can be safely transferred. Falls and movements of the equipment causing danger must be prevented by securing the work equipment or some other way.	Partly. Closer inspection for guards of mechanical energy transfer is included in risk assessment in Appendix C.
Section 3: Instructions for use of work equipment	When there are no manufacturer's instructions available, the instructions must be supplemented, or new instructions must be drawn up when necessary. The instructions must be kept up to date. The instructions must be available and understandable for all employees concerned. Before new work or a work phase is started, it must be ensured that the employee can follow the instructions.	Partly.

Section of the Decree	**Requirement (citations from unofficial translation)**	**Are requirements complied with?**
Section 4: Assessment and elimination of risks	The employer must systematically analyse and evaluate the safety of the work equipment. This has to be done especially in connection with changes in production or work methods. When carrying out the evaluation, attention must be paid to the hazards and risks caused by the work equipment and its moving parts, external structure, physical and chemical properties, automatic functions, electricity, and other hazards and risks caused by the work and working conditions. If the use of the equipment causes any hazard or risk, the employer must immediately take any necessary measures to eliminate the hazard or risk.	Yes. However, the closer inspection for risks originating from the analyzed area of the machine is in risk assessment in Appendix C.
Section 5: Ensuring the functional condition of work equipment	Any work equipment must be kept safe throughout its whole operational life by regular service and maintenance. Any hazard or risk caused by failure, damage or wear must be eliminated. The control system and safety devices must function faultlessly.	Yes. However, these requirements are partly included in risk assessment in Appendix C.
Section 5: Ensuring the functional condition of work equipment	The employer must continuously monitor the working order of the work equipment by carrying out inspections, tests, measurements, and using other suitable ways. A qualified person that is familiar with the structure and use of the work equipment can carry out the inspection and testing necessary to ensure the working order of the work equipment.	Yes.
Section 6: Properties of guards and safety devices	Any guards and safety devices of work equipment must in a reliable and appropriate way protect against that risk or those risks against which they have been installed.	Partly. These requirements are included in risk assessment in Appendix C.

Section of the Decree	Requirement (citations from unofficial translation)	Are requirements complied with?
Section 6: Properties of guards and safety devices	The guards and safety devices must: 1) be of solid construction; 2) not give rise to any additional hazard; 3) not be easily removed or rendered inoperative; 4) be situated at a sufficient distance from the danger zone; 5) not restrict more than necessary the view of the operating area of the equipment; and 6) they must allow the measures referred to in section 12: Safety of maintenance work.	Partly. These requirements are included in risk assessment in Appendix C.
Section 7: Warning devices and markings	Work equipment must bear the warning devices and warnings and markings essential to ensure the safety of employees. Warnings and markings on work equipment must be unambiguous and easily perceivable and understandable.	Partly. These requirements are included in risk assessment in Appendix C.
Section 8: Control devices and control systems	Control devices must be located outside danger zones, except for certain control devices that necessarily have to be used inside a danger zone. In that case, other measures have to be used to ensure that the use of the control devices does not cause any danger. Control devices must be protected in a way that prevents their unintended use.	Yes.

Section of the Decree	Requirement (citations from unofficial translation)	Are requirements complied with?
Section 8: Control devices and control systems	Control devices of work equipment that affect safety must be clearly visible and identifiable, and appropriately marked.	Yes.
Section 8: Control devices and control systems	Control systems must be reliable and they must, if possible, be secured in such a way that their failure or a change in their energy level does not cause any danger. The control systems must be chosen taking into account of the deficiencies, malfunctions and restrictions that are likely to occur in their intended operating conditions.	Yes.
Section 9: Starting the work equipment	It must not be possible to start work equipment by any other means but by deliberate action on a control device provided for the purpose.	Yes.
Section 9: Starting the work equipment	Before starting the work equipment the operator must be able to ensure, from the main control position, that no person is present in the danger zones. If this is not possible, (continues---)	Yes.

Section of the Decree	**Requirement (citations from unofficial translation)**	**Are requirements complied with?**
Section 10: Stopping the work equipment, and emergency stop	All work equipment must be equipped with a control to stop it completely and safely. Each workstation must be fitted with a control to stop some or all of the work equipment, so that the equipment is in a safe state. The stop control of the equipment must have priority over the start controls. When the work equipment or the dangerous parts of it have stopped, the energy supply to those devices must stop. Where appropriate and depending on the hazards the equipment presents and its normal stopping time, work equipment must be fitted with an emergency stop device.	Partly. These requirements are included in risk assessment in Appendix C.
Section 11: Isolation from energy sources	Work equipment must be fitted with clearly identifiable devices to isolate it from all its energy sources. When necessary, the devices must be lockable. When the energy supply has been switched off, it must be possible to remove the energy stored in the work equipment in a way that does not cause any danger.	Yes.
Section 12: Safety of maintenance work	In connection with installation, service, repair and other maintenance work, the employer must ensure that 1) the employee has received enough information, training and guidance concerning special circumstances;	Yes.

Section of the Decree	**Requirement (citations from unofficial translation)**	**Are requirements complied with?**
Section 12: Safety of maintenance work	2) when necessary, the persons representing the employer and carrying the responsibility for the work have accepted the work to be carried out and given their permission to begin the work;	Yes.
Section 12: Safety of maintenance work	3) any arrangements and measurements necessary for the safety of the work have been carried out in the workplace;	Yes.
Section 12: Safety of maintenance work	4) any pressure and flow of gas and fluids have been switched off;	Yes.
Section 12: Safety of maintenance work	5) electric tension has been switched off;	Yes.
Section 12: Safety of maintenance work	6) the load on lifting machinery has been secured in such a way that a failure of the machinery cannot cause any danger;	Yes.
Section 12: Safety of maintenance work	7) starting work equipment under repair has been prevented in a reliable way during the repair work, if the employee is situated in the danger zone;	Yes.
Section 12: Safety of maintenance work	8) the work equipment in use is in order and suitable for the intended purpose;	Yes.
Section 12: Safety of maintenance work	9) it has been taken care of that dangerous substances or lack of oxygen do not cause any danger during work in tanks or enclosed places;	Yes.

Section of the Decree	Requirement (citations from unofficial translation)	Are requirements complied with?
Section 12: Safety of maintenance work	10) appropriate personal protective equipment, instruments and other equipment are used;	Yes.
Section 12: Safety of maintenance work	11) sufficient arrangements have been made to ensure the stability and carrying capacity of scaffolds, work platforms and ladders;	Yes.
Section 12: Safety of maintenance work	12) any unnecessary access to the danger area has been prevented.	Yes.
Section 14: Special competence requirements	Drivers of devices for lifting persons must have a written permit given by the employer to carry out the work. Before giving the permit, the employer must ensure that the driver has sufficient ability and skills to use the work equipment.	Yes.
Section 26: Guard structures and equipment preventing falls	Guard structures and equipment preventing falls must have such strength that they, as effectively as possible, prevent persons from falling or stop their falling. Rails and other general safety structures against falls must be continuous, except for any access leading to ladders or stairways.	Partly. These requirements are included in risk assessment in Appendix C.
Section 30: Use and placing of ladders	Ladders must be used in such a way that the employees concerned can all the time hold them safely and get a safe support. Manual carrying of loads must not prevent maintaining a safe hold onto the ladder. Leaning ladders must not be used as work platform.	Partly. There is a low A-ladder in use which lack of handrail. These requirements are included in risk assessment in Appendix C.

Section of the Decree	Requirement (citations from unofficial translation)	Are requirements complied with?
Section 30: Use and placing of ladders	Ladders must be placed in such a way that they stand steadily during the use. Movable ladders must stand on a stable, durable, immobile base of appropriate size, so that the rungs remain in horizontal position. Suspended ladders must be attached safely and, except for rope ladders, in such a way that they cannot move or swing.	Yes.
Section 30: Use and placing of ladders	The risk of movable ladders falling or their legs sliding must be prevented by fastening their upper or lower end, using a device against sliding, or by some other means similarly effective. The ladders must be so tall that they extend far enough above the level to be reached, if a safe hold cannot be guaranteed by any other measures. Lockable multi-element combined ladders and extendable ladders must be used in such a way that the steps, limiters, joints and locking hooks remain strong and durable in the working conditions, and that the parts cannot move in relation to each other. Ladders on wheels must be placed in an immobile position before stepping on them.	Yes.

APPENDIX C: RISK ASSESSMENT

Phase of lifecycle of machine	Task	Origin of hazard	Hazardous event	Potential consequences, harm	Require-ments of the task	Assessment						Proposed solution/ Action required	Planned corrective actions	Verification	Validation
						Se	Fr	Pr	Av	Cl	Risk				
Operation and maintenance (machine is ON)	Task A, phase 2 **failing**: the product sticks to the doctor blade	Mechanical hazard, rotating elements	Access and contact with rotating elements, helping the product by additional work equipment	Injury to hand	Task requires access and visibility to the area	2	3	3	1	7	Acceptable	Usage of additional work equipment should be safe (action X needed concerning safeguards)	Action X	Ok	Ok
	Foreseeable **misuse:** When task A, phase 2 is **failing,** it is possible that operator uses his hand thoughtlessly close to the machine	Mechanical hazard, rotating elements	Access and contact with rotating elements, taking the product by hand	Injury to hand		2	3	3	3	9	Safety measures recommended	Access should be denied with guards	Guard	Ok	Ok
	Controlling the handle of the system Y within the task B	Mechanical hazard, rotating elements and sharp edges	Access and contact with rotating elements and sharp edges	Injury to hand	Task requires access and visibility to the area	3	5	2	1	8	Safety measures required	The control handle should be moved further away from the machine and located also outside of future guard	Guard. Relocating the control handle outside of guard	Ok	Ok
	Observing the tightness of the web	Mechanical hazard, rotating elements	Access and contact with rotating elements	Injury to hand	Task requires visibility to the area	2	4	3	1	8	Safety measures recommended	Safeguard with visibility	Guard with visibility	Ok	Ok

Phase of lifecycle of machine	Task	Origin of hazard	Hazardous event	Potential consequences, harm	Requirements of the task	Assessment						Proposed solution/ Action required	Planned corrective actions	Verification	Validation
						Se	Fr	Pr	Av	Cl	Risk				
Operation and maintenance (machine is OFF)	**Cleaning** task 1, (access from the place x)	Mechanical hazards, sharp edges	Access and working near to sharp edges	Injury to hand	Task requires access to the hatch	2	3	2	1	6	Acceptable		No action	Ok	Ok
	Cleaning task 1, (access from the place x)	High temperature	Contact with parts with high temperature	Injury to hand	Task requires access to the hatch	2	3	2	1	6	Acceptable	Information for use: warning sign of hot surface already exists; checking the cleaning instruction that it mentions to wait until the temperature has lowered before performing the task	Ok	Ok	Ok
	Cleaning the whole machine in general	Hazards are assessed within each cleaning task separately			Tasks require access, so all guards have to be					0		Guards should be removed as simply as possible: one tool for all screw (e.g. 19 mm) etc	New guards will be uniform and removing them is planned to be applicable	Ok	Ok
Statutory safety requirements	**Section/ subsection**	**Literal citation**	**Hazard, hazardous event**	**Potential consequences, harm**	**Requirements of the task**	**Assessment**						**Proposed solution/ Action required**	**Planned corrective actions**	**Verification**	**Validation**
						Se	**Fr**	**Pr**	**Av**	**Cl**	**Risk**				
Applicable requirements of Machinery Decree (12.6.2008/400) based on the Appendix B: Applicable safety requi-rements of Government Decree (12.6.2008/403)	1.2.4.3. Hätäpysäytys Stopping the work equipment, and emergency stop	Koneessa on oltava yksi tai useampia hätäpysäytyslaitteita, joiden avulla todellinen tai uhkaava vaara voidaan torjua.	Incapability to stop the machine in case of emergency might be possible on a certain place							0		To add emergency stop device, near miss finding reported	To add emergency stop device	Ok	Ok