LAB University of Applied Sciences

Mechanical hazards at the interfaces of a paper making machine and the responsibility of identifying hazards.

LAB University of Applied Sciences
Bachelor of Engineering, Mechanical Engineering
2021
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Tiivistelmä

Tekijä(t)	Julkaisun laji	Valmistumisaika
Tilli, Teemu	Opinnäytetyö, AMK	2021
	Sivumäärä 55	

Työn nimi **Mekaaniset vaarat paperikoneiden rajapinnoissa sekä vastuu vaarojen huomioimisesta.**
Tutkinto Konetekniikan insinööri (AMK)
Toimeksiantajan nimi, titteli ja organisaatio Laura Lehtonen, HSE-teknologiapäällikkö, AFRY Finland Oy
Tiivistelmä Opinnäytetyön tilaajana toimi AFRY Finland Oy, yritys halusi raportin paperikoneen mekaanisista vaaroista laiterajapinnoissa sekä valmistajan, konsultin ja asiakkaan vastuista uusien paperi- ja kartonkikoneiden valmistuksessa. Tietojen pohjalta on mahdollista selventää vastuu kysymyksiä eri tilanteissa sekä kohdentaa tarkempaa tarkastelua vaativat kohteet koneen turvallisuutta arvioidessa. Työssä selvitettiin lainsäädännön vaatimukset turvallisen koneen suunnittelua varten. Tätä täydennettiin tiedolla sovellettavista standardeista sekä riskinarviointi prosessista. Työtä varten haastateltiin kahta toimeksiantajayrityksen työntekijää joilta kyseltiin heidän kohtaamistaan yleisistä puutteista paperikoneen rajapintojen turvallisuuteen liittyen. Haastatteluja täydennettiin raporteilla työtapaturma tietokannoista. Työn tuloksena oli raportti rajapintojen yleisistä vaaroista sekä vastuista vaarojen huomioimisessa.
Asiasanat konedirektiivi, koneturvallisuus, riskinarviointi, rajapinta, paperikone, mekaaninen vaara

Abstract

Author(s) Tilli, Teemu	Type of Publication Thesis, UAS	Published 2021
	Number of Pages 55	
Title of Publication **Mechanical hazards at the interfaces of a paper making machine and the responsibility of identifying hazards.**		
Name of Degree Mechanical engineer (UAS)		
Name, title and organization of the client Laura Lehtonen, HSE Technology Manager, AFRY Finland Oy		

Abstract

The thesis was commissioned by AFRY Finland Oy who wanted a report on the mechanical hazards at the interfaces of new paper and board making machines and the responsibilities of the supplier, consultant and the client. The report clarifies the responsibilities of the participants and identifies the most common hazard types present in the interfaces of paper and board making machines.

In the thesis the applicable legislation was examined and this was complemented with instructions from the harmonized standards and the risk assessment process. Two employees working at AFRY were interviewed on their experiences regarding the common hazards at a paper making machines interfaces. The interviews were complemented with reports from work related accident databases.

The result of the thesis was a concise report of the common hazards at the interfaces of a paper making machine and the responsibilities of the participating parties.

Keywords

machinery directive, safety, risk assessment, interface, paper machine, mechanical hazard

Table of contents

1 Introduction

The subject of the thesis is to research the most common risks found at the interfaces of a paper making machine, its sub assembly's and to clarify the responsibilities of the manufacturer, designer/consultant and the end-user of the machine. This this will mainly focus on paper machines but the following concepts also apply to similar machines such as board making machines. The thesis was commissioned by AFRY Finland Oy as a guide for designers and other project team members and sales personnel.

The questions this thesis will seek to answer are:

1. What are the responsibilities regarding a paper making machines machinery safety in an engineering project in regard to the machine supplier, the consultant working for a client and the responsibilities of the end-user?
2. What are the most common risks and hazards present in the paper making machines interfaces and how could the identification of these risks be made easier?

Finding the answer to these questions will help everyone in the machine's creation and commissioning process, as everyone's responsibilities will be clearer from the outset leading to safer design along with less mistakes and discrepancies in the process. These outcomes enable the improvement of the safety of the workplace and its workers leading to increased workplace wellbeing.

The methodology used for gathering information on hazards included utilizing accident reports from the Finnish TOTTI-database to gather example cases in which a work-related incident had occurred as well as interviewing two experts working at AFRY. Lehtonen Laura is a HSE (Health, Safety, Environment) Technology Manager specializing in machinery safety and the directives and legislation regarding machines. Jari Peuhkuri is a Leading Technology Specialist who has experience working with paper making machines in the process industry.

The interviewees were selected from different disciplines to encourage different outlooks on machinery safety as this would enable a broader look at the core reasons behind bad design outcomes, lacking safety measures, worker and employer negligence as well as offering different viewpoints in regard to responsibility.

Company presentation (AFRY)

AFRY is a consultancy company providing services for multiple different sectors of industry. Formed in 2019 when Swedish company ÅF and Finnish company Pöyry merged, AFRY is one of the leading consultancy providers in the world. With multiple different fields of engineering represented AFRY is capable of delivering to a wide range of customers with complete designs and consulting, from start to finish.

Employing approximately 16 000 people in over 40 countries AFRY has a large talent pool of industry leading experts who have attained a lot of experience working on projects in over 100 countries in differing fields of engineering and scale. AFRY has set ambitious goals for itself to fight climate change and collaborate with different organizations on modern and innovative solutions to help increase sustainability in projects of all sizes. AFRY wants to accelerate the sustainability transition by halving CO2 emissions of employees by the year 2030 and achieving net zero emissions by the year 2040. This thesis aims to help the company in its goals to increase customer satisfaction and ensuring ethical business. (AFRY 2021a.)

This thesis was made as an assignment for AFRY who wanted a guide on the responsibilities of suppliers, consultants and clients on paper making machine engineering projects. Common hazards at the interfaces of machinery were also investigated to help determine what kinds of situations tend to lead to an accident.

The following contains the definitions of the participating parties in a paper making machine project:

- Supplier – The participant that delivers the machinery or a part of a machinery, this party is usually bound by the obligations of the machinery directive in the European Union and its corresponding legislation.
- Consultant – The participant that aids the client or supplier with design, engineering procurement, construction or management services depending on the agreed contract between the consultant and their client.
- Client/Employer/End-user – The participant who is the end-user of the delivered machine, usually the employer at a paper mill. They are usually bound by the legislation regarding an employer.

2 Machinery safety

2.1 Machinery safety explained

Machinery safety can be considered the act of designing a machine while taking into consideration all of the prevalent risks and hazards that affect the operator of a machine and the operation of the machine and its environment. Regulations require that machines of all forms should be made safe from hazards to their suppliers and users and that all of the necessary steps are taken to ensure the safety of the machine (Macdonald, 2004, preface).

The extents of the responsibilities in machinery safety are defined by laws and common engineering ethics which state that engineers must strive to comply with the principles of safety, health and welfare of the public in their designs.

The development of machinery safety has evolved together with work safety through the incorporation of legislation, better working conditions and better design practices, therefore it is not easy to mention one without the other.

When the industrialization of the world began, machines utilized were crude and not very safe to operate. Companies did not particularly care for employee safety at the time and the need for standardized machinery safety was not recognized. This started changing over the years as workers began demanding better working conditions and these requirements were started being implemented into legislation and iterated over the following decades. The speed of this development was very dependent on the developmental status of the country in question and in certain parts of the world is still very much an ongoing process. As safety measures were being implemented into law the discrepancies between countries legislation became apparent. This led to the creation of organizations which would develop standardized methods for the design and production of machinery. Countries usually have their own standardization organization which implements the designs of larger more influential organizations to increase the compatibility of their products specification with the legislation of other countries.

Even though the improvements in technology and design practices have been substantial in the past century the invention of new technologies brings with it a constant need to advance the safety aspects of the designs to include new features offered by the advancements. Machinery safety encompasses the act of reducing and mitigating hazards and risks present in a machine. This is done with the utilization of risk assessment, standards, standardized components and design practices, implementation of safety features and education on safe working methods.

2.2 Importance of machinery safety

The importance of machinery safety has been growing ever since the industrialization of the world. At first the main focus of machines was only to increase production and decrease the dependency on human labor. This resulted in poor working conditions and even the utilization of child labor. Manufacturers having the ability to increase the capacity of their production meant that the price of goods could be lowered to improve competitiveness. This in turn expanded the markets of goods therefore leading to more industrialization and to more machines being utilized. Workers began demanding safer working conditions and governing bodies were established to improve the conditions of workers. (Rockford Systems, LLC)

As the usage of machines increased the importance of machinery safety began to show its significance. Manufactures began to better realize the importance of machinery safety, its effects on employee well-being and its effects on the image of the company due to the pressure put on them by labor unions (Rockford Systems, LLC).

To monitor the effects of changes to legislation and directives on work safety it is necessary to have statistics that are updated, so that we can objectively compare if the desired outcome have been achieved.

In Finland the following bodies issue statistics regarding machinery safety:

- Finnish Workers Compensation Center (Tapaturmavakuutuskeskus)
- Statistics Finland (Tilastokeskus)
- Finnish Safety and Chemicals Agency (Tukes, Vaurio- ja onnettomuusrekisteri)
- Safety Investigation Authority, Finland, Investigation reports (Onnettomuustutkintakeskuksen tutkintaselostukset)
- Occupational safety and health administration in Finland (Työsuojeluhallinto)

Finnish Workers Compensation Center maintains records on work related incidents and occupational diseases. Statistics Finland gathers statistics on civic matters. Finnish Safety and Chemicals Agency publishes descriptions on incidents and dangerous situations and the Safety Investigation Authority gathers statistics on larger scale incidents and catastrophes and publish investigation reports on them.

The most prevalent of these for machinery safety are the Finnish Workers Compensation Center and its statistics database called Tikku. Tikku contains statistics on all national work-related incidents, on the job and on commute. It has data from the year 2005 onwards. Tikku does not contain case specific information only general data on case amounts, number of cases resulting in absence from work, the task being performed at the time of incident and the nature of the incident.

Figure 1 displays results for the total number of work-related accidents in industrial work for each year from 2005 to 2019. As can be seen from the Tikku application, the number of cases has dropped from 29 503 in 2005 to 15 442 in 2019, a total reduction of 52%. This can be considered a significant reduction in work related incidents for a 14-year time span.

Figure 1. Total work-related accidents in industrial work 2005-2019. (Finnish Workers Compensation Center, 2021 a).

When comparing the numbers between different years, one pair specifically jumps out. From 2008 to 2009 we see a decrease in reported incidents from 30 142 to 20 615. This is the most significant one year drop off in Tikkus records. This of course is the result of many factors most notably the 2008 financial crisis and its impact on the economy of the world which are still felt today, also changes to legislation as well as company and employee practices have affected these numbers. Noting the timeframe in which it happened and seeing the correlation of the timeframe with the implementation of the Machinery Directive is notable as there most likely is some correlation between the numbers staying low even as employment has increased thanks to the implemented safety designs brought forth by the Machinery Directive. The Machinery Directive will be expanded on in chapter 2.3.

In figures 2 and 3 we can see the numbers for work related incidents according to the task being performed, the nature of the accident, and the occupation of the worker at the time of the incident in industrial tasks for the years 2005 and 2019.

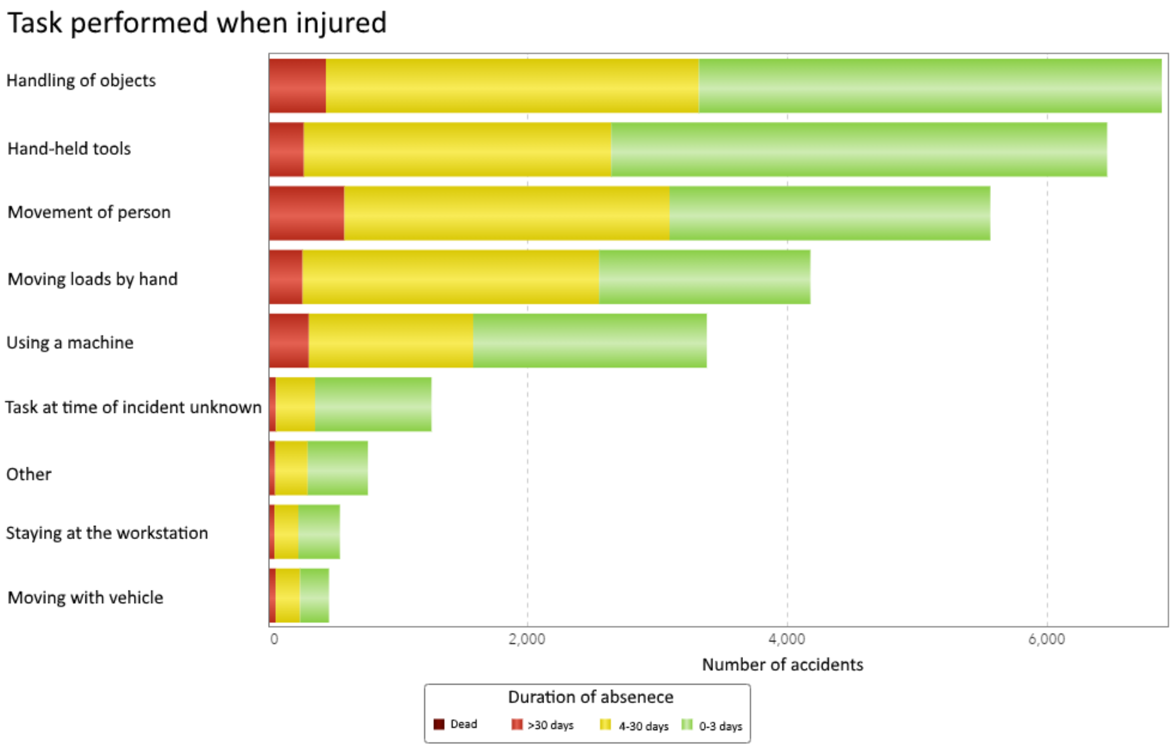

Figure 2. Work incident according to performed task at the time of incident for work in industrial tasks, 2005 (Finnish Workers Compensation Center, 2021 b).

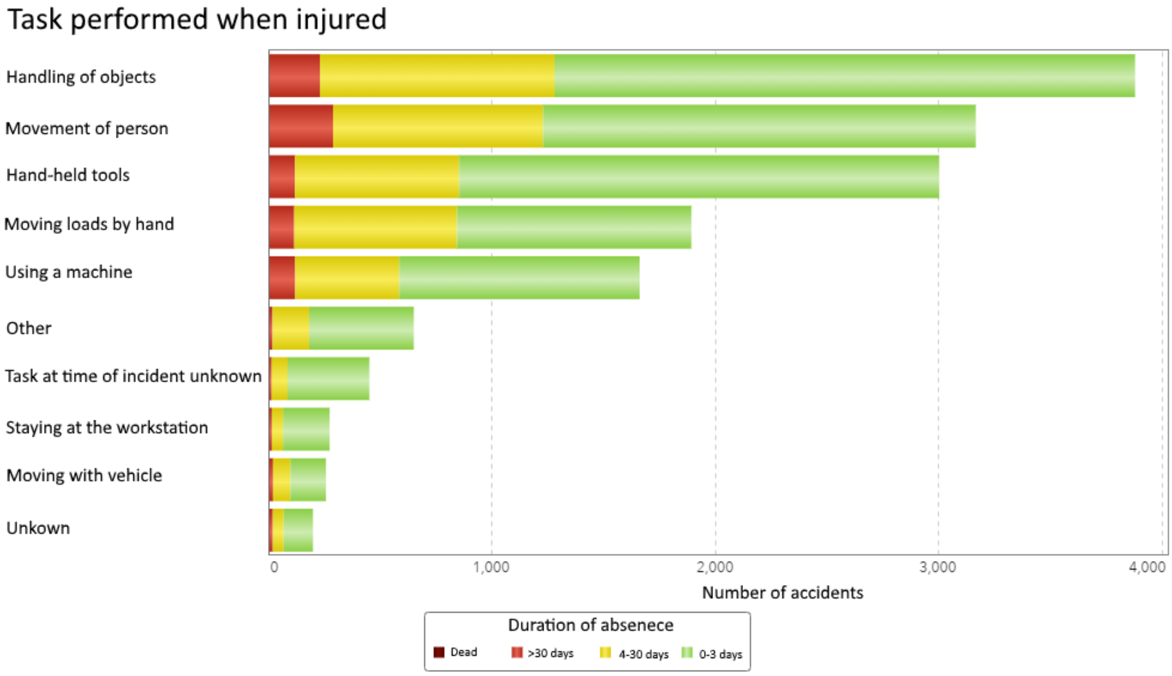

Figure 3. Work incident according to performed task at the time of incident for work in industrial tasks, 2019 (Finnish Workers Compensation Center, 2021 c).

Figures 2 and 3 seem similar overall except for the decrease in the total number of accidents. Of course, external influencers discussed earlier affect these numbers as well, but when inspecting the data provide by the Tikku application the incident cases leading to more than 30 days of absence when using a machine have decreased from 553 in 2005 to 298 in 2019.

Importance of machinery safety in the future will be growing, with customer demands for more ethicality and safety in the products and services they consume increasing. Worker satisfaction is also more important for companies to keep the employees they have invested in and not lose them to the competition.

2.3 Machinery Directive 2006/42/EC

The Machinery Directive 2006/42/EC by the European Commission is a directive which discloses the required information and procedures regarding machinery being put to into service in the European Union and its member states.

The Machinery Directive does not impose specific design demands on machinery as these are covered in the harmonized standards. The directive does present general guidelines and considerations that must be taken into account when designing machinery for European markets. It imposes demands on the responsibilities of the manufacturer regarding safe machine design and proper documentation.

The purpose of the Machinery Directive according to European Commission is to:

- Promote the free movement of machinery within the European market.
- Guarantee a high level of protection for EU workers and citizens.

(European Commission a.)

To enable the free movement of machinery between member states, safety demands and the documentation for machines need to be uniform across states. The uniformity provided by the Machinery Directive opens the possibility of larger markets for manufacturers and their products.

Correct implementation of these demands requires that the “ground rules” are set and defined clearly enough for designers and engineers to be able to implement these features in their work, but also be broad enough so that they are applicable to a wide selection of different kinds of machinery.

The European Commission has created the “Guide to application of the Machinery Directive 2006/42/EC” to help ensure the interpretation and application of the directive throughout the European markets. The contents of the guide provide more information on the terms of the Machinery Directive and clarifications on subjects. The guide is addressed to all parties involved in the application of the Machinery Directive, these include:

- manufacturers
- importers and distributors
- notified bodies
- standardizers
- occupational health and safety agencies
- consumer protection agencies
- officials of national administration
- market surveillance authorities.

(Guide to application of the Machinery Directive 2006/42/EC, Edition 2.2, page 2.)

This guide explains the definitions of the articles more clearly than the directive alone and is a helpful tool to utilize.

The important takeaways from the directive that will be expanded here are the scope of the directive, definition of a machine, the definition of an assembly of machines, the differences between complete machinery and partly complete machinery and the act of affixing the CE-marking.

Machinery Directives scope applies to the following products as noted in Article 1:

- machinery
- interchangeable equipment
- safety components
- lifting accessories
- chains, ropes and webbing
- removable transmission devices
- partly completed machinery (PCM)

The directive provides the definition for a machine:

- an assembly fitted with or intended to be fit with a drive system powered by other than human or animal effort, which consists of linked parts or components of which at least one moves, and they are joined together for a specific application
- a similar assembly as referred to in the first indent, missing only the components to connect it to a source of energy or motion or the components to connect it on site
- a similar assembly as referred to in the first and second indent, that is ready for installation and can only function once it is attached to a means of transport or installed on to a building or structure
- a similar assembly referred to in the first, second and third indent or partly complete machinery, which are arranged and controlled to function together for a specific task as one whole unit
- parts or components fitted together, at least one of which moves and has been assembled for the purpose of lifting loads and is only source of power is directly applied human effort

(Machinery Directive 2006/42/EC, Article 2, a).

Added to the Machinery Directive of 2006 is the definition of partly completed machinery (PCM). This definition was absent from the previous illustration of the Machinery Directive but has now been clarified in the directive.

The directive defines partly complete machinery as:

> *An assembly which is almost machinery, but which cannot In itself perform a specific application. A drive system is partly completed machinery. Partly completed machinery is only intended to be incorporated into or assembled with other machinery or other partly completed machinery or equipment, thereby forming machinery to which this Directive applies. (Machinery Directive 2006/42/EC, Article 2, g)*

PCM is a product that is intended to form a complete machinery after being fitted to a machine that is subject to the Machinery Directives scope. Partly complete machinery cannot perform a specific application by itself and must undergo further construction for it to be considered complete machinery. This further construction does not include the addition of a drive system to machinery lacking it. Machinery lacking necessary safety components can not be considered partly complete machinery as the machinery does not meet the requirements of the Machinery Directive. (Guide to application of the Machinery Directive 2006/42/EC, Edition 2.2, §46.)

The CE-marking, its style and affixing are also explained in the machinery directive. The CE-marking is meant to indicate the products conformity to the European requirements which apply to the machinery in question.

1. The CE-marking shall consist of the initials ‘CE’ as shown in the machinery directives Annex III.
2. The marking shall be affixed to the machinery in question so that it is visible, legible and indelible.
3. Markings, signs or inscriptions which are likely to be interpreted as the CE-marking are prohibited.

Figure 4 displays the design of the CE-marking. The markings vertical height may not be less than 5 mm unless the machinery in question is deemed small-scale. The CE-marking must be affixed to the immediate vicinity of the name of the manufacturer or his authorized representative.

Figure 4 CE-marking (Machinery Directive 2006/42/EC, Annex III)

The manufacturer or his authorized representative must affix the CE-marking to the machinery when the machines conformity to required regulations and directives has been fulfilled. This means that the affixing of the CE-marking is usually the last step when manufacturing and launching a new machine to the European markets.

However, the CE-marking is not a guarantee that the requirements for the machinery have been met, as there is no regulated inspection carried out to the machinery before it is brought to the market. If the machinery in question is later deemed not fitting to the required regulations, directives and essential health and safety requirements, the member state in which the machinery is sold is responsible for withdrawing the machinery from the markets.

The requirements of the Machinery Directive have been implemented into Finnish legislation via the Decree on the Safety of Machinery 400/2008 i.e. the Machinery Decree discussed in chapter 2.4.

2.4 Finnish Legislation

Machinery safety is implemented in multiple legislations across the world but in this thesis, it is narrowed down to the legislation and laws of the European Union and Finland. The European Union determines the broad directives which are then enforced locally by the laws of the nation according to their legislation.

In Finland the equivalent legislation for the Machinery Directive is the Decree on the Safety of Machinery (Koneasetus) 400/2008, in the following referred to as "machinery safety decree". The purpose of the machinery safety decree is to clarify the required steps and procedures from the manufacturers and the importers of machines that must be addressed before a machine can be brought to the Finnish market. The machinery safety decree incorporates the demands of the Machinery Directive into Finnish legislation, making neglection of these demands punishable by law.

Requirements that must be fulfilled include:

1. Ensuring that the machine fulfills the essential health and safety requirements concerning it.
2. Ensuring that the required technical construction file is available.
3. Ensuring that the machine includes the required guides, such as instructions.
4. Ensuring that proper risk assessments according to the harmonized standards has been done.
5. Produce a declaration of conformity.
6. Attach the CE-marking and other required labels.

(Finnish National Machinery Safety Decree 400/2008, §5, authors translation.)

The legislations regarding different parties involved are show in Figure 5.

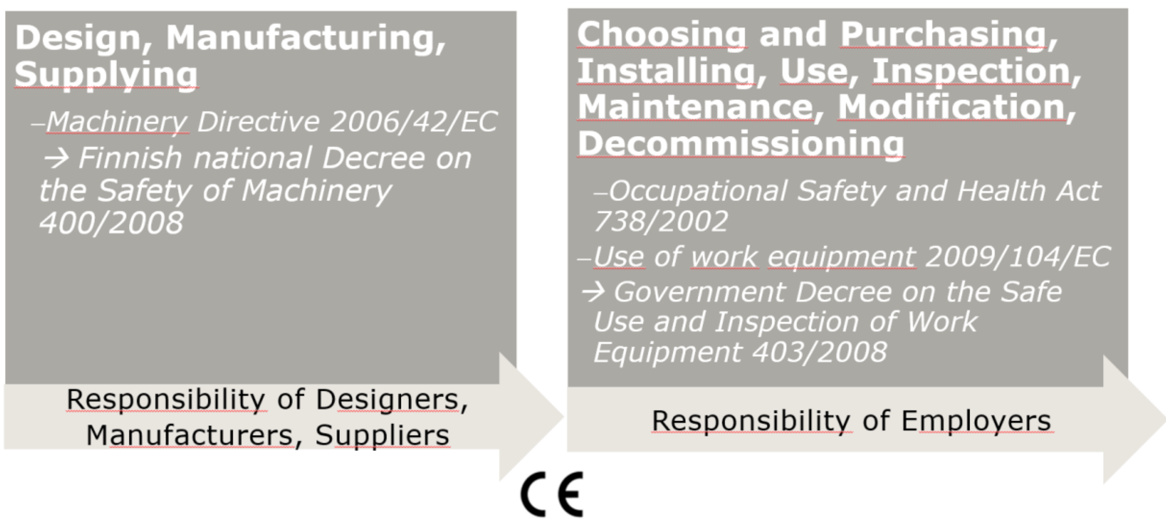

Figure 5 Legislations regarding the parties involved (AFRY, 2021b)

The authority in charge of supervising machines that are meant for professional use is the Occupational Safety and Health Administration (Työsuojeluhallinto).

2.4.1 Legislation regarding the employer

Another important Finnish law is the Occupational Safety and Health Act (Työturvallisuuslaki) 738/2002. The law's purpose is to improve the working environment of employees, guarantee their ability to work in safe conditions, prevent work related accidents, prevent occupational diseases as well as other physical and mental harm to the employee (Occupational Safety and Health Act 738/2002, §1).

In the Occupational Safety and Health act an employer is an entity or person that commissions work to be done or utilizes the employers decision-making power (VTT 2012, 12).

The employer is responsible for taking into account the nature of the work and its activities, systematically analyzing and identifying the hazards and risk associated with the work, its premises, the working environment as well as the working conditions. If the identified hazards and risks cannot be eliminated the employer must assess the consequences of said risks regarding the employee's safety and health and take preventative measures to minimize the occurrence of the risk. This risk assessment process is always on going and must be re-iterated if circumstances change. (Occupational Safety and Health Act 738/2002, §10.)

Alongside the machinery decree has been incorporated the Government Decree on the Safe Use and Inspection of Work Equipment (Käyttöasetus) 403/2008. This act outlines the safe use of tools and machinery along with their inspection demands. It also outlines the requirements for safety equipment and their proper usage.

2.4.2 Legislation regarding the designer

In the Finnish Occupational Safety and Health Act the responsibilities of designers that "by commission provides a design concerning a structure in the working environment, working premises, a working or a production method, machinery, work equipment or other device shall ensure that the provisions of this Act have been taken into consideration in the design of the item in question according to its intended use as stated by the designer" (Occupational Safety and Health Act 738/2002, §57).

This means that a designer must familiarize themselves with the laws that affect their design and that they are to be held accountable for design oversights and possible hazards along with their consequences. The designer basically has the same responsibilities as the employer in regards to worker safety. This coincides with the basic engineering ethics in stating that engineers should strive for designs that are safe for use and do not cause harm to the population.

The designer's significance in a design's safety cannot be understated. Since the designer's choices lay the foundation for a machines design and its safety, the better choices the designer can make the safer the end product will be. This of course will be limited by the costumer's own designs and budget. Even still the designer must not design an unsafe machine because of budget limitations. It is the designer's responsibility to inform the client if the design they request is not fit for purpose or the design cannot fulfill its task safely or be constructed or maintained in a safe manor (Occupational Safety and Health Act 738/2002, §57).

2.5 Standards on machine safety

When designing a machine for the European and Finnish markets, it is good practice that the machine is designed using the harmonized standards. These are European standards that are developed by a recognized European Standards Organization: CEN CENELEC or ETSI (European Commission b).

These are standards that are prefixed as EN-standards and they have been transferred unchanged to national standards of the member states (Macdonald, 2004, 31). Adhering to these harmonized standards means that the design has an "automatic presumption of conformity" to the Machinery Directive. Adhering to these standards however is not mandatory and designers are free to implement better and safer designs when possible, but the designer is responsible for proving that the differing design achieves at least the same level of safety or better.

If the manufacturer decides not to utilize the harmonized standards or chooses to apply only parts of them, the manufacturer must include the risk assessment and the steps taken to comply with the essential health and safety requirements. In this case the manufacturer should not list the references to the standards in the Declaration of Conformity, but they can indicate which parts of the standards they have utilized. (Guide to application of the Machinery Directive 2006/42/EC, Edition 2.2, §110.)

There are three types of harmonized standards for machines:

- type-A (basic safety standards)
- type-B (generic safety standards)
- type-C (machine specific safety standards)

(SFS-EN ISO-12100:2010, 11)

The purpose of the harmonized standards is to provide designers with guidance and the necessary tools to design machines that are safe for their intended use as implied by the Machinery Directive. They are also important when exporting machinery to other European Union member states to ensure that the design meets the required safety criteria for the machines intended use.

The hierarchy of the standards goes from the top-down meaning that if a machine has a type-C standard for its design this standard takes precedence over the type-A standard and type-B standard, this is displayed in figure 5. It is important for a designer to familiarize himself with the pool of standards so that he uses the correct designs and guidelines in his work.

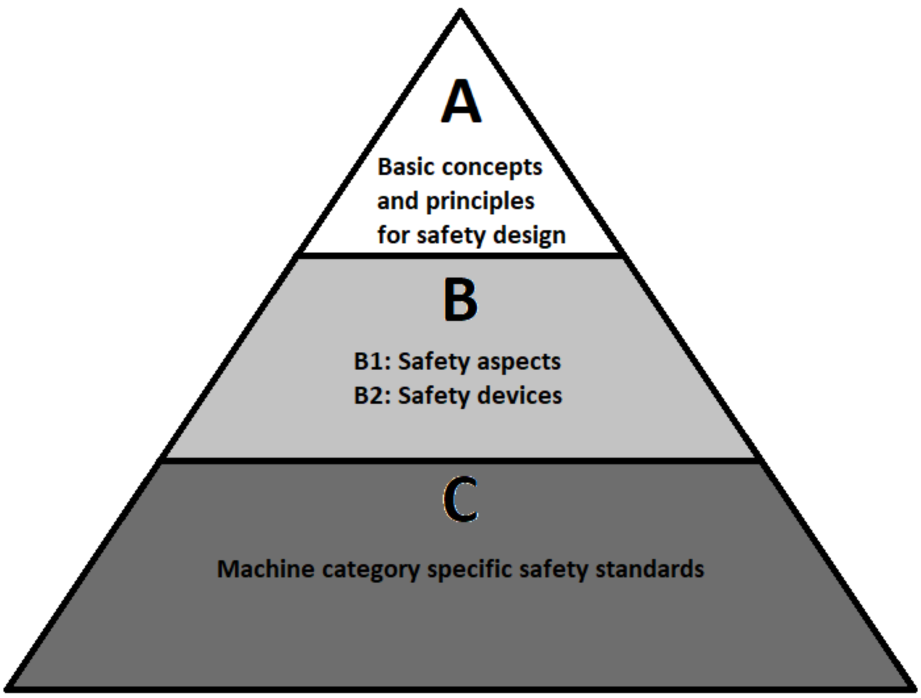

Figure 6. Safety standards hierarchy.

The type-A standard (EN ISO-12100:2010) outlines the basic safety principals, concepts and methods for all machines based on the requirements of the machinery directive issued by the European Parliament. It details the strategies for risk assessments, risk reduction, identification of hazards and safeguarding and protective measures. This is an international standard that lays the foundation for the requirements of the B and C-type standards which are created by the national standards associations.

The type-B standards deal with either a specific safety aspect or a safeguard. These are separated by the use of B1 (safety aspects) and B2 (safeguards) type standards. These standards offer solutions and designs for a wide range of different machinery.

The type-C standards are machine category specific. For instance, paper and board making machines have their own type-C standard series issued by the Finnish Standards Association (SFS) SFS-EN 1034. This standard is a multi-part series, each of which outline a specific machine or task performed by the paper making machine.

Due to the expansive nature of large machinery like paper machines, a lot of different directives and laws apply to the design of the machinery other than the machinery directive. For instance, electrical components up to a certain voltage and their requirements are explained in the Low Voltage Directive (LVD 2014/35/EU) which may apply to the paper machines electrical motors. For design of pressurized equipment, such as compressed air tanks etc. the Pressure Equipment Directive (PED 2014/68/EU) and standards regarding the directive apply.

2.6 Risk assessment based on EN ISO-12100:2010

Every machine designed for use in the EEA (European Economic Area) must be determined safe for use to an acceptable level. The Machinery Directive states that:

> *"The manufacturer or his authorized representative should also ensure that a risk assessment is carried out for the machinery which he wishes to place on the market. For this purpose, he should determine which are the essential health and safety requirements applicable to his machinery and in respect of which he must take measures." (Machinery Directive 2006/42/EC, recital 23.)*

Annex 1 of the Machinery Directive explains the steps that must be taken when undertaking the risk assessment procedure, these include in order:

- Determining the limits of the machinery for its intended use as well as all reasonably foreseeable misuse cases.
- Identifying the hazards created by the machinery and its hazardous situations.
- Evaluating the risks and whether risk reduction is required.
- Eliminating the hazards or reducing the risks of these hazards occurring with the use of protective measures.

These principles have been incorporated into the international standard EN ISO-12100:2010 Safety of Machinery, General Principles for Design, Risk Assessment and Risk Reduction. The standard lays out the strategy for the risk assessment and elimination process as well as the tools for risk management. Each type-C standard also has risk evaluation incorporated into its proposed designs and solutions for safe design. This does not however mean that the manufacturer isn't required to perform risk assessment on his product even if the machine is designed completely based off a type-C standard and its solutions. Risk assessment and evaluation must always be carried out for new machinery and old machinery that is being modified even when using type-C standards with a presumption of conformity.

Risk assessment is typically done to new machinery when it is still a "clean slate", meaning no safety features have been incorporated. It is important to note that risks should be assessed for each phase of the machines life cycle including, manufacturing, transportation and commissioning as well as decommissioning, disassembly and disposal (Siirilä 2008, 65, authors translation).

Risk assessment is an iterative process meaning that each time a risk has been assessed and measures taken to remove or reduce the risk, it is necessary to evaluate whether the measures taken are adequate and do not develop new hazards when implemented. Risk assessment is a process that is always ongoing during the whole design and construction of the machine. (Machinery Directive 2006/42/EC, Article 158.)

Before the risk assessment can begin the limits of the machine must first be defined. These include properties such as the speed of components, heat, chemicals, pressure, electricity, the intended users and control systems. These are the basis of information from which it can be assessed if a certain feature of the machine presents a risk. If a similar machine already exists it can be helpful to use it as a base from which to gather information regarding common specifications for the limits and hazards.

Risk assessment can be either quantitative or qualitative. Quantitative risk assessment means assessing the risk and its properties with quantitative measures such as reviewing the frequency of the risk occurring in conjunction with working hours performed. Qualitative risk assessment utilizes more subjective measurements such as defining whether a risk factor is severe or mild, not utilizing a quantitative measure such as time. Qualitative risk assessment is better utilized when specific values for a risk cannot be obtained but is more prone to deviations due to its subjective nature.

According to the standard EN ISO-12100:2010, information that is required for the performing of the risk assessment should include:

1. Information relating to the machinery description which contains:
    a. user specifications
    b. machinery specifications
    c. documentation of previous similar designs
    d. information regarding the use of said machinery
2. Information relating to the applicable regulations, standards and other applicable documents such as technical specifications and data sheets.
3. Information relating to the past user experience of a similar type of machine including accidents, malfunctions and damage to health from emissions and chemicals.
4. Information regarding the relevant ergonomic principles.

There are other methods developed for safety analysis depending on the nature of the process being reviewed. These include methods such as HAZOP which identifies accident factors which can lead to process malfunctions and dangerous consequences, based on changes to the process parameters. Potential problem analysis (PPA) is another method which utilizes brainstorming methods to recognize potential threats which are then analyzed and categorized based on their nature and severity. Failure mode and effects analysis (FMEA) divides the system being reviewed into individual components and recognizes each components failure modes and the resulting risks that can develop. (Hirsjärvi et al., Wiki service of Metropolia.)

These are just a few of the available risk assessment methods. These should be utilized in conjunction with the primary risk assessment to ensure that all aspects of the machine and process are taken into account when designing it.

2.6.1 Risk assessment process

The risk assessment process is presented as a flow chart which consist of the following steps based on EN ISO-12100:2010.

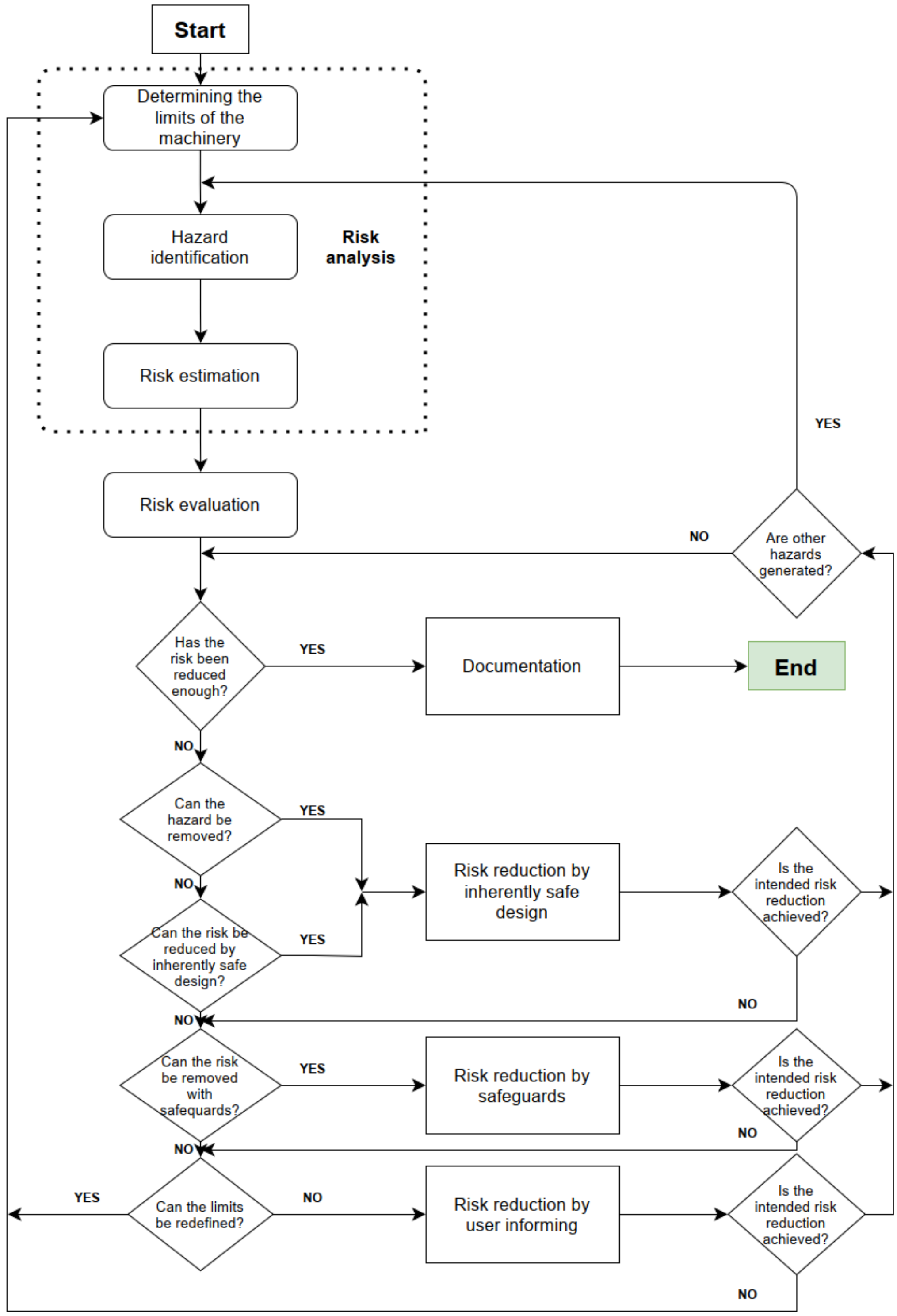

Figure 7 Risk reduction process based on EN ISO-12100:2010, authors representation

As can be seen form the flowchart in figure 7, the risk assessment follows the procedures mentioned earlier in the same order.

First the limits of the machinery are determined, these include use limits, space limits, time limits and other limits.

Next comes the hazard identification, the hazards are presented in EN ISO-12100:2010 but for a simplified summary they include:

- kinetic energy of moving parts
- sharp corners
- sharp objects and parts
- falling objects and parts
- height
- high pressure
- moving and turning parts
- crushing
- cutting

The next step is risk estimation. This includes taking the noted hazards, assessing their severity and multiplying that by the frequency of the hazard occurring. After the estimation it is determined whether the risk being evaluated is significant enough to validate further action.

After this comes risk evaluation. Here we evaluate the risks noticed and determine whether the risks identified in the machinery are at an “acceptable level”. This means that either the effects of the risks are low enough where they do not present a significant enough impact on a workers health and wellbeing, or the frequency of the hazard occurring is low enough so that it should not materialize during the life-cycle of the machine.

When all of the above has been done we question whether the risk has been adequately reduced. If the risks are now at an acceptable level, we can move on to documentation and complete the risk assessment process. If the risks are still prevalent and cannot be justified, we have to re-iterate the risk reduction. If significant risks are still present in the design they must be primarily removed completely or when removal is not possible reduced by inherently safe design measures.

Only after these options have been considered and tried without satisfactory results can we move on to the utilization of guards and protective devices. This is always a secondary option to removal and reduction as the hazard is still present in the machine even after the implementation of safeguards.

Only if the risk still is not at an acceptable level after the implementation of both previous steps can instructions be utilized. Instructions aren’t usually an effective means of safety as these are susceptible to being forgotten in time or ignored completely.

2.6.2 Documentation of risk assessment

After these steps have been iterated over and adequate safety for the machinery has been achieved it is time to move on to documentation. Documentation of the risk assessment includes:

- the machinery information and its limits
- relevant assumptions that have been made such as loads, speeds etc.
- the information that the risk assessment was based on
- risk reductions to be achieved by protective measures
- protective measures implemented
- residual risk left in the machine
- results of the risk assessment
- forms included and used in the risk assessment

(SFS-EN ISO-12100:2010, 51.)

When performing risk assessment, it is important to remember that the act of assessing a risk and its significance is a human based task. There are tools and methods that aid the person in assessing the risk, but the final conclusion is always done by a human being that is prone to misjudgment and biases based on past experience. If possible, it is good practice to have multiple people from different viewpoints involved in the risk assessment process (even for relatively small machinery) to decrease the possibility of a risk being left unnoted or being estimated as too insignificant.

2.7 Responsibilities in engineering projects

When a machine is being designed there are usually a multitude of people and companies working on the design, evaluating the risks involved, designing alternative solutions and documenting the process.

Siirilä (2008, 23, authors translation) listed the following responsible parties in regard to regulation when designing a machine:

- designer
- manufacturer
- importer to the European Economic Area (EEA)
- seller of the machine
- installer of the machine
- renter of the machine
- owner or user (employer) of the machine.

For this thesis we will primarily be looking at the parties usually associated in engineering a new paper or board mill. In these large projects the parties involved are commonly:

- The end-user of the machine and their project organization.
- The machinery supplier/suppliers.
- The consultant/EPCM designer.

Each of these groups have their own areas of responsibility instated by laws, directives and ethics depending on their role in the designing and commissioning of the machine.

2.7.1 Supplier/manufacturer

The machinery supplier is responsible for their supplied machines safety and ensuring that the machine conforms to the required directives and laws. The supplier is responsible for creating the required technical file for their product, affixing the CE-marking and signing the declaration of conformity as stated in the Machinery Directive. The supplied product must be safe for its designed application as well as foreseeable misuse cases. Even if the machine has been operated with disregard to provided instructions the supplier is still responsible since the product should have been designed safe for unintended use also.

In Finland the supplier of a dangerous machine is susceptible to being fined if the supplied machine has unacceptable risks present and said risks lead to an accident. These fines are given to the company, but in cases where serious injury or death have occurred as a result of bad design or neglect of required safety features, the individual persons in charge of the company and of the design are liable to being prosecuted. (Occupational Safety and Health Act 738/2002, §63.)

The supplier should also properly inform sub-contractors and designers on their responsibilities and oversee their designs conformity to the essential health and safety requirements, as well as the clients demands. The supplier should also ensure that the sub-contractors and designers have adequate knowledge and skill to produce a safe and functioning machine.

2.7.2 Consultant/EPCM engineer

The consultants responsibilities vary depending on the type of deal the client has agreed to with the consultant. The consultant is responsible for their designs conformity to the regulations, laws and client requirements. The consultant/designers role in regards to safe design is crucial as the foundation for a safe working environment is laid out in the design phase of a project. The further the project moves towards completion the more limited the designer will be in his designs to enable safe and effective solutions.

Requirements for the designer are extensive, involving:

- Understanding requirements of legal legislation and standards.
- Understanding the limits and how to implement these requirements.
- Understanding what features the client requires, appreciates and needs.
- Understanding the general development of his field of expertise.
- Social skills and the ability to see his part in the extents of the project.

(VTT, 2012, 16-17)

Today however the number of participating companies in a project is very expansive. There are usually multiple different companies working on different aspects of a large machines design, with each company employing hundreds of designers. Due to the nature of contracts and agreements between the client and different companies it can be difficult for a designer from one company to correct the shortcomings and mistakes of other companies engineering. It has been said that basic engineering ethics are outdated and should be replaced more with business ethics (VTT, 2012, 17). The designer should still bring forth all of the shortcomings and defects he finds in the machinery, even if the design itself is not his scope of responsibility.

If the client and consultant have agreed to a EPCM (engineering, procurement, construction management) deal, in which the consultant has committed to a “turn-key” solution, then the scope of the consultants responsibilities change. In a EPCM contract the consultant is responsible for overseeing the entirety of the products design, procurement, and construction until the product is completely finished and ready for use. This means that the consultant is responsible for the entirety of the delivered product, until it is transferred over to the client.

2.7.3 Client, employer, plant operator

The client is responsible for the safety of their employees as well as being responsible for providing adequate training for their employees. Responsibility of the workers safety is however not solely on the employer as this expands to the responsibilities of the designer who also takes responsibility for his designs safety to the end-user (VTT, 2012, 13). The responsibilities can change in regard to the final product if the client has used an EPCM designer with turnkey delivery, but still the employees training and informing remains the employers responsibility.

The client must also be aware of responsibilities to perform risk assessment on their processes and machinery. Even when risk assessment has been outsourced, the responsibility for the processes safety still lays on the client/employer. (Occupational Safety and Health Act 738/2002, §10.)

Depending on the size of the client organization it is possible that the client in charge of the project is a subsidiary or a different branch of a larger company. Especially for companies in the process industries the main clients are usually large scale multi-national organizations with their own project branches working on the construction and issuing of new plants and machines. This means that the client organization in procurement might be different than the client organization which the end product is delivered to. Constant communication and agreement on responsibilities during the projects lifespan is necessary to ensure that each party involved stays up to date on their responsibilities.

The client must also acknowledge that he may turn into a machinery supplier if he is the one responsible for combining two pieces of machinery to form a production unit. This means that the suppliers responsibilities hence forth apply to the client as well.

2.7.4 Summary of responsibilities

Consistent communication between the manufacturer of the machinery, consultant and the client is essential in large scale projects. The parties involved should consistently be up to date with information regarding the clients design information and wishes. Communication should be constant between parties and the channels for communication need to be clear, as well as the project personnel’s fields of responsibilities mapped out.

Especially the responsibilities regarding safety should be outlined clearly to each party involved right from the beginning. The supplier and consultant need to inform the client of possible changes to the client’s responsibilities when different assemblies are joined together to form an expansive machine as in these cases, the client can actually turn into a machinery supplier. This means that the client now has to perform the responsibilities of the machinery supplier. In cases where this can occur the supplier and consultant must keep the client aware of the responsibilities regarding the client and inform them of the possible outcomes and changes in responsibilities.

For the end product to be suitable for its required use and be safe during its manufacturing, operation and maintenance it is important that the responsibilities of each party involved in the issuing and designing of the machine are as clear and defined as they can be.

The directives and laws include the responsible parties for each part of the machine in its life cycle, but these have to be clarified and agreed upon before the start of the project as the requirements tend to be vague. If responsibilities are left unnoted the possibility of design flaws and risks being left unnoted can increase dramatically resulting in increased costs and the possibility of injury or even death.

To summarize the responsibilities of the machinery for its life cycle the table of responsibilities pictured below contains an overview of the main takeaways of this chapter.

Client (Government decree on the safe use and inspection of work equipment, Finnish National Machinery Safety Decree when the client is considered a manufacturer of the machine)	**Consultant** (Government decree on the safe use and inspection of work equipment, Finnish National Machinery Safety Decree)	**Supplier** (Finnish National Machinery Safety Decree)
Provide the supplier with the information and requirements of the design.	Understand the requirements of laws and directives that apply to your design.	Ensure that the requirements of laws and directives are applied correctly to your design.
Perform risk assessment on the supplied machinery when necessary.	Understand the clients requirements and needs.	Create the technical file and affix the CE-marking.
Be aware of your responsibilities regarding safety and of situations where you might become the manufacturer of a machine.	Inform the client of the designs implications on safety.	Sign the declaration of conformity.
Provide training on the use of the machine for employees.	Remove risks with inherently safe design solutions.	Ensure that everyone involved in the design is aware of their obligations for safe design and ensure that the product is safe for its intended application as well as all foreseeable misuse cases.

Figure 8 Table of responsibilities

As can be noticed the responsibilities of each party involved intertwine with the decisions and choices of each other. This is why good communication is crucial during all phases of the products life cycle to ensure everyone's information is up to date and to ensure that the end product is as requested and suitable for its application in regard to laws, directives and most importantly safety.

3 Mechanical hazards in paper machines

3.1 Overview of a paper machine and its parts

Paper and board machines are very similar in terms of the general layout of them. They usually consist of 7 subassemblies of machinery bodies and the winder slitter. These sub-assemblies are:

1. Forming section
2. Press section
3. Dryer section
4. Coating unit
5. Flotation dryers
6. Calender
7. Reel section
8. Winder section

Each of these sub-assemblies together form the paper making machine. In between each subassembly is an interface where the paper in production moves from one sub-assembly to the next. The way these interfaces are formed, and their purpose will be expanded upon further in the following chapters. It is the common risks at these interfaces that this thesis aims to clarify. To understand the formation of these interfaces, first the papers formation and movement through the machine must be understood. To help visualize the paper making machine a schematic diagram will be utilized.

First the pulp mass which is created in a different plant is fed into the headbox of the forming section as pictured in figure 9. The mass is laid on to a wire to a specified thickness depending on the wanted thickness of the final product. The line then moves through the forming section in which suction boxes and similar solutions soak up water from the paper line. If the paper or board is multilayered, each layer will have a separate headbox applying a new layer of mass on to the wire section at different stages.

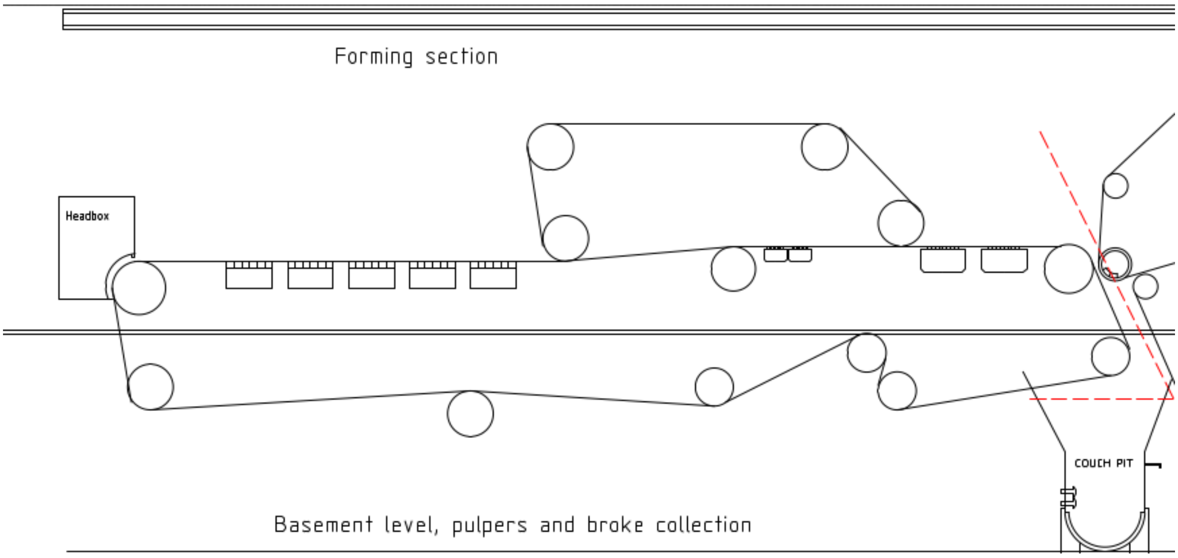

Figure 9 Forming section

After the forming section the paper is fed into the press section pictured in figure 10. Here the paper is fed through a machine which typically has 1-5 nips in which water is pressed out of the line and the surface of the paper line is smoothed to achieve the wanted properties of the final product in terms of surface smoothness and clarity of color.

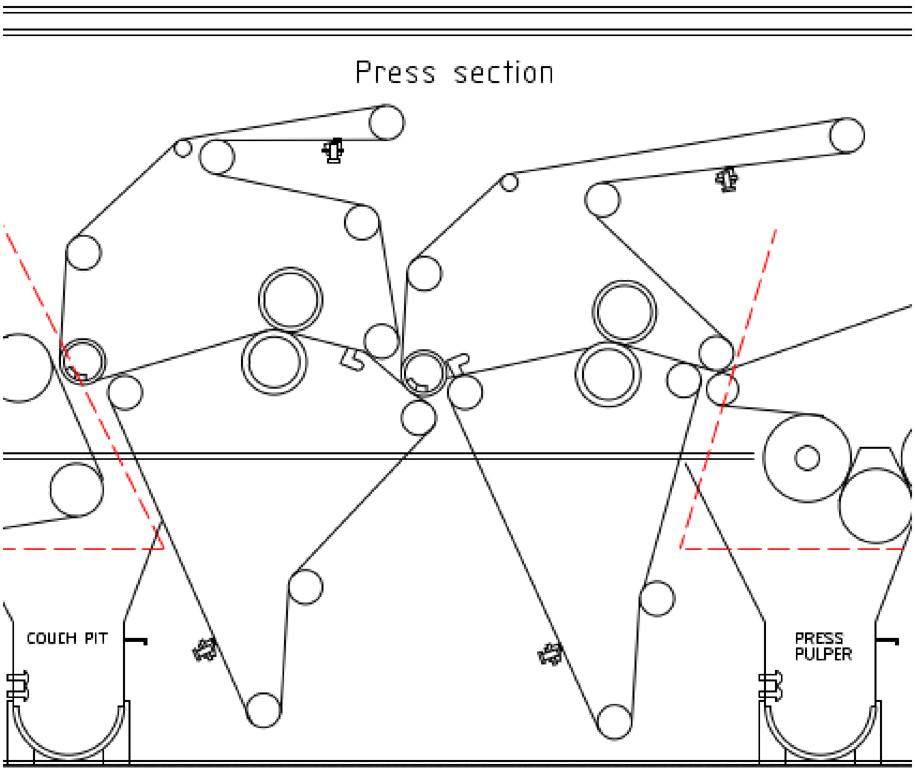

Figure 10 Press section

Following the press section, the paper is moved to the drying section pictured in figure 11. These are steam heated cylinders which dry the paper as it moves in contact with them while being supported by more wires. The heat emitted by the cylinders evaporates the water from the paper at each drying group. The drying section is typically the longest part of the entire paper machine and its length varies depending on the ranges of paper being produced, since this determines how much water needs to be removed from the paper line. Below the dryer section is located a broke conveyor which leads to a pulper, this is for when the paper line breaks and the resulting broke needs to be fed into the pulper for repurposing. This prevents the need for stopping the entire machine in case of a break of the paper line.

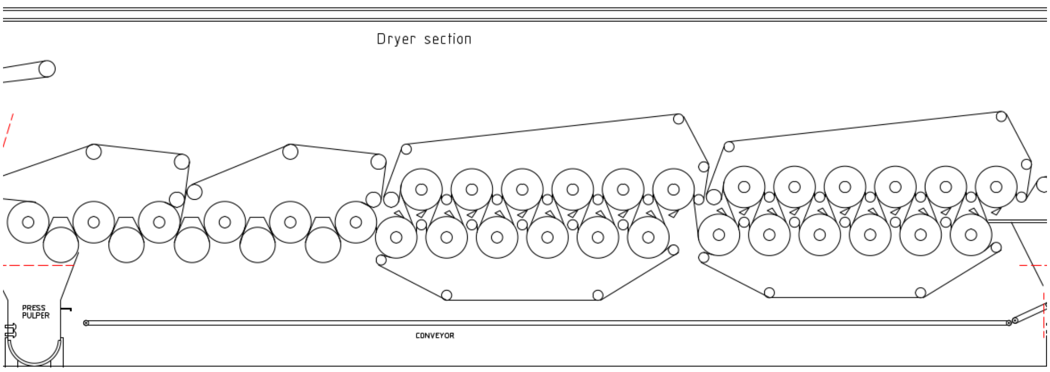

Figure 11 Dryer section

After the drying section comes the coating section pictured in figure 12. Here the surface of the paper is treated with chemicals, starch, pigments and glue to achieve the desired properties. These can be applied with differing solutions such as sizers etc. For example, if the paper needs to be able to withstand water, such as coffee cups, glue must be applied to the paper in order to achieve enough water resistance for the cup to not dissolve when coffee is poured into it. If the desired surface finish needs to be of high quality in terms of shininess and printability, different chemicals need to be applied to achieve this. The configuration of the coating section can vary significantly machine by machine. As the paper is being treated in coating its moisture level rises. This is why flotation dryers or similar solutions are implemented after the coating process, to reduce the amount of water in the paper being produced.

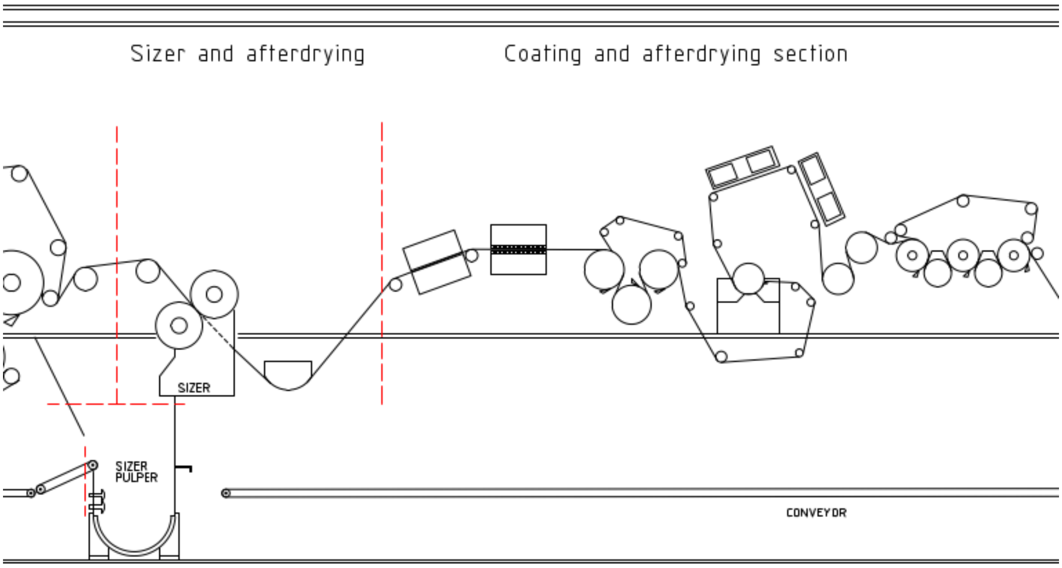

Figure 12 Coating and afterdrying section

After the coating section comes the calender (pictured in figure 13) which purpose is to smooth the surface of the papers finish to the required specification. This is achieved with a nip in which a smooth roller refines the surface as the line passes through the unit. Depending on the type of paper being produced the calender may be positioned before the coating unit if the paper does not need coating. There can also be multiple calenders before and after the coating unit if the quality of the coat of the paper must be of high quality.

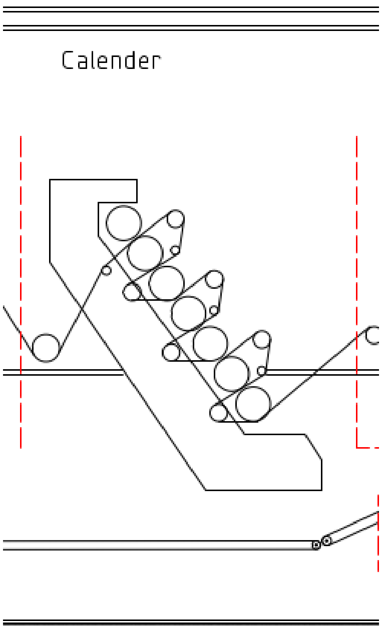

Figure 13 Calender

From the coating section and calender the paper is fed into the reel section pictured in figure 14. Here the paper is finally complete in terms of its surface finish, dryness and quality. The line is fed onto a machine roller. The machine roller is fitted with a sleeve, and it spins at the same speed as the paper machine. Glue is applied to the paper as it is nearing the machine roller and ones in contact with the roller the line sticks to it. After this the machine roller continues turning until the desired amount of paper has been rolled around it. Depending on the thickness of the paper being produced this can be tens or even hundreds of kilometers of paper rolled around the machine roll. After the roll is complete meaning enough paper has been rolled on to it, it is moved forward while still spinning and a new machine roll is lower to the line. The reel then cuts the paper and applies it to the new machine roll, beginning the process again.

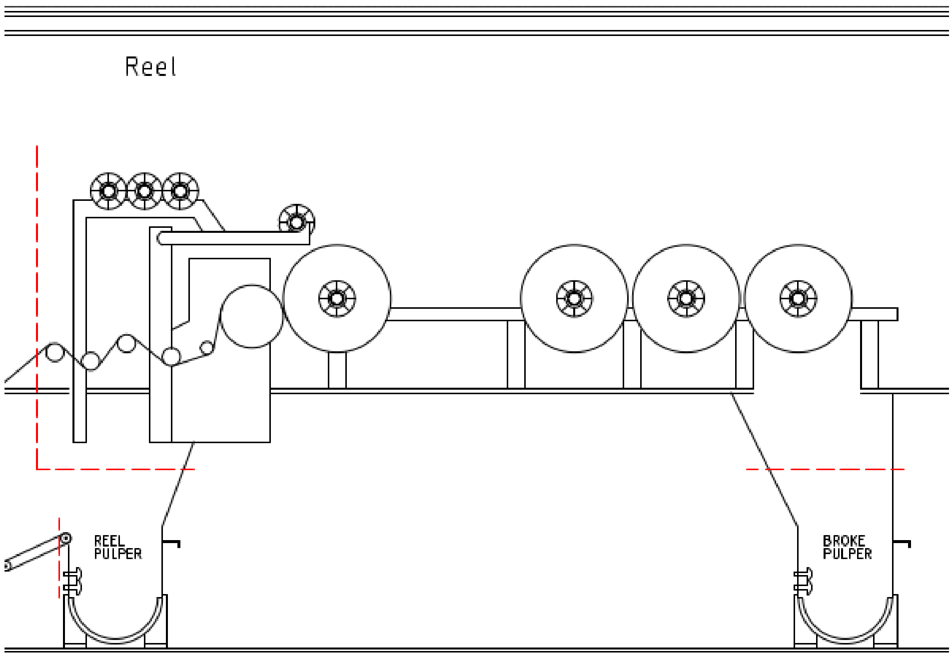

Figure 14 Reel section

Finally, the machine roll is transported either by guides or a crane to the winder pictured in figure 15. Here the paper from the machine roll is transferred from the machine roller to cartridges after which it will be delivered to the sheet cutters or the final customer. The machine roll is attached to a motor which turns the machine roll, and the “head” of the paper is fed into the winder. This machine contains multiple cutting blades which slit the paper into multiple different size lines, depending on the customer’s request for the width of the roll of paper he has ordered. After being slit the paper is then rolled around cartridges, the tails of the paper are taped, and labels are glued on the rolls.

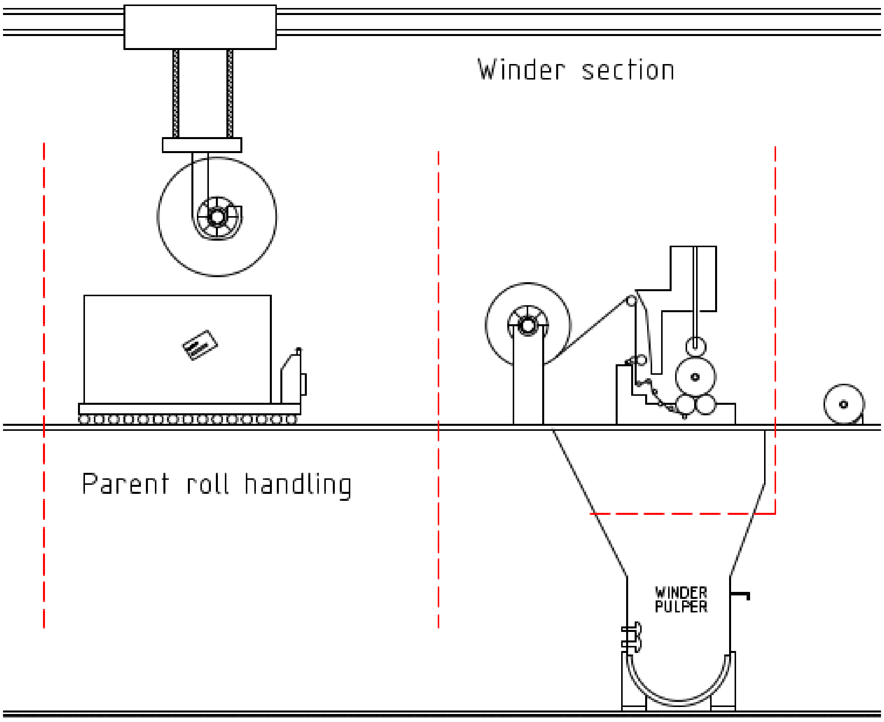

Figure 15 Parent roll handling and winder section

After this the rolls continue to either the packaging section or the sheet cutters as displayed in figure 16. This is the end of the sections being investigated for this thesis.

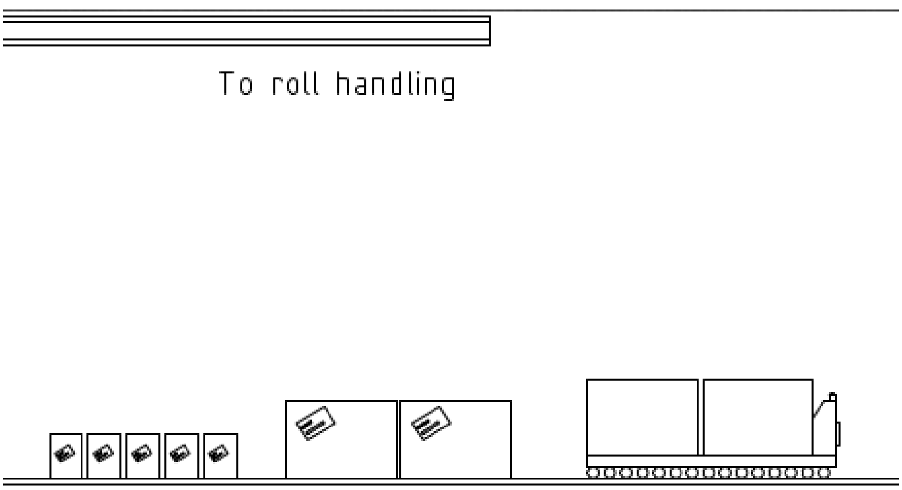

Figure 16 Transportation to roll handling

3.2 Hazards at the interfaces of machine sub-assemblies

A common place for these risks to cluster at are the interfaces of the sub-assemblies of the machine. These interfaces commonly occur where two sub-assemblies of a machine combine. The definition of an interface according to Cambridge Dictionary is:

A situation, way, or place where two things come together and affect each other.

This definition for an interface is very broad meaning that almost everything incorporated into a paper making machine has an interface with another unit. These units can be other sub-machinery, control systems, safety systems etc. For example, maintenance platforms are not categorized as machinery in terms of the machinery directive, but they can expand across multiple parts of the paper making machine, making the platforms, rails, stairs and guards a part of the interfaces of the machine. This is why it is important to also inspect the design solutions of maintenance platforms as well.

In the case of a paper making machine both machines on the other sides of the interface affect the paper being produced since the paper travels from one machine to the next. For example, when the paper moves from the former to the drying section there is an interface, this marks the border of the two machines or machine sub-assemblies. If the former and drying section are provided by different manufacturers or even the same supplier, the way in which the paper is fed from one machine to the next is usually a unique solution, since the layout of the factory and the machines are almost always unique solutions themselves. This means that every project has variables that need to be taken into account when combining two machines together, this also includes things such as maintenance platforms which change from factory to factory. Each location where a machinery supplier changes, the operation or the controls of the machine change, a machine sub-assembly changes or safety or maintenance mechanisms are applied there is an interface.

The different subassemblies may have machinery and parts from different manufacturers and providers, this is why these interfaces regularly require unique solutions to work. Responsibility of the design of the interface must be made clear to the contractors supplying the machinery since if these matters are not discussed the possibility of a risk being left unnoticed increases.

At the end of the project when the machinery is transferred to the end client, the machinery along with its remaining risks and required risk assessments fall on the responsibility of the client.

3.3 Mechanical hazard types present in a paper/board machine

The harmonized C-type standard SFS-EN 1034-16 for paper making machinery contains a list of significant mechanical hazard types present in a paper making machine. As these machines are very expansive nearly all types of mechanical hazards are present. Below is a table containing these hazards and example cases of possible scenarios for where and how they might occur.

Mechanical hazards	
Crushing	Movement of machinery parts, cranes and ejection of production units.
Shearing	Linear movement of machinery in conjunction with another static or moving piece of machinery.
Cutting or severing	Edges of wires and paper track, sharp edges of machinery.
Entanglement	Access to moving ropes, nips and wrapping points.
Drawing-in or trapping	Nips on rolls and cylinders, wrapping points of fabrics, ropes and trans-mission units.
Impact	Access to fast moving machinery parts.
Stabbing or puncture	Access to linear moving parts of sharp machinery pieces.
Friction or abrasion	Contact with fast moving parts, rolls, wires and felts.
High-pressure fluid ejection	Ejection of high-pressure fluids in cases of equipment malfunction or pipe/hose breakage.
Loss of stability	Bad attachments of maintenance platforms and similar constructs.
Slip, trip and fall hazards in re-lationship with machines	Improper walkways, passages and inadequate design of the workplace layout.

Figure 17 Mechanical hazard types and their presence in a paper machine, adapted from SFS-EN 1034-16 tables 1 and 2.

3.3.1 Information gathering and interviewing questions

Information on these hazards occurring at work was gathered from the TOTTI-database in the form of real-life cases and by interviewing a leading technology specialist Jari Peuhkuri and a HSE technology manager Laura Lehtonen on hazards they had come across during their work. The TOTTI-database search was narrowed to only include cases which had occurred at an industrial setting and from these the different cases involving paper making machinery were selected. A total of 16 cases were examined of which 7 cases were analyzed more in-depth. For the cases involving automated guided vehicles there were no cases in the TOTTI-database which is why 3 cases from the United States were utilized instead using accident reports from the United States Department of Labor's Occupational Safety and Health Administration at osha.gov.

The interviewees were asked questions regarding machinery safety, responsibility of its implementation, typical hazards and risk that they have come across during work, reasons for these hazards and risk materializing and ideas on what needs to be implemented and improved for safer working conditions.

The questions were:

1. What are the most common hazards at the interfaces of a paper making machine?
2. Why do employees enter dangerous areas?
3. What are the most common unclear or undefined safety responsibilities?
4. What is the designers/consultants perspective on safety?
5. How can we prevent access to the dangerous areas of a machine?
6. Do we implement systematic safety checks or similar during AFRY's projects?
7. How are the differences in responsibilities regarding safety noted in projects involving a new machine or an already existing machine? Are we aware of possible differences in responsibilities?
8. How does a designer end up utilizing an unsafe design?
9. How do we approach the safety of broad interfaces such as automated guided vehicles and cranes?

The following chapters contain work related accidents in regard to the areas and constructs of the paper making machine in which they occurred. First the case is narrated after which the hazards and risks will be laid out. This is followed by ideas for prevention of such hazards after which the interviewees observations will be presented.

3.3.2 Slipping, tripping and falling from working platforms and walkways

The most common implementations which are applied to interfaces are different walkways, stairs and working platforms. These usually carry on in long strips for the length of the machine and are commonly outsourced to different sub-contractors. Solutions and requirements for these designs are explained in the harmonized standards, but the implementation of these solutions can still be lacking since the solutions might not take into account modifications done afterwards to the machinery or design changes which occur during the commissioning phase. Unique designs for attachments are also a potential point of risk if not properly implemented and inspected.

As paper machines are very tightly packed, extruding motors, valves, lines and similar components on the walkways of working platforms are not uncommon. These cause a tripping hazard when present at a low height, and possibility for head trauma or cutting when positioned higher. Working platforms sometimes need to have ability to be removed for maintenance work. This can lead to gaps and improper reattachment if the instructions and person in charge of securing the platform after the work is done are not defined clearly. Below are a few examples from incidents that have occurred on working platforms and walkways.

Worker falls when a working platform collapses, case TOT 9/98

The TOTTI incident report database has example cases such as TOT 9/98 in which a team of workers were tasked with changing of the press sections pick-up felt. The team was tasked with cutting the 30 m long 8,4 m wide felt and reeling it out of the press section, after which a new felt could be inserted into the machine. There was no supervisor assigned to the task as usually the person in charge of the changes was the main operator of the machine. This along with bad verbal communication and a misunderstanding led to the felt being cut from two different locations. When one half was reeled out of the press section it was noticed that the other half was still left inside the press section. The workers decided to pull the ~8 m long section out of the press section by utilizing a crane. The crane operator had meant to pull the felt aside from the machine above the 3rd press section, but one of the operators decided it would be better to pull it aside at the location of a working platform, due to there being guide flaps which could be damaged if the felt was pulled out at the 3rd press section. From the working platform the felt could also be inserted straight into a waste container. The working platform that they chose to lower the felt from was a removable unit which had not been marked in any way to indicate its removability. When the felt had been moved on top of the working platform, the crane operator along with the two process operators on top of the working platform began to pull it aside from the machine. When only 1-2 m of the felt remained on top of the working platform the level suddenly collapsed sending the two operators falling down along with it. The height of the drop was 7,3 m, one of the operators survived the drop with fractures and bruises but the other operator fell headfirst in to the ground hitting a spot light on the way down. He died instantly.

In the investigation afterwards it was discovered that the attachments of the removable working platform were inadequate and not as designed. The working platform was missing plates attached to the constructs which purpose was to prevent the movement of the working platform in other directions except upwards. Due to this the working platform was able to move sideways because of the felt being dragged across it and dislodge from the paper machine, causing the collapse. The inadequate attachment and non-conformity with the design was not known to the employer or the occupational safety and health personnel.

The report does not state why the company in charge of assembling the working platform had not completed the assembly properly, seeing as this would have prevented the accident. Probable reasons for the improper assembly can be misinterpretation of the drawings, forgetting to finish the assembly work, neglection etc. The employer also has his responsibility of assuring the constructs conformity to safety and design when he commences work.

To prevent such a situation from happening proper documentation of the design and the assembly process should be available to the installers. There should also be supervision and checks that the end product conforms to its design. Risk assessment should be carried out properly to the design of the maintenance platform for its entire lifecycle, which includes the installation phase.

Hole in a working platform leads to a worker falling, case TOT 11/98

Not related directly to work at a paper machine, another case TOT 11/98 involves an incident where a worker doing maintenance work for a pulp plant fell through a hole in the maintenance platform. The hole had been cut to make it possible to lift tools through it to the upper levels. The worker was working during the night and at approximately 4:30 he went for his coffee break. Due to possible tiredness and dim lighting, he did not notice the hole in the maintenance platform which had not been properly closed. The worker fell down 4,4 m to another maintenance platform and passed away due to his injuries the next day.

The hole had been unnecessary for several days as the necessary equipment had already been lowered down earlier. The hole had not been covered up properly or fixed, possibly due to a misconception. Two different companies had utilized the hole, and this possibly led to uncertainty on the responsibility of covering the hole, leading to the death of the worker. There were no warnings, hazard strips, tape or other markings to indicate the hole in the platform, if there were the incident might have been avoided. Routine weekly inspections also weren’t either broad enough to notice the hole or were neglected by personnel. The plants guidelines state that everyone who notices a potential gap on the walkways must immediately notify their supervisor or a person in charge if they cannot eliminate the hazard themselves.

Worker falls while installing a working platform, case TOT 7/10

TOT report 7/10 contains a case which does not affiliate directly with a paper machine, but a similar case could occur in the construction phase of a paper machine. The report handles a situation where workers were installing a new maintenance platform for a heating plant. The platform was being lifted by a telescopic handler, and there were three workers involved in the operation. Due to the platforms size a hole had been cut on the side of the plants wall for the platform to be lifted through. The platforms dimensions were 5,9 m long and 1 m wide and it was attached to the handler by lifting slings. The platform had been moved inside the building but had not yet been positioned correctly due to a smoke duct in its path. One of the maintenance platforms safety rails was too long to fit past the smoke duct and needed to be cut shorter. The operator of the handler decided to get on top of the hanging platform which was supported on one end by the structures of the plant and on the other end by a lifting sling. The worker cut the end of the safety rail, which was on the slings side, after which the sling started to slide off towards the edge of the rail. The worker did not notice this and the platform suddenly dropped from one end, sending the worker to fall from a height of approximately 4 meters. He died from his injuries a week later.

The worker had over 20 years of experience working for the same company and had done similar work on approximately 20 similar sites. During the investigation of the incident, it was noticed that the risk assessment performed on the maintenance platform had not included the work to be done on site, it was only limited to work done at the manufacturing location of the platform. As the plant was an already existing one the dimensions of the plant and its structures were pre-established. To prevent the incident the designers could have included the installation task in the risk assessment and consulted the owner of the plant for its limitations regarding its dimensions. Other neglections include no use of safety harnesses during the cutting, no written plan for the lifting operation of the platform and working on top of an unsecured load. The sum of these parts is eventually what lead to the fatal risk occurring.

Interviews and summary

Similar points of concern as the ones which made these incidents possible were also brought up during the interviews with a technical specialist and a safety expert both working at AFRY. When asked about the most common hazards at a paper machine both mentioned maintenance platforms as the most obvious and common one. This includes improper movement paths with obstructions, inadequate guard rail solutions, holes and openings in the walkways and a lack of assessing new possible risks manifesting with the implementation of maintenance platforms. The conditions affecting the worker were also mentioned, these include tiredness, urgency and pressure to perform. These are factors that may affect judgement and cause deviations from the normal working procedures increasing the possibility of a risk materializing.

Proper protective structures and limiting accessibility to hazardous places does help reduce the risk, but according to Peuhkuri (2021) if the implementations are not secure enough the temptation to bypass them increases in cases of urgency with pressure to meet production demands. According to Peuhkuri this is much more common in countries and cultures where the importance of safety is not yet as pronounced as in more developed countries. Implementing too many obstructions especially unnecessary or badly designed ones can also lead to resistance from workers due to hindering the production speed and possibly increase the urgency of employees. In these cases, the employer should provide more time for the performed tasks and continue to emphasize the importance of safety and safe procedures. The design of the implementations must also consider the hinderance it causes to the production as well as the increased time the task being performed now takes. This can be helped with feedback from the end users of the machines.

Lehtonen (2021) also mentioned that the design of new working platforms to old machinery might enable access to a previously inaccessible place. This oversight could enable workers to utilize the platforms in an unsafe manner to reach dangerous areas. This could be prevented with proper risk assessment and comprehensive measures for prevention of access to dangerous areas.

Lehtonen (2021) also mentioned that sometimes the guard rails of working platforms are utilized as a measure to block access to dangerous parts and areas of the machine. This might seem like a clever way to utilize the guard rails as a safety feature, but it must be remembered that the requirements for guard rails do not match the requirements of a protective structure. This is why they should not be utilized as risk reduction measures for rotating or moving machine parts.

To summarize, maintenance platforms are easy structures in theory to implement, but the design of them requires significant knowledge and communication with the client and the end users. Walkways and their solutions should be constructed in a way which removes obstacles, protruding hazards and other hazards such as moving machinery parts and objects. The implementation and constructions of the maintenance platform must be planned out and proper risk assessment carried out in communication with the client and end user to assure safe installation and maintainability. Checks and other systematic means of identifying hazards and risks have to be in place and the end user must have sufficient knowledge of how to work safely on these platforms and what kind of work is allowed on them.

3.3.3 Entanglement and getting drawn into nips and wrapping points

As the paper travels along the machines length and is being processed, it travels through multiple wires and felts. These are carried by rollers and rotating cylinders which apply heat and remove moisture from the paper. Each point where two rollers or a roller and a wire or felt come in contact, is a possible spot for a wrapping point or a nip. These are some of the most dangerous points in the machine. As the speeds of the machines and the process have increased the prevalence and danger of wrapping points and nips has increased with them. Wrapping points exist everywhere where there is rotation by a roller along a suitable sized gap (smaller than the object susceptible to getting wrapped) exists. Getting entangled to ropes and other utilities in contact with a nip can also lead to the person getting drawn into the wrapping point.

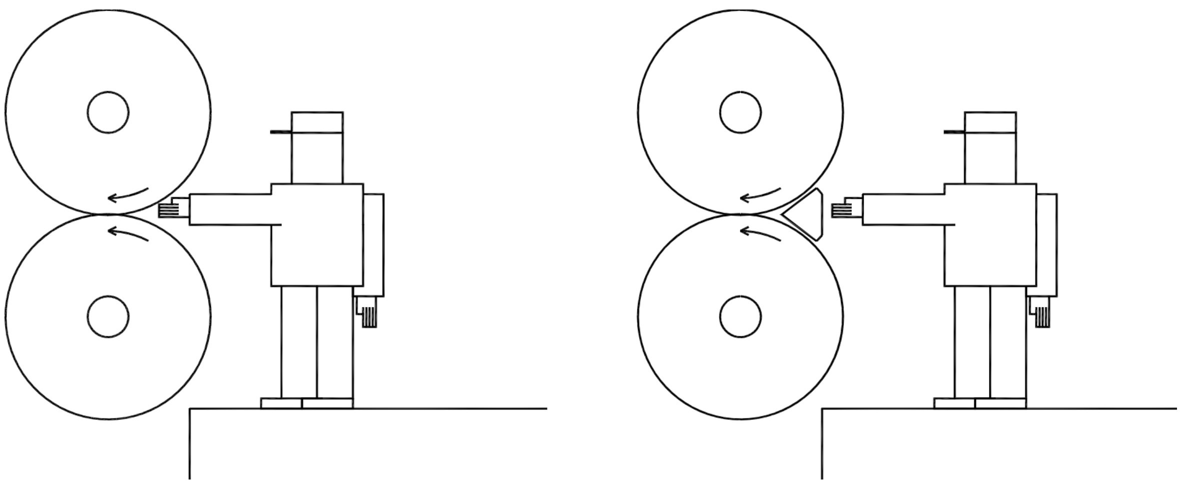

Figure 18 Example of an exposed nip and a nip with a safeguard implemented.

Operator gets drawn in between a paper roll and a machine, case TOT 11/11

The TOTTI incident report database has example cases such as TOT 11/11 in which an employee responsible for preparing a 2 ton roll of paper for production in the arc cutter, noticed that plastic bands used to hold the ends of the paper roll from unwinding was getting sucked into the unwrapping stations rolls. The employee tried to quickly grab the plastic band and in the process his hand was caught in the nip of the roller. The employee was found dead 23 minutes after with his head and upper body trapped in the nip.

There was no emergency stop close enough for the employee to reach nor was the system restricted in a way which would have prevented the employee from being affected by the hazard. Restricting the rolls rotational controls to the control panel requiring constant physical input would have separated the worker from the hazardous area, preventing the accident from occurring.

Case TOT 9/12

Also report TOT 9/12 has a nip/wrapping point incident which lead to the death of an employee. In this case the paper line had broken, and the operators were in the act of restarting the process. The employee had signaled to the other workers that he would go downstairs to examine the start up. There he saw that the guide roll of the drying wire had gunk on its surface. The employee decided to move to a maintenance platform (pictured in figure 19) from where he could clean the surface of the roll with a scourer. While cleaning the guide roll the employee was caught in the nip of the guide roll and was sucked through a 14 cm gap between the roll and another guide roll.

The working platform from which the worker was standing on had been made obsolete by a change in the process. The height from the working platform to the roll was only 165 cm. This had left an unnecessary risk in the workplace as the working platform should have been removed after the process change. The employee had been instructed on safe working procedures and he was wearing the appropriate safety gear. However, he did not follow the instructions to stay outside of the machine during operation and start up. The accident could have been prevented with the removal of the platform and proper protective structures which would have prevented moving inside the machine when it was in production.

Figure 19 Picture of the working platform on which the accident happened. (Tapaturmavakuutuskeskus 2012)

Interviews and summary

The experts working at AFRY have noted that the safety of nips and wrapping points has increased thanks to better safeguard implementation and instructions for workers, but they have noted issues regarding the modernization of older paper machines. Lehtonen (2021) mentioned that typically the contractor in charge of the modernization agrees to only inspect and guarantee the safety of the machine or modification they supply as they want to limit their liabilities. This can lead to the creation of new hazards which were previously not present unless the client has a dedicated and experienced project manager who is aware of the responsibility to perform risk assessment and assure the implementations conformity to the directives and laws.

Lehtonen (2021) noted that the employer may forget or not be aware of their responsibility to perform risk assessment and assume that the supplier of the machine or modifications is solely liable for shortcomings in the final design. She also mentioned that the client may assume that performing modernization work on an older machine is an easier task to perform even though this is not true. This can further increase the possibility of inadequate risk assessment as the effects of the modification are not fully understood. If the supplier and client are not aware of the new implementation's effects on the current working environment the possibility for a risk to materialize increases.

Peuhkuri (2021) mentioned that the differences in safety culture between more developed and developing nations affect workers decisions to perform hazardous operations like working close to nips. From his experience this is mostly due to the fear delaying the projects schedule but also due to the lack of a proper safety culture. He mentions that the workers might not have even realized the danger of the setting they are working in. Proper safety implementations help in reducing the occurrence of these situations, but they may sometimes cause resistance from workers due to the implementation's effects on workflows.

3.3.4 Impact and crushing injuries from cranes and AGV's

The paper machine produces a large diameter machine roll which can have tens or even hundreds of kilometers of paper wrapped around it. This machine roll is transferred for further processing, usually to the winder slitter, by an overhead crane. This crane is operated with the use of a remote-control device, operated by a worker. As the machine rolls weight is tens of thousands of kilograms, the operator of the crane must have sufficient knowledge of the controls and the performed task. Walking underneath a moving load is forbidden in the mill environment, but this is usually not enforced with the utilization of automated protective structures or other solutions. The paths from the maintenance side of the machine to the operating side often cross underneath the cranes operating path, leading to a potential risk. If the crane operator is not aware of a person moving in the forbidden are of operation and the operator is susceptible to stress due to urgency or other distractions an accident can occur in the form of a collision between the hoisted load and the personnel. Cranes are also regularly used in maintenance tasks for instance when disassembled rolls are moved out of the machine for change or service. When operating with cranes the task should be possible to be performed without need for human operation beneath the cranes area of operation. Another way the rolls are handled is by the utilization of AGV's or automated guided vehicles. These are vehicles capable of autonomously moving rolls between different stations for handling and processing. The AGV's utilize cameras and motion sensors to identify personnel moving in their area of operation. As these are autonomously moving heavy vehicles handling significant loads, they present a crushing and impact hazard to personnel.

Crane supported roll fatally strikes a worker during maintenance, case TOT 9/10

In TOT report 9/10 an incident involving crane operation during maintenance work occurred. Three workers were in the process of moving a fiber roll from the paper machines calander unit for service. The roll weighed 10 000 kg and needed to be lifted by a crane. One of the workers was in charge of the cranes operations and the two other workers were responsible for removing the bolts connecting the roll to the calander and monitoring the gap between the fiber roll and the mold roll above it. The crane operator got the command from both workers from each end of the roll to lift the roll after which the two workers below would remove the bolts holding the roll in the machine. After this the crane operator was given the command to take the fiber roll out of the machine. The operator started moving the fiber roll but noted that the roll did not move with the crane, the fiber roll was in contact with the mold roll. After a few seconds the fiber roll quickly swung out of the calander and hit one of the operators at the end of the roll. He suffered trauma to the head and died instantly.

The act of removing the roll required good teamwork and communication between each worker. Investigations after the incident found no defects on the crane or the lifting sleeves used on the fiber roll. However, the workers did not follow standard procedure which says that no working below or in the immediate vicinity of a cranes load is allowed. The crane also did not have a gauge or and indicator for loads or contact with other constructs, this means that the crane operator did not get indication that the fiber roll was in contact with the mold roll. An indicator like this could have shown the operator that the roll was stuck, and the crane needed to be moved back.

Automated guided vehicles

Often in new mills and modernizing projects of old mills automated guided vehicles are being utilized. These are autonomous robots that can handle the transferring of heavy paper rolls to other production units in the factory. They do not need guide rails for their paths which make them easy to implement and enable them to have a broad area of operation. They utilize motion detecting cameras to monitor their surroundings and the paths they utilize need to be taught to them beforehand. The area the AGV's operate in needs to be properly fenced off since the presence of large heavy automated units presents a significant crushing hazard to employees, as well as an impact hazard depending on the speed of the AGV and its deceleration time. The TOTTI database had no incidents involving an AGV, but the United States Department of Labor has incidents where an AGV has failed to detect a person in its area and caused a collision. The cases usually involved human error such as steering in the way of an AGV with a forklift while the AGV was turning (Summary number: 200900348, Inspection number: 300646619), not checking behind a corner when moving in the AGV's area of operation (Summary number: 111019.015, Inspection number: 1360310.015) and cases where the AGV's detection system hadn't noticed the human presence in its area (Summary number: 201924669, Inspection number: 311960876). These cases are available at https://www.osha.gov/pls/imis/accidentsearch.html with the inspection number.

Interviews and summary

Concerns regarding cranes were also presented by the interviewees. One notable difference between factories in developed and developing countries is the utilization of clear marked pathways and fenced areas which take into account the operating paths of cranes, other machinery and conveyors. As cranes and AGV's are heavy, fast-moving machines they present a significant hazard to the workers operating in their area. Lehtonen (2021) mentioned in her interview that the operating areas of AGV's should be inspected systematically as the supplier of the AGV usually only provides the requirements for example the minimum gaps which are allowed to occur. The operating area needs to be inspected to assure that these requirements are met and the organization responsible for these inspections should be agreed upon as early as possible. Lehtonen also mentioned that the paths of conveyors for roll handling and broke handling need to be inspected for possible crushing points.

The users of these machines need proper training and the regular work and maintenance procedures which involve these machines must have their risks assessed. The areas of operation for cranes and AGV's must be inspected, and possible points of danger identified such as, blind corners, possible crushing points, obstructions and pathways for workers. Also cranes utilized in maintenance work must have their operations regarding the maintenance inspected and risk assessment must be performed. In Finland the Government Decree on the Safe Use and Inspection of Work Equipment 403/2008 §20 lays out the required operations that need to be made to aid in ensuring a safer lifting operation.

3.3.5 Crushing injuries from moving machinery parts

Many of the components and machinery comprising a paper machine produce some kind of movement. Mostly this is rotation in rolls and cylinders that are in contact with the paper but there is also a lot of linear movement which occurs in components such as dryers, presses, doors, hydraulic arms and so on. This linear motion produced by high power hydraulic presses produces a significant crushing and impact hazard. Crushing points however do not require high speeds as even a slow-moving component can be out of the field of vision of a worker if he is focused on a task especially during a disruption in the process.

Moving in the close vicinity of the paper machine is commonly forbidden when production is ongoing but during maintenance situations personnel can be performing actions inside the machinery. In these cases, proper stoppage of the machine and procedures for locking the controls are paramount for safe working conditions. This also means that the personnel must have sufficient knowledge of the interfaces and the interconnected machinery to ensure that each machine under maintenance does not cause movement to occur when the maintenance personnel are working on it.

Operator is squeezed between an infrared heater and its support beam, case TOT 4/16

TOT report 4/16 has an incident in which moving machinery parts were involved. The incident occurred at the paper machines infrared heaters which are located at the coating section. The machine was in regular operation when the workers were alerted by the automated fire alarm system. The workers noticed the fire was occurring at the coating section and decided to cut the track before the coating section and direct the broke to the pulper. When the track is cut the infrared heaters (shown in figure 20) at the coating section turn off and return to their home position to allow for work and movement in the area. The heaters have two positions, the home position which is displayed on the right of the picture of figure 20 and the production position show on the two leftmost images. The fire was then extinguished, and the track brought back to production. After this the employees discovered a new smolder which the fire alarm system had not detected due to its small size. The workers had decided not to cut the paper track and try to eliminate the fire with the machine in production. One worker was reaching inside the gap formed by the infrared heater and the frame of the paper machine. He contacted the other workers by radio and informed them that the paper track needed to be cut again. As the other employees cut the track the operator inside the infrared heater did not notice the heater returning to its home position and he was crushed inside the machine. He died instantly from his injuries.

Figure 20 Gap between the infrared heating unit and the paper machine (Tapaturmavakuutuskeskus 2017).

The report notes multiple deviations from standard practices which led to the incident. First the paper track had been left on and hadn't been cut even when the smolder had been detected. Second the smolder was positioned in an abnormal location which was not a regular occurrence. Third the worker decided to reach inside the machine, this being against company rules, and he ordered the paper track to be cut while inside the machine.

These deviations in conjunction with the contributing risk factors such as free movement to the risk area, no visual connection between the different workers, lackluster guidance and supervision and the possible unclear positioning of the heater unit to the worker due to the heating unit not being active enabled the risk to materialize. Preventative measures suggested by the report included limiting access to the hazard area, better camera coverage of the machinery, developing better methods for radio communication, preventing embers and fires from getting into hard-to-reach places and issuing better more fitting firefighting gear.

It can be presumed that the risk identification process done to the machinery had been lacking as the hazard had been identified earlier during maintenance work and a report had been made of the possible crushing hazard present. The report had been handled but it was thought that no one would have access to the area when the paper machine was operational due to the high temperature present at the coating section. This had not taken into account the situation where the infrared heaters were not enabled but the paper track was on.

Interviews and summary

The interviewees acknowledged the common lack of inspections done to the final product and its conformity to design. Peuhkuri (2021) mentioned that additional checks on the design and product introduce more costs which the client may not be willing to pay for. He mentioned that often the client is relied upon for feedback and that it is presumed that the client will inspect the designs. This is an obvious point of fault as the client may presume that the design work he has ordered conforms to the directives and standards requirements. Tight schedules and the fragmentation of responsibilities may also contribute to lacking design work. Peuhkuri did mention that designers do not design unsafe solutions wittingly, but it does not mean that unsafe design solutions cannot occur. Papermaking machines are fundamentally a dangerous machinery and extra cautions should be taken when working with them.

Lehtonen (2021) mentioned that the clients responsibilities may not always be clear to the them. They may presume that the machine delivered incorporates all of the safety features and risk assessment needed for it to be considered safe for use. This can be especially dangerous if the end-user is not able to differentiate between a complete CE-marked machinery and a partially complete machinery. She mentioned that the additional systematic checks and inspections mentioned would be a good way to improve legal protection of the designer/consultant and reduce unnecessary confusion between the different design principles. As the machine is transferred over to the end-user its safety becomes the end-users responsibility. This ensures that there is always a responsible body for the machineries design, but this may also lead to lacking internal risk assessment and inspections on behalf of the manufacturer as they may presume that the client will identify the possible left over risks in the machinery.

4 Results

4.1 Observations

When the cases in chapter 3 were examined, it was noticed that most commonly the occurrence of fatal accidents did not happen during normal work performances. Most of the accidents tend to occur during malfunctions, during the startup of a process or during maintenance work. This is due to the fact that the processes are largely automated and human interaction with the machinery is less common during production. This may also be an explanation for why most hazards occur during either maintenance work or a malfunction as these situations which deviate from standard operations may not have had their risks assessed and inspected properly during the design and construction phase.

Inadequate design solutions may also lead to improvised and unsafe solutions for performing work which the designer has not taken into account. For example, the design of walkways and maintenance platforms should incorporate solutions for transferring tools and equipment to minimize to amount of crane operations needed and to prevent the need for cutting holes in the platforms. Possible malfunctions during production need to be prevented or their occurrence minimized as these are some of the most dangerous situations a worker can be involved in.

4.2 Solutions for identified risks

When examining the accident cases in the previous chapter some commonalities are found. Common reasons for being exposed to risks include the following:

- Deviation in production or from standard procedures
- Negligence when performing a task and or circumvention of safeguards
- Urgency
- Improper informing
- Lacking design
- Lacking safety design and risk assessment
- Insufficient supervision and inspections

Nearly all of the cases examined contained some kind of deviation from the standard operating procedure. This usually occurred due to negligence, urgency, a malfunction or improper informing of the employee. This in conjunction with lacking safety design, insufficient supervision and inspection of workflows lead to a risk materializing resulting in the injury or death of an employee.

To prevent these risk occurrences significant care must be taken when addressing the following questions:

- Is the manufacturer of the machine aware of the machines interfaces with other machinery and has the responsibility of inspecting the safety of these interfaces been assigned to a specific entity. Can these interfaces and limits of supplier assemblies be reduced to minimize the number of interfaces?
- Is the design compliant with the required regulations and the clients requirements and has its conformity been checked and ensured with inspections and audits? Have all of the possible risks and hazards been noted to a reasonable extent?
- Are the safety measures and precautions taken adequate enough to remove or reduce the risk to an acceptable level? Who is in charge of determining this and does he understand the machineries limits and attributes? Can a safety expert be utilized to help the designer in charge?

To help with the recognition of these areas and to help with solutions for these questions the following measures can be helpful:

- Have an agreement on the responsibilities regarding interfaces as early as possible in the design and designate clear areas of responsibility.
- Include in the contract the level of safety to be pursued with clear objective goals.
- Designate a person in charge of the safety design who has enough experience with safety measures and has influence to change the design if it is deemed unsafe.
- Ensure that the project managers are aware of the machinery features and limits and they understand whether the machine is suitable or not for its purpose. This should be continuously developed with tools for assessment and training of personnel.
- Have systematic checks and inspections in place to ensure that the product conforms with its design. Safety features and their functionality should not be taken for granted. This should be an always ongoing process throughout the products design and commissioning phases.
- Companies should perform inspections on their products and design practices to minimize risks. Use of modular design packages and previous designs is helpful

and can remove hazards but it should not be taken as granted that the design will always be safe and suitable for its desired application.

- Take into account the serviceability of the machine and remember to inspect the designs safety during exceptional work.
- Companies and schools should invest more into safety design and understanding of the required directives and legislations which regard the designers and companies of their selected profession.

The previous chapters example cases contained situations which could have been prevented with proper inspection and review of the processes being performed by utilizing comprehensive risk assessment. Many of the incidents could have been prevented with slight changes to the way the machinery in question was operated or a proper inspection of the final products conformity to its design. For instance, the working platform which enabled the worker to reach the nip when cleaning the roll should have been noted after the production changes were made and the risks of leaving the platform assessed which in turn could have led to the removal of the platform.

Proper guides for how to perform maintenance work and clearly designated personnel in charge of the maintenance work are also required to improve the safety of maintenance tasks as these often occur in exceptional conditions.

Safety procedures should be enforced with remarks and ultimately suspension from work if not followed properly. Many of the cases contained a situation where an experienced worker had gone to a forbidden or dangerous area regardless of the guidelines and warnings. This can occur due to pressures to maintain production and not wanting to let your co-workers down. Delays in production can result in pressure to the employees and upper management if the set goals are not met. Inspecting the working methods in use is important to ensure that workers have adequate time and resources to perform their job safely.

The design should strive to take note of human error and implement safeguards and solutions to minimize effects of improper use and neglect. This can be further minimized with the help of guides and training, but as is the case in the reports many of the workers are trained and experienced professionals who still got exposed to a risk. This is why guides and training are not sufficient enough to reduce risks at the workplace. This should be aided with well-designed implementation of constructs and machinery which take into consideration the nature of the task and possible deviations in standard procedures, eliminating the hazards that are present when performing these tasks.

5 Conclusions

A lot of useful information and observations were gathered for the solutions in chapter four. However, safety is a very broad subject and even narrowing it down to one machinery type, there were still many hazards and viewpoints that were not analyzed. The information from the TOTTI-database presented good cases for study but all of the cases in the database are situations which have resulted in death. This means that there are no cases where a worker might have nearly come in contact with a dangerous situation or machine. To broaden the knowledge base reports from the employers which contain close call situations could be utilized. This might change the outlook on predominant hazard types and situations and give a broader perspective on the subject. Comparing machinery safety across multiple countries with differing laws and regulations might also provide new aspects for hazards and general safety.

Interviewing experts helped in filtering out the non-essential information and provided guidance on the most common hazard types and the reason for why these hazards occur. The interviews brought forth knowledge of the clients demands and requirements. These are sometimes in conflict with the requirements of regulations, standards and engineering ethics as the clients may also ask for removal of safety features (Lehtonen 2021).

This was in line with what François Gauthier et al. noticed in their study on the practices and needs of machinery designers and manufacturers where they identified that manufacturers sometimes are content with meeting the bare minimum requirements required. They also noted how some manufacturers have made safety an integral part of their brand and that this has helped them in being able to design safer and easier to use equipment when compared to their competitors. (François Gauthier et al. 2021.)

Control systems were not in the scope of this thesis although some cases contained mentions of safety controls. Researching the implementations of control systems would enable a broader look at safety controls and the logic implemented into them making it possible to identify short comings in their design. In addition, future research could examine contractual aspects regarding interfaces between machinery, as well as factors affecting procurement activities.

Interviewing experienced workers who have worked with paper making machinery might also present different outlooks on the common hazards and employee thought processes in dangerous situations. This information could be utilized when designing a machine so that common dangerous solutions and hazards could be minimized. Feedback from previous projects should also be utilized to identify common misconceptions regarding the responsibilities of suppliers and designers to ensure that no gaps are able to develop during the design and construction phase. These should be documented and reviewed after each project with all of the participants.

Employers should also put more emphasis on safety culture and analyze the effects of new safety rules and features. For instance, applying industrial protective structures is a good way to limit access to dangerous places, but if the area needs regular access to during production the fencing may increase the time demands of the task. The growing time demands for workers may increase the possibility of an accident occurring. Employers need to recognize the down sides of safety features to ensure that they do not create new hazardous situations for the employees.

Postscript

The goals laid out in chapter one for the thesis were achieved, as this thesis answered the main responsibility questions regarding the different entities working on a paper machine project in a clear and concise way. The responsibilities were defined, and the points of possible misunderstandings explained along with solutions for how to avoid them during the project. The third chapter explained the general function of a paper making machine and defined the meaning of an interface. After this the interfaces in the paper making machine were identified along with associative risks and hazards which were gathered from accident reports and the interviewees personal experiences. From this information the general hazards at the interfaces were explained with example cases from similar situations and possible solutions for avoiding these risks and identifying them were presented.

The thesis provided the author with a lot of knowledge on the structure and meaning of the machinery directive and machinery safety in general. The authors skills for analyzing accident reports and the overall safety of a machine were improved along with a deepened understanding of the laws and directives which affect a large-scale machinery project such as a paper making machine. As the machinery directive encapsulates a broad range of different machinery, the author believes that his ability to perform risk assessment and inspecting a machines conformity have significantly improved. The authors ability to interpretate standards and determine which standards along with their requirements need to be applied to his work as a designer.

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