Diploma Thesis

Criticality Analysis as a Tool for Strategy Development in Maintenance

An exemplary Application on new Woodyard Equipment at a Pulp- and Papermill in Russia

Submitted by

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In cooperation with

MONDI UNCOATED FINE & KRAFT PAPER GmbH

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Danksagung

„Leider lässt sich eine wahrhafte Dankbarkeit mit Worten nicht ausdrücken." (J. W. v. Goethe)

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Abstract

An international paper manufacturing group is expanding their production site in Russia. At the pulp mill, equipment based on newest technology will be installed. To fulfill the new requirements on equipment uptime and reliability, an improvement of practical and methodical knowledge of the maintenance organization on site is necessary. Criticality analysis is a tool in maintenance engineering to optimize the efforts in maintenance activities. This work is providing a guideline in order to apply a criticality analysis based on the practical example of wood yard equipment. Key equipment and common failures are mainly identified by experiences at foreign mills and analysis of the plant layout. Risk matrix, failure mode and effects analysis and a maintenance strategy portfolio are the explained and used tools. The importance of risk based strategy development and the implementation of a clear reporting and planning system are examples of interesting potentials which were found.

Kurzfassung

Ein internationaler Papierhersteller erweitert seinen Produktionsstandort in Russland. In der Zellstofffabrik werden Anlagen mit der neuesten Technologie installiert. Um die neuen Anforderungen an Laufzeit und Verfügbarkeit zu erfüllen, ist eine Verbesserung des praktischen und methodischen Wissens der Instandhaltungsorganisation notwendig. Die Kritikalitätsanalyse ist ist ein Werkzeug der Instandhaltungs-Technik, um die Instandhaltungsaktivitäten zu optimieren. Diese Arbeit liefert einen Leitfaden für die Anwendung einer Kritikalitätsanalyse, basierend auf dem praktischen Beispiel eines Holzplatzes. Schlüsselkomponenten und übliche Störfälle werden durch Erfahrungen anderer Fabriken und durch Analyse des Anlagenschemas identifiziert. Die Risiko-Marix, eine Failure Mode and Effects Analyse und ein Portfolio an Instandhaltungsstrategien werden erklärt und angewendet. Die Bedeutung einer risikobasierenden Strategieentwicklung und die Einführung eines Berichts- und Planungssystem, sind interessante Potentiale, die unter anderem gefunden wurden.

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1 Introduction

1.1 Initial Situation

The international Mondi Group is an integrated packaging and business paper producer. The Group is fully integrated across the paper and packaging process, from the growing of wood and the manufacture of pulp and paper (including recycled paper) to conversion of packaging papers into corrugated packaging and industrial bags. Mondi has production operations across 35 countries and had an average of 33.400 employees in 2008. The Europe & International Division has 95 production plants and is producing corrugated paper, bags, specialties and uncoated fine paper (UFP). The business unit Uncoated Fine Paper has 4 mills and 10 paper machines producing more than 1,5 million tons of paper.

Since 2002, the mill in Syktyvkar (Komi Republic, Russia) has belonged to the Mondi Europe & International Division (at that time Neusiedler Group, a subsidiary of Mondi Group). Syktyvkar is located 1.200 km away from Moscow and 1.000 km from St. Petersburg. The mill produces more than 672.000 tons of pulp (hardwood, softwood, CTMP) and over 830.000 tons of board and paper per year, with one board machine and three paper machines. The mill is provided with energy by its own power plant generating with a capacity of 468 MW. Excess electricity and heat is on-sold to the Komi Republic. Between 2008 and 2010 Mondi Group is investing more than 500 million EUR in Syktyvkar (STEP-project). The STEP-project is designed to increase the pulp production by 190.000 tons per year and the board and paper output by 120.000 tons per year.

1.2 Problem statement

One of the main principles of the STEP-project is the application of newest technologies for pulp- and paper production. Due to this, the maintenance concept of the mill has to be adapted. Wood yard, evaporation plant and recovery boiler will receive completely new and modern equipment. Therefore, the development of new maintenance concepts for these departments is necessary. Currently, a lot of redundant equipment is available in the case of break downs. The future situation (after STEP) of the mill will lead close to a single line concept. So the influence of breakdowns on the time efficiency of the production lines will be serious. The previous strength of the maintenance organization lies in repair activities (reactive maintenance). This system will not be sufficient to ensure the reliability of the plant. An additional challenge in ensuring a maximum of equipment up-time is Syktyvkar's "remote location", geographically away from other industrial infrastructure. It is a corporate requirement to build up a new maintenance organization with best practice character. The target of the pulp mill in Syktyvkar is 350 days of continuous production and one annual shutdown (10 – 14 days). So maximum equipment up-time at minimum maintenance costs are the overall target. Therefore it is important to know, which effort in maintaining certain equipment is essential and which effort is sufficient.

1.3 Approach and Objectives

In order to identify an adequate maintenance strategy, the criticality of a certain device will be determined. Experiences from other mills using similar equipment, are the first sources for figuring out the critical plant assets. Therefore, a benchmarking with the pulp production area of other mills will be initiated. A questionnaire and personal mill visits are the basis of this benchmarking process. Regarding wood yard, evaporation plant and recovery boiler, three core questions should be answered:

- Which critical equipment can be found at these systems?
- What are the most common failures and their reasons?
- How is the maintenance organization handling the related tasks?

The second input is delivered by the original equipment manufacturer (OEM) and his operation and maintenance manuals. During this work, the manuals will be evaluated to find out whether they fulfill the requirements to be useful for maintenance management and maintenance execution in the daily work.

The next phase is solely concentrating on the new wood yard. A closer look at the plant layout (flow sheets) of the new equipment should help to discover possible bottlenecks. If a breakdown of an equipment is influencing (constraining) the production process, this equipment should be considered as a key equipment. Based on this information (other mill experiences, supplier instructions, plant layout), the crucial equipment will be identified.

To recommend a certain way of treating equipment by maintenance, the knowledge about the failure risk and the risk of failure results is necessary. The next step is a failure mode and effects analysis (FMEA) of the plant. This will be done in an interdisciplinary workshop. The gained results should be criticality classes for certain failures and a list of the most critical items.

Summarized overview of the process:

1. Basis input
    - Identification of key equipment (other mill experiences, supplier instructions, plant layout)
    - Identification of common failures (other mill experiences, operator experiences, supplier experiences)
2. Failure modes, effects and causes
    - Severity of failures
    - Likelihood of failure occurrence
    - Probability of failure detection
3. Criticality determination
4. Outcome
    - Maintenance strategies based on risk assessment
    - Criticality ranking of process areas, equipment, items, etc.

The result of this work is a tool to apply the methodology of a criticality analysis in maintenance engineering projects. It should help to understand the importance of a selective strategy development and simultaneously act as a guideline for practical use.

1.4 Work Structure

Chapter 2 ("Theoretical background") explains the meaning of frequently used terms. It describes the theoretical framework of maintenance in the industry. Chapter 3 ("Theoretical basics and tools") describes the applied methods and illustrates the scientific basics of criticality analysis. Chapter 4 ("Criticality analysis of wood yard equipment at MSY") represents the practical work of a criticality analysis. The scientific theories of the previous chapters and the practical results of questionnaire, layout study, etc. will be combined to a brief and open criticality analysis. Chapter 5 ("Conclusions and recommendations") shows the results of the analysis itself, but also points out some improvement potentials for maintenance at Mondi Syktyvkar.

2 Theoretical Background

2.1 Maintenance in general

To understand the approach of this work and comprehend the meaning of its outcomes, it is recommended to know about the framework in which this work is embedded. Maintenance engineering and maintenance management are essential for the profitability of a mill.

2.1.1 Maintenance definition

Maintenance and all its related processes and activities are part of the Asset Management. "The main role of the asset management is to administer operating resources in view to corporate goals. Operating resources are plants, equipment (machines, devices), manufacturing facilities, means of transport and spares." (Biedermann, 2007)

The German standard DIN 31051 describes "all measures for maintaining and restoring the target condition as well as determining and assessing the actual condition of technical equipment in a system". (Stengl & Ematinger, 2001)

Thus maintenance is a procedure to create values in order to balance or recover expended or consumed values. (Biedermann, 2007)

Maintenance is composed of

- Service
- Inspection
- Repair

Service summarizes all actions taken to keep the target condition, like cleaning, lubricating, replacing, adjusting, etc. Actions like detecting and proving are inspection activities and attend to the identification of the actual condition. To rebuild the target condition, repair work like correcting and replacing has to be done. (Biedermann, 2007)

The main outcome of all maintenance actions is to ensure sufficient reliability and availability at minimal costs.

2.1.2 Maintenance strategies

"Maintenance strategies are rules to quote, which actions should be done on which devices at which time." (Matyas, 2002)

Four basic maintenance strategies are established in the industrial practice:

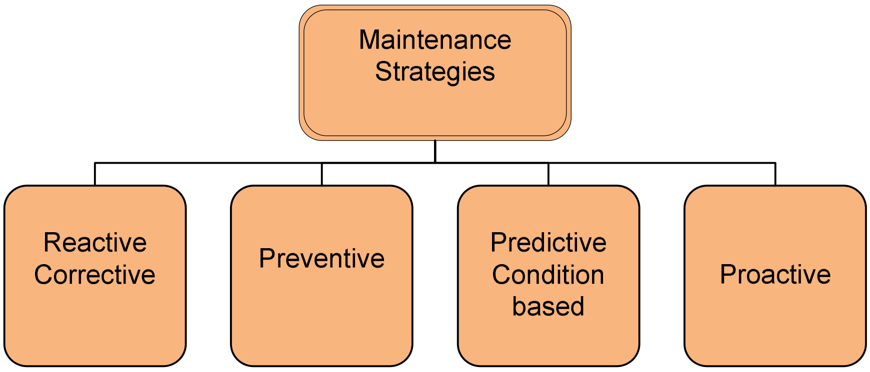

Figure 2-1: Maintenance strategies

Reactive/ corrective maintenance:

Breakdown based strategy. The strategy is to apply the corrective action (repair, restoration, replacement) only, when it is required to correct a failure that has occurred. There are no routine or scheduled tasks. The principle is also known as Run-to-Failure Maintenance.

Preventive maintenance:

"This is a time based strategy where on a predetermined periodic basis, equipment is taken off-line, opened up and inspected, repairs are made and the equipment is then put back on-line." (Jabar, 2003) The idea is to prevent a failure before it occurs.

If the equipment wear is checked within defined intervals, the strategy will be called periodical preventive maintenance. (Rasch, 2000)

Predictive maintenance:

Condition based strategy. Adequate diagnostic and monitoring systems are providing on-time information about variations from the target condition. So the maintenance activities can be based on the concrete rate of wear of the equipment. This enables the planning and execution of maintenance activities to optimized costs.

If the maintenance period is adjusted to the actual condition of the equipment, the methodology is also called deterministic-sequential. (Rasch, 2000)

Often used diagnostic measurement is vibration measurement for bearings. In most cases, the condition monitoring is done by hand, but in the last years a lot of online diagnostic systems have also come up.

Proactive maintenance:

"The principle of this strategy is the detection and correction of root causes to equipment failures. It is also designed to extend the useful age of the equipment." (Jabar, 2003) Proactive maintenance is not only concentrating on the symptoms. It is also looking for the causes of equipment failures, to eliminate these factors, so that a further appearance of the failure can be avoided. This approach has to be supported by analysis work (e. g. laboratories) and would be most effective in combination with real-time data.

In the modern industry, a mix of these strategies is utilized. Which equipment and device is maintained by which strategy is identified by a substantial analysis. The following criteria will be determined: interlinked equipment, redundant equipment, environmental-, safety- and health criteria, employment law, time to repair, availability of spare parts, buffer time, peak load. (Matyas, 2002)

2.1.3 Maintenance engineering

A maintenance strategy is always defined for certain maintenance objects (devices, items, etc.) and is developed within a maintenance engineering process. Parts of maintenance engineering are:

- Criticality analysis, Failure Mode and Effects Analysis (FMEA)
- Maintainability analysis
- Life cycle analysis
- Root Cause Failure Analysis (RCFA)
- Development of inspection and lubrication plans and routes
- Determining of spare part needs
- Set-up and modification of the Computerized Maintenance Management System (CMMS)
- Etc.

Maintenance engineering influences each section of the maintenance function and makes the conditions to do

- the right maintenance
- on the right equipment
- at the right time
- with the right people
- for the right reasons

(Velthoven, 2009)

2.1.4 Maintenance organization

The maintenance organization is a framework within which the corporate maintenance policy is put into practice.

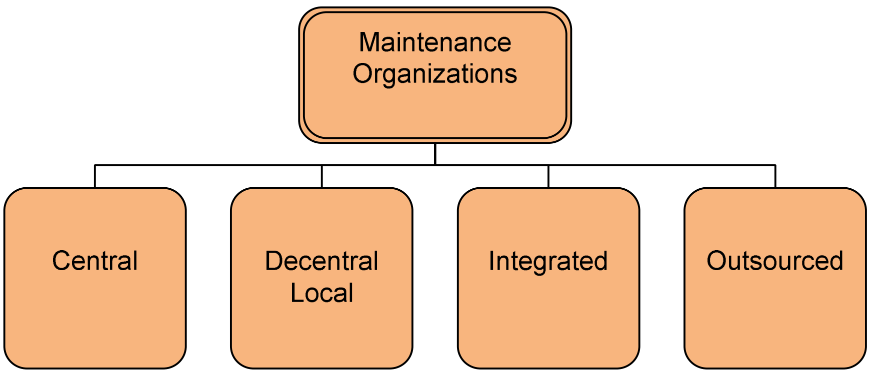

Figure 2-2: Maintenance organizations

It is a structural plan for job functions and responsibilities, communications, work requests, record keeping and lines of supervision. (FAPET, 2007)

Central Maintenance:

All the maintenance functions for the whole production site (mill) are executed by one maintenance department. This department provides its service to the different production sections. Sometimes this organizational form is also called functional maintenance. (Biedermann, 2007)

Decentral (local) Maintenance:

Each production section (departments, “business units”) has its own maintenance department, which is responsible for all maintenance activities (including planning and scheduling). It is also called object oriented maintenance. (Biedermann, 2007)

Integrated Maintenance:

The operators are part of the maintenance function. Inspection, lubrication and repairs, which could easily be done, are executed by the operators. Maintenance personnel will be called just for special inspection and repair tasks.

Outsourced Maintenance:

The maintenance tasks are transferred to an outside contractor. The external partner builds up his own inner structure.

Most of the organizational concepts in the industrial praxis are a mix of these forms. For instance, Mondi Ruzomberok has decentral maintenance departments in their business units (e. g. recovery line), and those are supported by a central maintenance department for special tasks and in case of staff shortage. The more interwoven the central maintenance and the local maintenance are, the more it is important to clarify the responsibilities. It is essential to avoid overlapping, especially in the case of shutdown planning.

Outsourcing is seldom used in its pure form, like at Metsa-Botnia mill in Fray Bentos (Uruguay). (Andritz AG, 2007) On the other hand, it is common to call external contractors for big shutdowns (annual shutdown, revision) and special tasks.

2.1.5 Maintenance management

The maintenance management represents all the functions to plan and control the maintenance organization in terms of effectiveness and efficiency. It is a closed loop process, based on decisions on the corporate level.

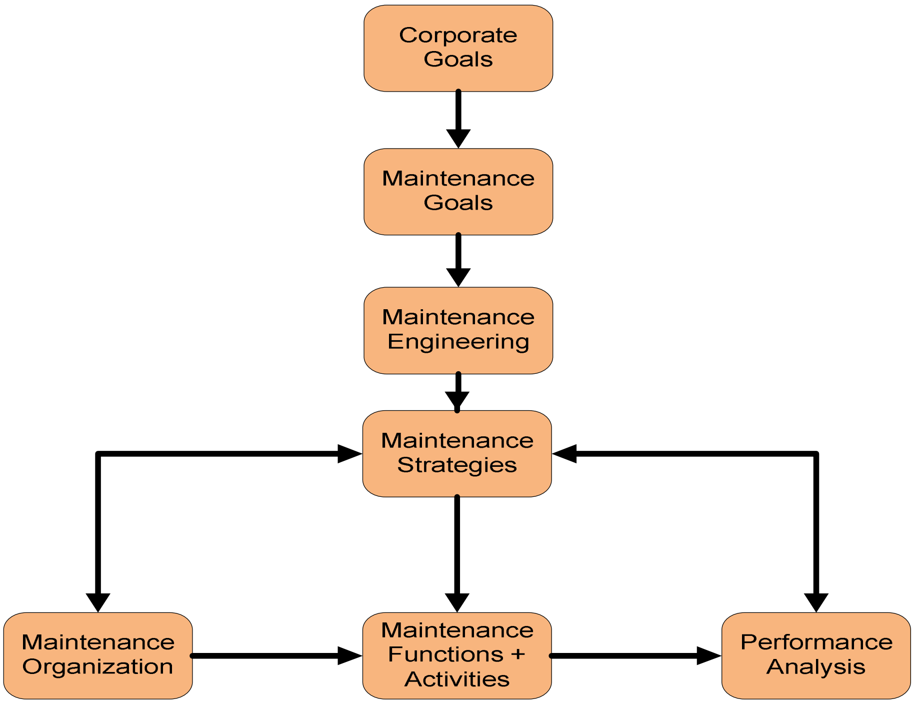

Figure 2-3: Maintenance management process

The maintenance function has to execute the tasks according to the maintenance strategy, under the basic conditions of the maintenance organization. It is the executing part of the process and delivers the main impact on the maintenance performance. Therefore it is essential for performance analysis to have meaningful and controllable information available in each section of the maintenance function.

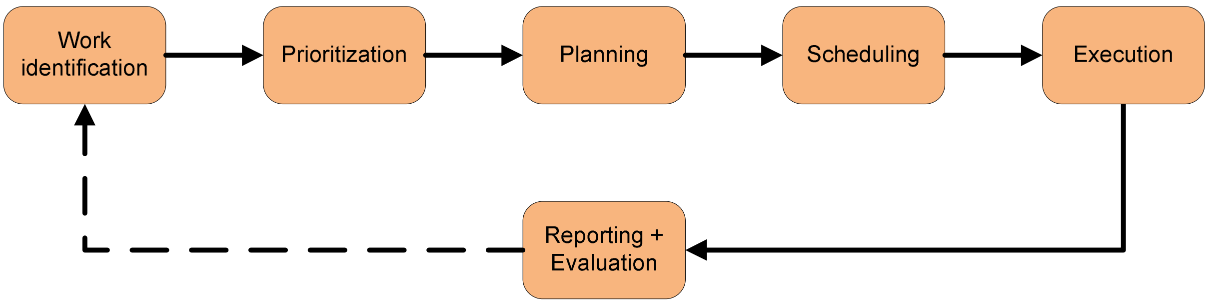

Figure 2-4: Maintenance function and activities

To expand and support the strategies mentioned before, several management tools are offered. Some of them are part of "maintenance philosophies", which have started to come up in the last few decades like Reliability Centered Maintenance (RCM), Total Productive Maintenance (TPM), etc. One of the most powerful tools for maintenance management are Key Performance Indicators (KPI). Measures are widely spread instruments to figure out whether an organization is making progress towards a defined goal. For example at the work scheduling section: the percentage of work orders completed during the scheduled period before the late finish or required by date (world class maintenance should achieve >90 % schedule compliance). (Weber, 2005) KPI are classified as leading or lagging indicators. Leading indicators (e. g. percentage of maintenance work orders requiring rework) measure and track performance before a problem arises, while lagging indicators (e. g. maintenance costs/manufacturing costs) show if certain results were achieved. (Smith & Hawkins, 2004) Both types of KPI should be considered. It is more productive to use less, but meaningful measures. The effectiveness-KPI registering the target achievement and the efficiency-KPI should display if the target has been reached in a convenient way.

2.1.6 Reliability and Reliability Centered Maintenance (RCM)

Moubray is defining RCM as “a process used to determine what must be done to ensure that any physical asset continues to what its user wants it to do in its present operating context.” (Moubray, 1997) This definition is too imprecise. It has to become clear, what is really meant by the term reliability. Reliability means a reasonable confidence in the equipment to fulfill its function at the required time in the required quality. To build up this reasonable confidence, it is indispensible to gain information about the breakdown characteristics of the item. For that reason, the following definition of RCM is more appropriate:

“RCM is a step-by-step instructional tool for how to analyze a system’s all failure modes and define how to prevent or find those failures early.” (Idcon Inc., 2006)

In other words, RCM helps to establish the need for and the type and frequencies of preventive and predictive maintenance. (Dufresne)

But the reason to utilize RCM is not just because of improving the equipment availability. Benefits will also be gained from a better balance between maintenance costs and maintenance advantage. In applying this concept, several other tools, like FMEA, RCFA, etc. will be used. So the RCM is not a self-standing process, but rather a fusion of analyzing and implementing tools. The result is a mix of maintenance strategies according to the real needs of the maintenance object.

Some of the fundamental considerations of the present work are influenced by RCM.

2.2 Relevance of maintenance in the pulp- and paper industry

Pulp- and paper production is characterized by highly developed equipment and complex processes. Therefore the investment costs and further on the fixed costs of the assets are very high. It is an important challenge to keep equipment uptime as high as possible. Maintenance costs constitute 4 – 14 % of production costs in the paper industry. (FAPET, 2007)

There are two major risks for the asset management in the industry:

- Risk of breakdown
- Risk of breakdown consequences

The last result of a breakdown is the production loss on salable pulp or paper.

Example: Pulp mill

Pulp mill production output: 2000 t/d Non Bleached Softwood Kraft Pulp (NBSK)

Pulp sales price: 456,54 €/t (Actual price for NBSK on 2009-07-28) (FOEX Indexes Ltd.)

Resulting sales value of the lost production for one downtime day: 913.080,- €/d

Maintenance costs pulp mill: 30,- €/t

Resulting maintenance costs for one production day: 60.000,- €/d

This means that an investment of 1,- €/t in maintenance can generate more than 15,- €/t in production value. On the other hand, if 1,- € is invested in improper maintenance and causes a breakdown, the resulting costs are more than 15,- €.

Example: Integrated mill (pulp and paper production on one site)

Paper production output: 2.500 t/d   A4 B-copy (uncoated woodfree)

Paper sales price: 805,37 €/t (Actual price for A4 B-copy on 2009-07-28) (FOEX Indexes Ltd.)

Resulting sales value of the lost production for one downtime day: 2.013.425,- €/d

Maintenance costs integrated mill: 45,- €/t

Resulting maintenance costs for one day: 112.500,- €/d

So the ratio would be nearly 1:18 for improper maintenance expenses and their resulting costs.

Gross margin pulp mill: 322,15 €/t

Loss of gross margin for one downtime day: 805.375,- €/d

As these examples show, everything has to be done by mill management to enable very good and smooth maintenance performance.

On mill level it is not possible to control the market or the raw material costs. Thus the mill is forced to look inward to find ways for improving its bottom-line results. For most mills, improved reliability is a key area of cost and productivity improvement. (Hykin, 2003)

On the Fortune 500 listening from 2004, the forest and paper product sector is ranked on position 42 out of 45, related to its return on assets (ROA). (Steele, 2006) In the same listening from 2008, the forest and paper sector has already disappeared. Concerning this fact, several approaches to increase the profit margin in this industry are needed. One of these ways is to improve the equipment efficiency together with lowering the maintenance costs.

2.2.1 Influence of maintenance on the production

The common goal of all mill departments is to produce pulp and/ or paper in the most competitive way. In achieving this goal, both departments, operations and maintenance, are equal partners.

At this point it must be considered that time efficiency, operating rate and overall equipment effectiveness (OEE) are not only maintenance related KPI. These measures are strongly interlinked with operations. Related to definitions from the associations Zellcheming and FAPET: (Zellcheming, 2005)

Time efficiency = Production time / Maximum available time

Production time = Maximum available time - Idle time

The idle time contains breaks and setup works (e. g. grade changes) as well.

Maximum available time = Calender time - Time not available

If the production line is shut down for external reasons and the operations is not responsible for these reasons (holidays, rebuilds, crashes, lack of orders, etc.), this downtime is called time not available.

The approach behind the definitions by Zellcheming refers directly to the six major losses. (Ouvreloeil, 2004)

OEE-factor	Loss	Remarks	Influenced by maintenance	Influenced by operation
Availability	Equipment failure causes production downtime	Maintenance assistance required	Yes	(Yes)
	Setup and adjustments	Grade changes	No	Yes
	Small stops	Minor adjustments, simple tasks (cleaning)	Yes	Yes
Speed	Speed losses	Lower machine speed because of machine wear, substandard materials, operator inefficiency	Yes	Yes
Quality	Losses during regular production	Less than acceptable quality	(Yes)	Yes
	Losses during warm-up	Less than acceptable quality during the first period after downtime	(Yes)	Yes

Table 2-1: OEE-factors and major losses

Obviously, maintenance and operations are belonging together. The OEE is influenced by both elements, so it can also be called overall plant efficiency (OPE).

Maintenance work delivers equipment reliability and prolonging life of assets and the operations department delivers process reliability. Their common result is production reliability. (Idhammar, 2001) According to Idhammar, reliability can be measured with the following formula: Reliability = Mean time between production loss (MTBPL) / mean production loss (MPL). (Idhammar, Operations + Maintenance = Production, 2000) To avoid operational and equipment problems and to increase OPE and reliability respectively, both departments should work on increasing the MTBPL and decreasing the MPL. High OPE increases the production output and net sales of the mill.

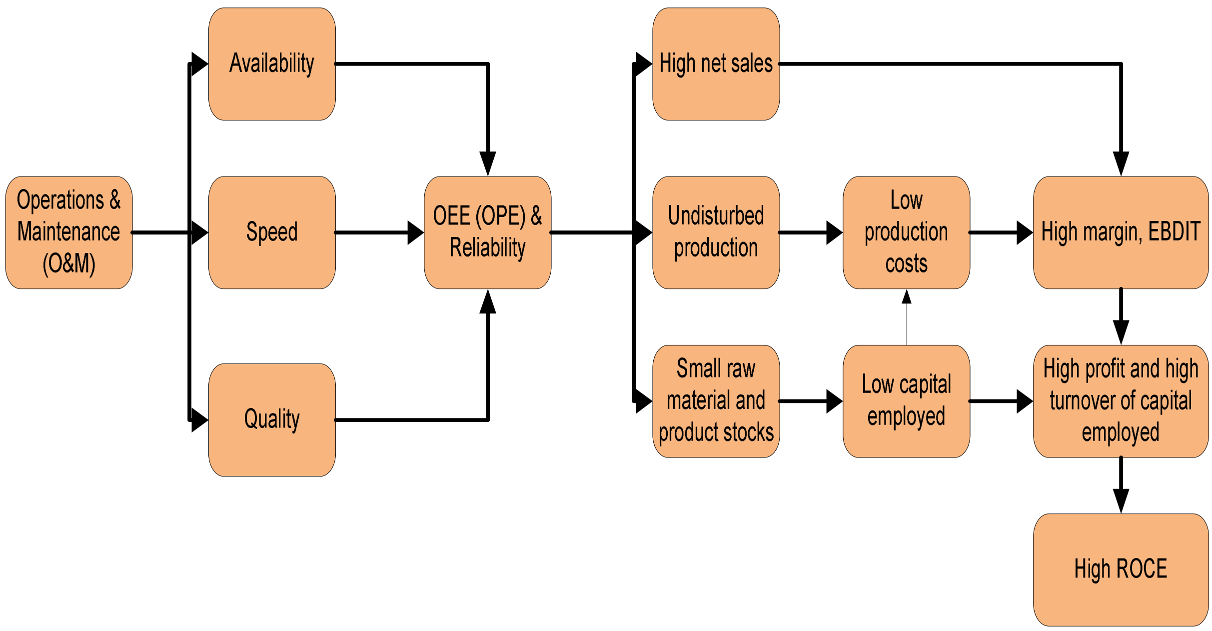

Figure 2-5: Influence of operations and maintenance on production

A PricewaterhouseCoopers survey in the global forestry industry has shown that the average ROCE of the Top 100 companies dropped from 4,9% in 2007 to 2,4% in 2008. (PricewaterhouseCoopers LLP, 2009) This movement has its reason in the global economic slowdown. But during market downturns, it is important from a cost saving point of view to prevent the need for repair work and to execute the maintenance activities more efficiently. Well defined inspection and lubrication routes and root cause failure analyses would eliminate many repair works, as well as good operating practices. A clear work identification and prioritization, accurate planning and scheduling and detailed reporting will help to do maintenance activities more cost-efficiently. The Norske Skog mill in Skogn (Norway) had 30 planned bearing replacements (at three paper machines) in 2004, based on their inspection route and condition monitoring. The planned replacement work saved on average four hours to an unplanned work. This resulted in an additional 120 hours production time, which represented 2880 t of saleable paper at a market value of 850.000 USD. (Jonsson, 2005)

3 Theoretical Basics and Tools

The practical approach of a criticality analysis is based on several scientific methodologies in fields like risk management, reliability engineering, etc. These methodologies and tools will be briefly explained below.

3.1 Risk Matrix

RCM tools like Failure Modes and Effects Analysis (FMEA) are requiring a lot of time and personal resources. Therefore these tools should be applied just on really critical equipment and parts. A new wood yard will have approximately 20.000 items, and not all of them must fulfill the same requirements on reliability. The Pareto-Principle applied to the plant means that 20% of the equipment is causing 80% of the problems. (Cowley, 2006)

To preselect the most critical equipment, a risk assessment was done. The whole product flow at the wood yard was divided in typical process steps. Each process step and its main malfunction were evaluated by defined criteria:

- Impact, consequence, effect of break down
- Likelihood, probability of break down

3.1.1 Risk assessment approach supported by Turnbull

The company was applying a Turnbull-Guidance in 2004. Turnbull is mainly used for corporate risk management processes, and was modified to use it in the context of maintenance. The result of this approach is a risk matrix, which should easily show the equipment with the highest priority.

	Machinery Break down		LIKELIHOOD				
	HARM TO Business		DAILY	WEEKLY	MONTHLY	ANNUAL	>10 YEARS
			Z	Y	X	W	V
IMPACT	1 month breakdown	A	9	8	7	6	5
	1 week breakdown	B	8	7	6	5	4
	1 day breakdown	C	7	6	5	4	3
	Reportable breakdown	D	6	5	4	3	2
	Minor	E	5	4	3	2	1

Table 3-1: Turnbull Risk Assessment Matrix (Mondi AG former Neusiedler AG, 2004)

Red cells (numbers 6, 7, 8, 9): Most critical

Yellow cells (numbers 4, 5): Medium critical

Green cells (numbers 1, 2, 3): Less critical

3.1.2 Risk portfolio approach established in maintenance

Several authors recommend a risk matrix model following the ONR 49001 (Risk Management for Organizations and Systems - Risk Management - Practical use of ISO/DIS 31000) (Strohmeier, 2006)

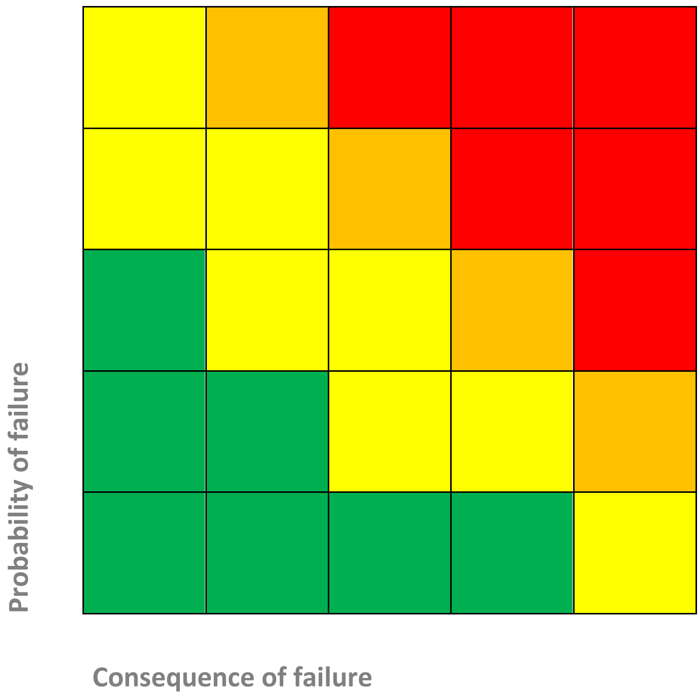

Figure 3-1: Risk portfolio, criticality matrix

Red cells: Most critical; Principle of risk mitigation by maintenance.

Yellow cells: Medium critical; Principle of expenditure minimization in maintenance.

Green cells: Less critical; Principle of close to zero expenditure in maintenance.

	Consequence rating	SHE	Production	Repair
Catastrophic	4 - 5	Death, large number of serious injuries, environmental disaster	Serious interruption of production process, big production loss, more than 1 week downtime	Extensive repair costs > 1.000.000,- EUR, equipment replacement
Major	3 - 4	Serious injuries, extensive injuries, massive effect on environment	Stop of production process, more than 1 day downtime, extensive loss in product quality	High repair costs < 1.000.000,- EUR
Moderate	2 - 3	Medical treatment required, contained environmental impact,	Interruption of production process, more than 6 hours downtime, moderate loss in product quality	Moderate repair costs < 100.000,- EUR
Minor	1 - 2	First aid treatment required, minor environmental effect	Short interruption of production process, less loss in product quality	Slight repair costs < 10.000,- EUR
Insignificant	0 - 1	No injuries, no environmental impact	Very short or no interruption of production process, no loss in product quality	Insignificant repair costs

Table 3-2: Rating criteria for failure consequence

	Probability rating	Occurrence
Almost certain	4 - 5	Expected to occur in most circumstances. Often repeating, several times per day
Likely	3 - 4	Will probably occur in most circumstances. Weekly
Possible	2 - 3	Can be expected at some time. Monthly
Unlikely	1 - 2	Occurrence can not be expected on a regular basis. Once per year
Rare	0 - 1	Occurrence is an exception.

Table 3-3: Rating criteria for failure probability

3.2 Failure Modes and Effects Analysis (FMEA)

FMEA is a risk management and quality management tool and was originally developed by the NASA (National Aeronautics and Space Administration, United States) in 1963 for the Apollo-project. The methodology is utilized to determine potential failures and their effects in systems, processes, equipment, etc. as a future looking approach. It can be divided in three main phases: (Kmenta, Fitch, & Ishii, 1999)

- Identify: What can go wrong?
- Analyze: How likely is a failure and what are the consequences?
- Act: What can be done for prevention and elimination?

The NASA defines FMEA as:

“A methodology to analyze and discover: (1) all potential failure modes of a system, (2) the effects these failures have on the system and (3) how to correct and or mitigate the failures or effects on the system. (The correction and mitigation is usually based on a ranking of the severity and probability of the failure.)” (NASA)

3.2.1 FMEA process

FMEA is a deductive procedure and will be done as a top-down analysis. The following structured approach is recommended: (Denkena, 2009) (Bitsch, Canver, & Moik, 1999)

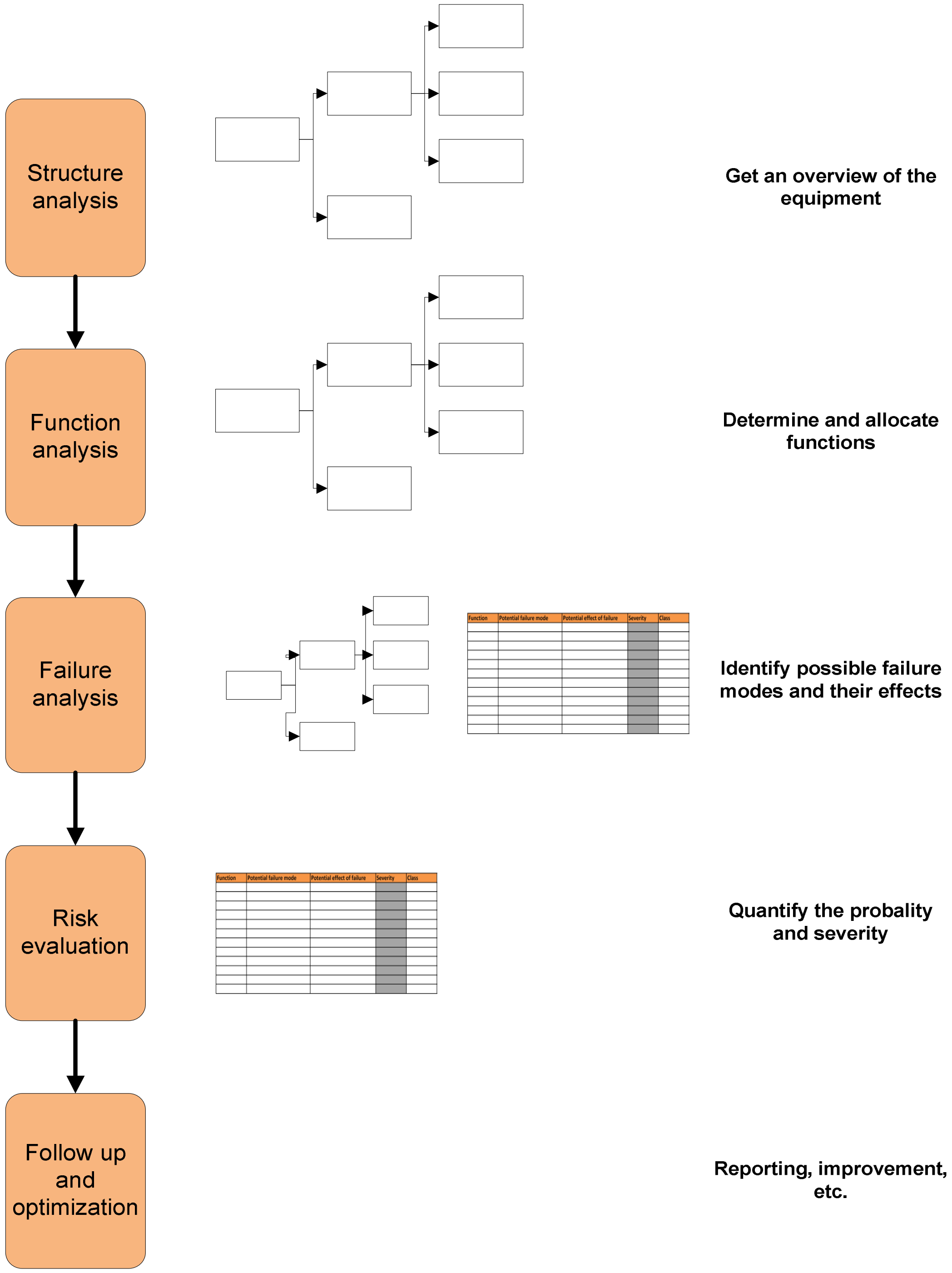

Figure 3-2: FMEA procedure

1. **Structure analysis:**

At first there must be a clear description of the process which will be the subject of the FMEA. To illustrate the structure, it is helpful to create a block diagram, wherein each block represents a major element of the process. Furthermore, the elements will be split in sub-elements and so on. The result is a hierarchic picture, comparable with a tree structure.

2. **Function analysis:**

Each element and sub-element has to fulfill a certain function and task. This function will be determined and allocated. The functional coactions of the elements will also be shown in tree structures.

3. **Failure analysis:**

Potential malfunctions of elements or sub-elements will be determined. The result is again a structured overview of potential failures and their systematic connections.

4. **Risk evaluation:**

A rating of the severity, probability of detection and probability of occurrence of each failure should give a measure about the risk.

5. **Follow-up and optimization:**

Based on a failure ranking list and/or critical items list, the improvement process will be started. Clear responsibilities for improvement actions and revision must be pointed out.

3.2.2 Failure analysis

Each element and sub-element has to fulfill a certain function. The inability to perform its function is characterized as a failure. (Denkena, 2009) [The malfunction will be analyzed by its:

- Cause
- Consequence (Effect)

According to the functional structure, a failure structure can be built. Sometimes it might be necessary to do the examination on a deep level of small maintainable items.

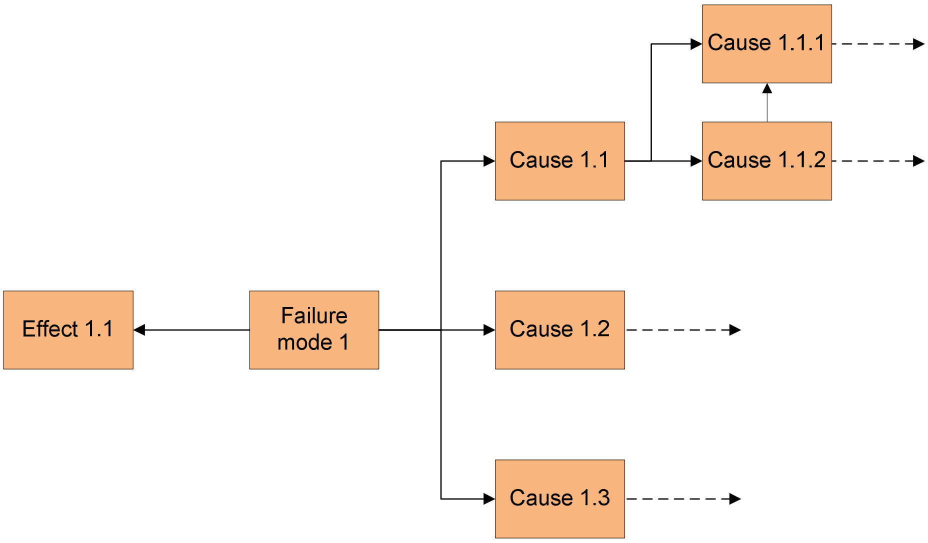

Figure 3-3: Principle scheme of failure structure

Operating and environmental conditions should be considered in any case. The manner, in which a process, element, item, etc. could potentially fail to meet its intent, can be called failure mode. (Crow, 2002) Behind each failure mode observed, there is a mechanism of occurrence like: corrosion, cracking, deformation, abrasion, material fatigue, electrical short, etc. Each failure mode can cause a further failure mode in another element. It is strongly recommended to execute the failure analysis by an interdisciplinary team of experts. The complexity and importance of the procedure require a lot of experience in different fields (e. g. engineering, technology, operations, maintenance, etc.).

The 5-Why-Method:

This method is an analytical tool, which can be easily applied to get the root cause of a problem. In asking “why?” five times, the root cause of a problem should be discovered. It goes beyond the scope of this work to discuss advantages and disadvantages of this method.

Other tools to determine root causes:

Fishbone diagrams, logic trees, brain storming, etc.

3.2.3 Risk evaluation

The risk evaluation process should also be done by the team of experts mentioned before and is answering the following questions:

- How probable is the detection of a failure with consideration of the current actions for prevention and detection?
- How severe or serious is a failure for safety, health, environment, process, plant, product, etc.?
- How is the likelihood or frequency of the occurrence of a failure?

To gain appraisable information out of the answers to these questions, a risk priority number (RPN) will be calculated. Each of the three questions results in a certain amount of "risk points". The RPN will be calculated by multiplying the three single assessments for each failure mode relating to each element and/or sub-element. (Denkena, 2009) (Crow, 2002)

RPN = Detection (D) * Severity (S) * Occurrence (O)

The figures D, S and O reach from 1 to 10 or even higher, depending on the amount and details of the data available and experiential knowledge. If the estimation of the probabilities is just vague, the evaluation scheme should also be chosen roughly. (Denkena, 2009) For this work, the evaluation scheme (risk criteria) established at Mondi Ruzomberok is used. Modifications were just done on terms and abbreviations. See table 3-4. A higher RPN indicates more critical failure modes. But one should consider that severity is the most decisive factor in assessing risk. So it is possible to have failures with equal RPN, but one of them has a higher severity, and also failures with low RPN compared with the others but with higher severity. These effects will be considered by using criticality as the product of severity and occurrence. (www.fmea-fmeca.com)

Criticality = S * O

Some analyses found in literature are purely based on criticality. (Souza & Álvares, 2008) (Latino, 1996). A risk evaluation or criticality analysis should be done on a regular basis (for example once a year) by a project group or at least after changes in equipment or maintenance strategies.

FAILURE IMPLIES A RISK TO SAFETY, HEALTH AND ENVIRONMENT (SHE)	
Significant: Significant impact on SHE (injury, illness, destruction, etc.)	**Yes**
Insignificant: Impact on person or environment is insignificant.	**No**

FAILURE IMPLIES A RISK TO PRODUCT QUALITY	
Exists: Status of the equipment failure has considerable influence on quality of production process and products. Menace of customer loss.	**Yes**
Does not exist: Quality of production process is not endangered. Insignificant influence on quality in case of element or sub-element or whole unit function failure.	**No**

Maintenance:

PROBABILITY OF FAILURE OCCURANCE – O	POINT ASSESSMENT
Small: It is not probable that failure occurs. The failure would be exceptional. The element and/or sub-element works only temporary. Dynamics of the plant is small.	**1**
Medium: Occasionally, the failure of minor meaning could occur. Based on experience, failure occurrence could be expected. In the past, failure has already existed. The element and/or sub-element is not used to full capacity, but the operation is dynamic.	**2**
Big: It is almost sure that failure will occur. Very often repeating failures. Very high exploitation in element and/or sub-element operation. Very dynamic influence.	**3**

SEVERITY OF FAILURE – S	POINT ASSESSMENT
Insignificant: Failure has no influence on production process, will not limit the production. Alternate (redundant) equipment is existing, parallel production.	**1**
Medium: Failure will limit production process.	**4**
Serious: Loss of element and/or sub-element function will stop or interrupt production process. Big production losses.	**6**

PROBABILITY OF FAILURE DETECTION – D	POINT ASSESSMENT
Big: Detection of failure and its reason is probable, can be identified easily. Result and demonstration of failure are obvious.	**1**
Medium: Detection of failure or its reason is difficult.	**2**
Small: Detection of failure or its reason is impossible or very unlikely. Result is not visible immediately.	**3**

COSTS CAUSED BY REPAIR AFTER FAILURE	POINT ASSESSMENT
Negligible: Failure simply removable. Quick exchange of the element and/or sub-element. Costs for failure remove will not exceed 30% of the element and/or sub-element price. Quickly available spare parts. Time and costs for repair are not significant.	**1**
Considerable: Failure hardly and slowly removable. The costs will exceed more than 30% of the price of a new element and/or sub-element, high value equipment value. Long delivery time for spare parts. Big labour consumption for repair.	**2**

Table 3-4: RPN criteria, (Mondi) modified by author

The scheme shown in table 3 enables the assessment of risk. This information is now summarized in the RPN and can be easily exploited. The flow chart for determining the criticality classes is shown in figure 3-4.

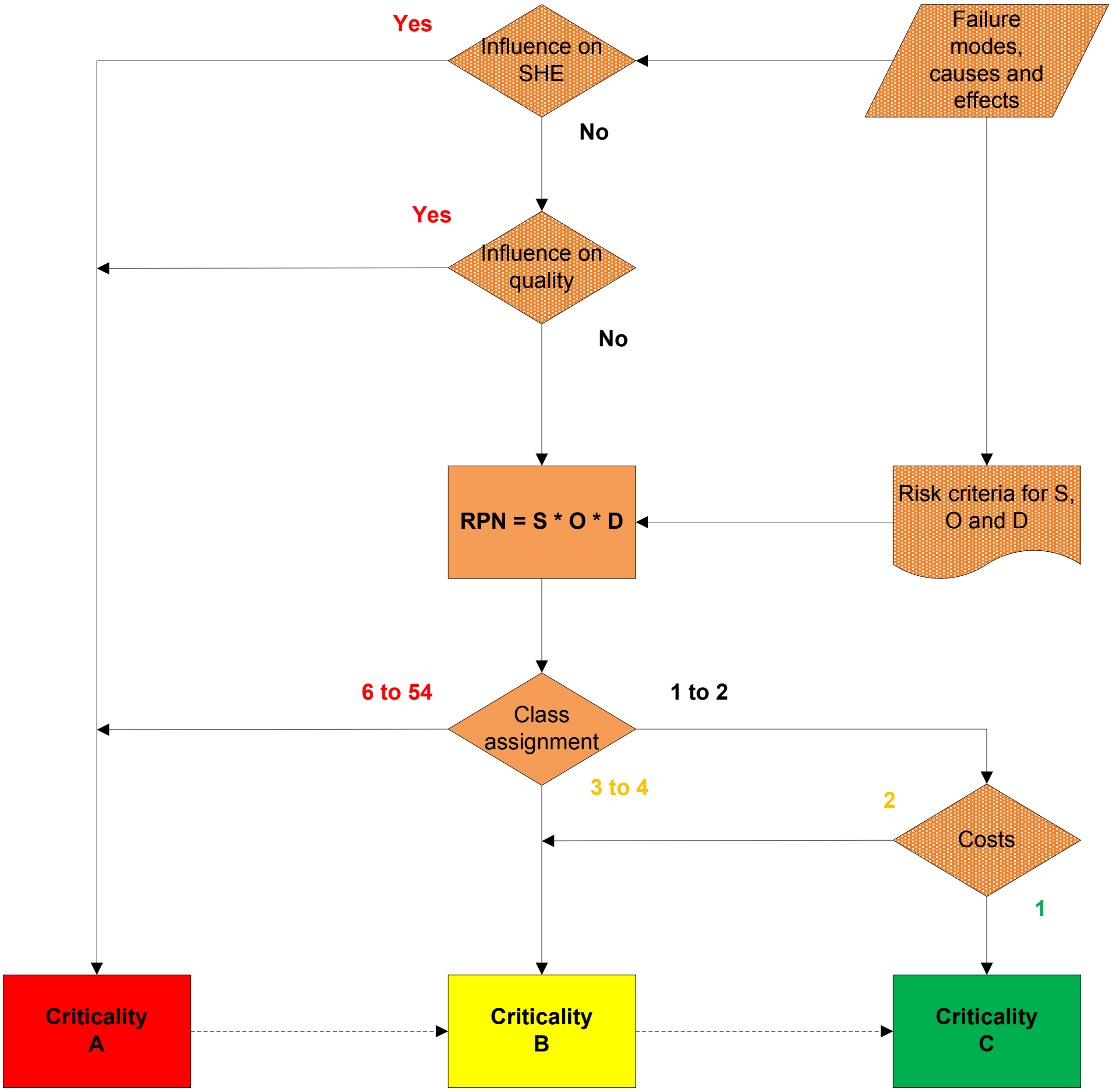

Figure 3-4: Process for determining criticality classes, (Mondi) modified by author

Criticality classes for each failure related to a certain element (equipment, etc.) and/or sub-element (device, component, etc.) are the result of the analysis and have a big impact on defining the right maintenance strategies.

3.2.4 Follow-up and optimization

The follow-up and optimization phase includes all actions to utilize the risk analysis results for improvement actions. Based on criticality classes, strategic maintenance actions can be taken. It is important to understand that neither the RPN and criticality nor the criticality class have an exclusive influence on the maintenance strategies or further decisions in treating the equipment. Life cycle costs, maintainability, recommendations of the original equipment manufacturer (OEM), etc. will also be considered.

Pareto analysis:

A Pareto analysis can support the evaluation and help to define the right strategy. The Pareto analysis can be done according to RPN, criticalities and/or criticality classes, and identifies which failure cause presents the greatest risk to the system. (Mayfield)

3.3 Strategy development

3.3.1 Maintenance strategy based on severity and occurrence

It is possible to use the criticality matrix again to define the right maintenance strategy for the objects which were analyzed by FMEA. The most occurring failure mode and its severity will be opposed in the same portfolio matrix as mentioned in chapter 3.1.2. This helps to select rough directions for maintenance activities.

Criticality A: Principle of risk mitigation	Attention by maintenance above OEM recommendation. Frequent maintenance
Criticality B: Principle of expenditure minimization.	Attention by maintenance meets OEM recommendation. ALARP (as low as reasonable practicable - via periodical and condition based maintenance). Regular maintenance
Criticality C: Principle of close to zero expenditure	Attention by maintenance can be below OEM recommendation, but be aware of guarantee requirements. RTF (run to failure). Intermittent maintenance

Table 3-5: Maintenance strategies based on criticality matrix, (Herold, 2009) modified by author

3.3.2 Maintenance strategy based on criticality and detection

The maintenance strategy portfolio enables the user to develop a concrete maintenance strategy by opposing criticality and detection.

	Planned maintenance		
		Unplanned maintenance	
	Criticality		
Detection (D)	**High (not tolerable) 9 - 12**	**Medium (tolerable) 4 – 8**	**Small (insignificant) 1 - 3**
High (predictable) 1	Preventive actions; Considering age and lifecycle; Inspections	Preventive or event driven actions, depending on: effort, costs, break down scenario, etc.	Run to failure; Event driven actions; Avoiding accumulation; Stock keeping, Ability to deliver
Medium (noticable) 2	Preventive actions; Condition monitoring; Inspections	Preventive or event driven actions, depending on: effort, costs, break down scenario, etc.	Run to failure; Event driven actions; Avoiding accumulation; Stock keeping, Ability to deliver
Small (not predictable) 3	Preventive actions; Inspections; Redundancy; Protection and safeguarding	Preventive or event driven actions, depending on: effort, costs, break down scenario, etc.	Run to failure; Event driven actions; Avoiding accumulation; Stock keeping, Ability to deliver

Table 3-6: Maintenance strategy portfolio, (Biedermann & Schröder, Risikoorientierte Strategien in der Instandhaltung, 2007) modified by author

3.3.3 Maintenance strategy based on RPN and detection

The rubric “criticality” and its scores are replaced by RPN in the strategy portfolio of chapter 3.3.2.

4 Criticality analysis of wood yard equipment at Mondi Syktyvkar

It is intended by Mondi Syktyvkar to start a detailed maintenance pre-engineering project for wood yard, evaporation plant and recovery boiler by external assistance. This work is not in the scope of the project. Its purpose is to provide a guideline for doing a criticality analysis on mill level without support of external consultants. The following analysis has just an exemplary character, and has already been carried out, when the maintenance pre-engineering project started. The wood yard was chosen as an example because of its clearly laid out equipment structure.

4.1 Plant and process overview

4.1.1 Process description

Generally, the wood yard consists of

- Wood room (debarking drum, chipper, bark handling)
- Chip storage (stacker, piles)
- Chip handling (reclaimer, conveyors)
- Chip screening (gyratory screen, etc.)

The wood yard represents the link between forest and pulp production. Operating conditions and methods at the wood yard have an enormous impact (chip quality) on pulp production (cooking conditions, yield, etc.). The process can be divided in nine steps. The following description is mainly based on the documentation of Andritz OY, Finland and FMW Industrieanlagenbau GmbH, Austria, and is just slightly modified by the author.

1. Wood receiving

Wood is delivered by trucks to the wood room area of the pulp mill. Two similar lines for debarking and chipping are installed, one for softwood (spruce, pine) and one for hardwood (birch, aspen). The logs are unloaded from the trucks by mobile cranes directly onto the loading section of the deicing conveyor. Logs are unloaded to the wood storage only when the wood room is not in operation or for intermediate storage to compensate seasonal fluctuation in wood supply.

2. Deicing

Freezing of logs increases the bond strength between wood and bark, therefore deicing is necessary before the debarking process. Log bundles are carried to the debarking drum by infeed, which consists of a deicing conveyor section. The conveyor is equipped with adjustable conveying speed to regulate the feeding capacity. Warm water is sprayed on the logs to melt remained ice and snow. Water temperature is adjusted by adding the right amount of steam into the deicing water. Spray nozzles are located under the conveyor cover. Retention time of wood in the deicing chamber can be 15 to 30 seconds. At the end of the conveyor, the log bundles are disintegrated and sand is removed by washing.

3. Debarking

Bark is not suitable for pulp production and further on for paper making. It has a high content of ash, its particles can break easily and it can be hardly bleached. This results in dark spots in the paper. Sand and stones are also often brought in by bark and can harm mechanical equipment like chipper knives. Therefore, bark is removed by dry tumbling debarking in a debarking drum. The logs are moved through the rotating drum and become debarked by rubbing against each other. The bark goes through the outlet slots of the drum to the bark handling equipment. Frequency converters allow a variable rotational speed of 3 to 7 rounds per minute (rpm) of the drum. A double drive system on two rolled steel support rings, supported by steel wheels, is driven by a girth gear. A hydraulically operated diagonal gate and the feeding capacity of the drum are controlling the retention time of the logs. The bark chutes are furnished with overhead shrouds and rubber sealing against the drum shell. One of the two debarking drums is working 100% with hardwood, whereas the other drum is just working one third of its production time with hardwood. Thus the second drum is running as a batch-process (1/3 HW, 2/3 SW).

4. Bark handling

Bark and waste coming out of the outlet slots of the debarking drum are collected by bark chutes and fed onto the bark belt conveyor under the drum. Loose bark from deicing and washing section is collected with water flumes and led through underground channels via screw pump to the dewatering conveyor. From the dewatering conveyor, the dewatered bark and waste are discharged onto the bark belt conveyor under the drum and mixed with the bark from the drum.

5. Chipping

Chip dimension, especially the thickness of the chips have a significant impact on the process and the result of pulping. Penetration in the pulping process depends on the specific surface of the wood chips. Water, heat and chemicals should be able to penetrate uniformly into the material. Disintegration during cooking is forced by diffusion. The longer the way for lignin to diffuse out of the chip, the longer the cooking time and the higher the risk of re-condensation (“black cooking”). To meet all the preconditions for good pulping results, an optimum chip size for softwood is approximately 25 mm of length and 4 mm of thickness, and 20 mm of length and 3 mm of thickness for hardwood. (FAPET, Wood handling, 2007) After debarking, the logs are transported by a chain conveyor to a roller case where they get washed by four high-pressure showers. The logs are also passing two stone traps, wherein the first one is connected to the stone conveyor that automatically empties the stone trap. Logs from the roller conveyors are fed via a belt conveyor equipped with a metal detector for protecting the chipper against ferrous material to the chain conveyor for chipper feeding. Detected logs are lifted out of the line with an overhead crane of knuckle boom loader. To enable a smooth log flow to the chipper, the chain conveyor is equipped with a spreading section. The chipper is of horizontal feed type, employs a multi-motor drive and has a side discharge directly to an equalizing bin mounted beside the chipper. The capacity depends on the log flow to the chipper and on the diameter of the logs. The chip level in the equalizing bin is controlled by a level indicator, based on capacitive function. There is a disc brake mounted on the chipper shaft for braking down the chipper for knife change and also a turning device for rotating the disk to the next position. The casing of the chipper is furnished with a hydraulically operated large access opening for maintenance and knife change. From the surge bin, the chips are discharged by a metering screw feeder at a constant output rate to chip conveying lines to feed them onto the storage piles.

6. Stacking

Chips received from two chipper dischargers are directed via the screw conveyor and receiving conveyors to the selected pile (to the softwood pile or to the hardwood pile). Stacker feeding conveyors transports the chips to the stackers and the piles. The piles (softwood pile and hardwood pile) are equipped with two identical stacker systems. The pile stacker is of rotary cantilevered design with a 360° rotation capability in order to build up a circular pile. The stacker is equipped with a travelling stacker conveyor. Stacking will be continuously controlled to build up the pile to the maximum level. As a safety feature for strong wind, the stacker is equipped with an anemometer with the following function.

Stop of pile feed conveyors and the stacker is automatically turned into an optimal position towards the wind when the wind is above 80 km/h (adjustable 50 ... 80 km/h).

7. Reclaiming

The piles (softwood pile and hardwood pile) are equipped with two identical reclaimer systems. Reclaiming of pile will be maintained by the automatic reclaimer system. The pile reclaimer is of rotary design with a 360° rotation capability in order to reclaim the chips on the basis of the first-in, first-out method with a 100% active volume rate. The reclaimer main frame is supported by the central wheel arrangement at the centre of the pile and by the drive / wheel arrangement at the circumference of the pile. A multi-supported reclaim screw travelling with the main frame is constantly moving the chips along the pile slab to the central hopper of the pile. A rake moving along the main frame ensures a constant flow of chip from the pile slope to the reclaim screw. The central hopper is level controlled and equipped with a multi screw discharger, which meters the reclaimed chips onto the chip reclaim conveyor. A lump breaker at the multi screw discharger breaks down the frozen lumps, which can arrive occasionally. Each of the chip reclaim conveyors (for hardwood chips and for softwood chips) transports the chips to the hardwood and softwood screening. The chip reclaim conveyor is equipped with a belt scale and magnet separator.

8. Screening

Hardwood screening:

Chips received from the pile reclaiming system are distributed by a distribution screw conveyor onto a chip screen. A two way chute in front of the distribution screw is responsible for the bypass of the screens, if necessary. The chip screen separates the chips into three fractions. The accept fraction is transferred by accept conveyors to the transfer point. Separated fines are transferred via a fines conveyor to the existing fines and bark handling system. Separated overs are sent via reversible oversize conveyors to the re-chipper, which blows the chips to the screen for re-screening or to the existing fines and bark handling system. After screening, the accept fraction is moved to the cooking plant by a conveying system.

Softwood screening:

In principle the softwood screening system is equal to the hardwood screening.

9. Sawmill chip handling

Saw mill chips are unloaded from self-unloading trucks and dumped directly into a receiving hopper. The receiving hopper is covered with a safety grate and equipped with a multi screw discharger. This discharger meters the chips to a disc screen (scalper screen) via a transfer conveyor in order to eliminate occasionally transported large impurities. The transfer conveyor is equipped with a magnet separator for ferromagnetic separation, a metal detector and a two way chute for non-ferromagnetic separation and a belt scale. Beyond the disc screen, the purchased chips are fed to the softwood pile.

4.1.2 Plant layout

Figure 4-1 illustrates the process flow in principle, without any details, and is based on layout drawings, flow sheets and P&I-drawings from Andritz OY, Finland and FMW Industrieanlagenbau GmbH, Austria. Bark handling and bark pressing, stone and waste handling, water piping, etc. are not displayed. More detailed drawings can be found in the appendix.

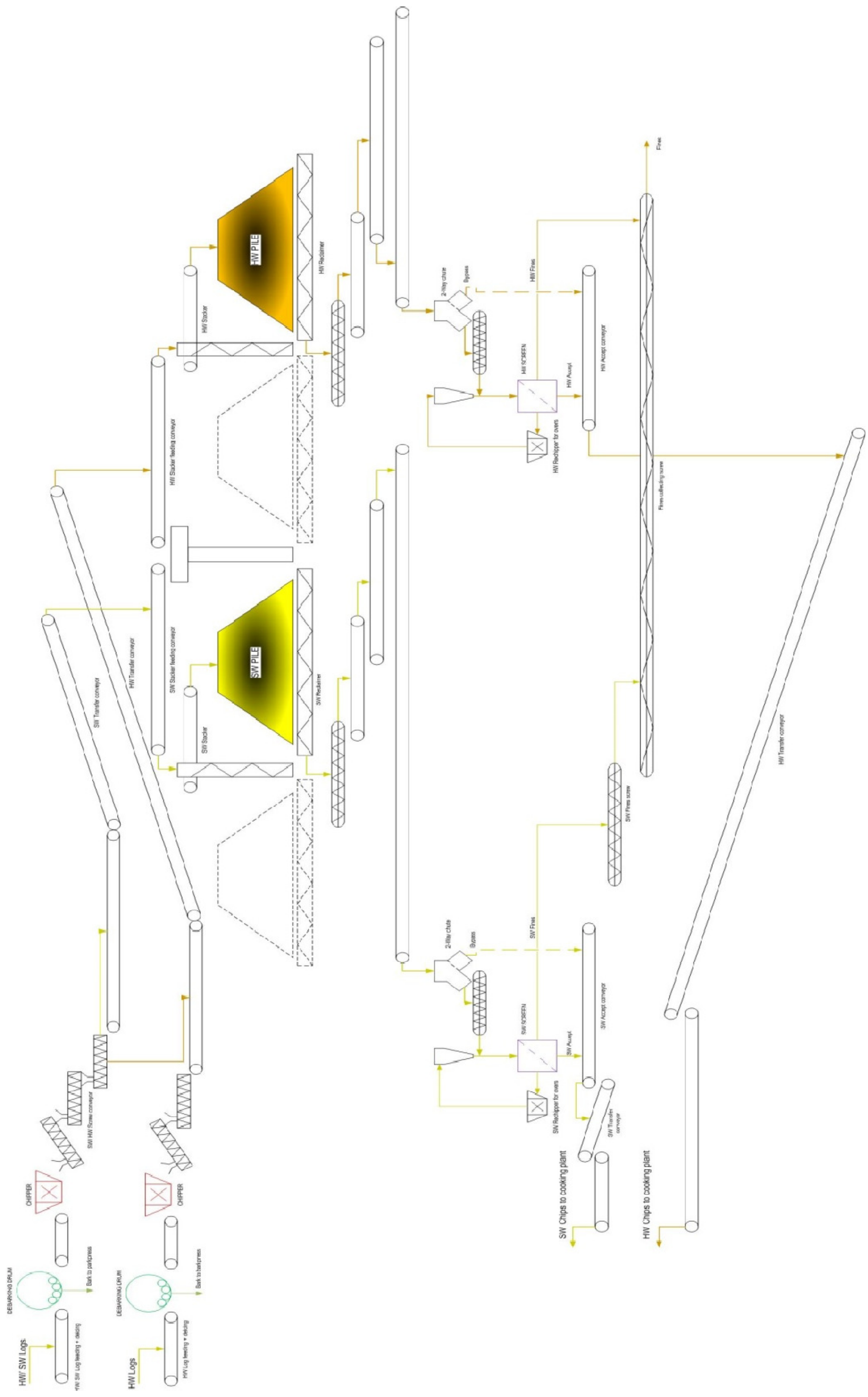

Figure 4-1: Principle flow sheet of the wood yard

4.1.3 Equipment

The wood yard at MSY consists of two debarking and chipping lines, one for hardwood and one for softwood. Two different storage piles (hardwood and softwood) are needed as well. Each pile has its own reclaiming system and the chips are moved to two screens. It is possible to bypass the screens in case of a break down. A connection to the existing wood yard is not designed.

Equipment	Capacity	Others
Deicing + debarking		
2 feeding-deicing conveyors	415 solid m3/h SW, 300 solid m3/h HW	
2 debarking drum	415 solid m3/h SW, 300 solid m3/h HW	Diameter 5,5 m; length 42 m
2 drum discharge conveyors	360 solid m3/h	
Chipping		
2 chipper feeding conveyors	360 solid m3/h	
2 horizontal feed chippers	360 m3/h	Disc diameter 3,8 m; 18 knives, electrical performance 4x315 kW, spout width 1010 mm (max. log diameter)
2 chip equalizing bins	32 m3	
2 screw conveyors	1200 loose m3/h	
2 dewatering conveyors		
2 belt conveyors with magnet separator		
1 central lubrication unit for debarking and chipping		
Bark handling		
2 bark shredders	135 loose m3/h	
2 bark presses	100 loose m3/h	

Equipment	Capacity	Others
Drives, gears, hydraulic units, cooling fans, stone traps, pumps, wet cyclone, etc.		
Stacking + storing		
Receiving screw conveyor SW	900 loose m3/h	
Conveyors to SW-pile incl. sawmill chips	1300 loose m3/h	
Receiving screw conveyor HW	2000 loose m3/h	
Conveyors to HW-pile	2000 loose m3/h	
2 pile reclaiming systems	1000 loose m3/h	
Softwood pile	124.000 loose m3	
Hardwood pile	142.000 loose m3	
Screening		
Transfer conveyors to screen-ing from each pile	1000 loose m3/h	
2 chip screens	800 loose m3/h	
2 conveying systems to cooking	1000 loose m3/h	
Drives, gears, screws, chains, belts, cyclones, etc.		

Table 4-1: Wood yard equipment at MSY

4.1.4 Plant profile

The following profile gives a brief overview of the situation and condition of the plant. It helps to characterize the plant without going into detail.

Plant/ equipment profile			
Determinate	**Score**		
Complexity	High	Middle	Low
Sensitivity to failures	High	Middle	Low
Interlinking internal	High	Middle	Low
Interlinking external	High	Middle	Low
Break down costs	Always high	Depending on duration of breakdown	Low
Key equipment	Yes	No	
Role of operation staff	Supervision	Active control	
Drive of technological development	High	Middle	Low
Level of load	High	Middle	Low
Risk potential	High	Middle	Low
Maintenance knowledge of operation staff	High	Middle	Low
Methodological knowledge of maintenance staff	High	Middle	Low

Table 4-2: Plant profile

The wood yard is a key equipment at the pulp mill. Its main functions are:

- making chips out of pulp wood (logs) and
- storing the chips to ensure a continuous production flow

In general all machines and devices at the wood yard are robust and solid in their construction. The internal and external interlinked equipment structures are reasons for paying sufficient attention by maintenance.

4.2 Experiences at other mills

The experiences at other mills in operating and maintaining wood yard equipment are some of the inputs to define key equipment (most important equipment) at the wood yard. The underlying questionnaire was focusing on maintenance in general and on maintenance at wood yard, evaporation plant and recovery boiler in particular. It was sent to the mills in Frantschach, Ruzomberok and Poels. A personal visit at these mills to directly discuss the topics was following. Just the information regarding wood yard was used for this work. Evaporation plant and recovery boiler are out of scope, and just important for Mondi Syktyvkar in general. The questionnaire can be found in the appendix. The results and reports of the mill visits and the survey are property of Mondi Group and will be not displayed within the current work. Just data related to wood yard maintenance are included.

4.2.1 Mondi Frantschach

Frantschach is located in the southern part of Austria. The mill specializes in packaging and kraft paper. Therefore the integrated pulp production needs long fiber pulp (soft wood) only.

Wood demand	1.100.000 solid m3/a	Softwood
Market pulp	55.000 t/a	Unbleached
Packaging paper	230.000 t/a	60 – 125 g/m2
Kraft paper	21.000 t/a	30 – 140 g/m2

Table 4-3: Key figures of Mondi Frantschach

A new wood yard was started up in 2007. This replacement investment was necessary because of cost reduction, quality improvement, production increase, and improvement of the environmental situation (e. g. surface water, noise emissions, etc.).

Equipment	**Capacity**	**Others**
Log loading section	290 solid m3/h	
Debarking drum	290 solid m3/h	Diameter 5,5 m; length 32 m
Chipper	250 solid m3 (without bark)/h	Disc diameter 3,3 m, electrical performance 4x400 kW, max. log diameter 850 mm
3 storage silos	27.000 solid m3	
Silo reclaimer	50 – 250 m3/h	Screw dimensions: diameter 1,1 m, length 18 m
Sawmill chip take over	1000 m3/h	12 truck loads per hour; 12 railway containers per hour
Round pile	30.000 solid m3	
Pile reclaimer	90 – 350 m3/h	Screw dimension: diameter 1 m, length 53 m
Screen		Thickness screen: disc distance 7 mm, Fine screen: disc dis-tance 0,7 mm

Table 4-4: Wood yard equipment Frantschach

There are several differences to the wood yard at MSY. Mondi Frantschach (MFR) is just using one line without a deicing conveyor. Also the capacities are much lower than at MSY. The technical principles are predominantly the same and notable differences in possible fail-ure modes cannot be found. From this point of few, a comparison of the two wood yards is allowed. Preventive and predictive activities are well developed at Mondi Frantschach. The total amount of measurement points for condition monitoring has increased from 5769 (in 2001) to 11541 (in 2006). There are 79 different monitoring routes in the mill.

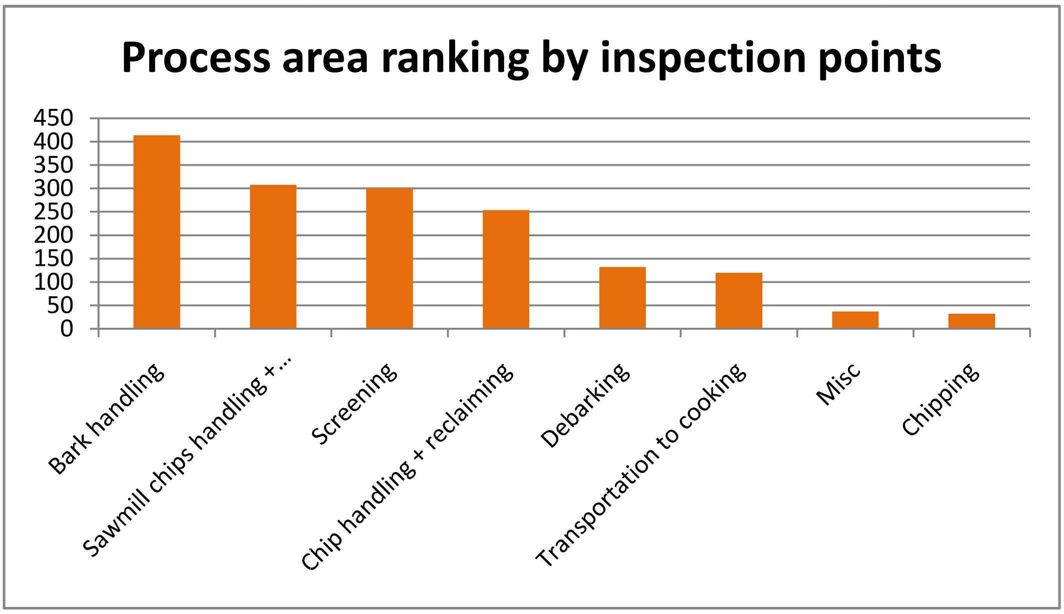

Figure 4-2: Ranking of process areas at MFR by inspection points

Visual and audio checks, condition monitoring (thermovision, infrared, vibration measurement) and lubrication actions are summarized in the amount of inspection points. The amount of electronic aided condition monitoring points is 70 for the whole wood yard. Bark handling, chip handling and screening are those areas with the highest effort on preventive and predictive activities.

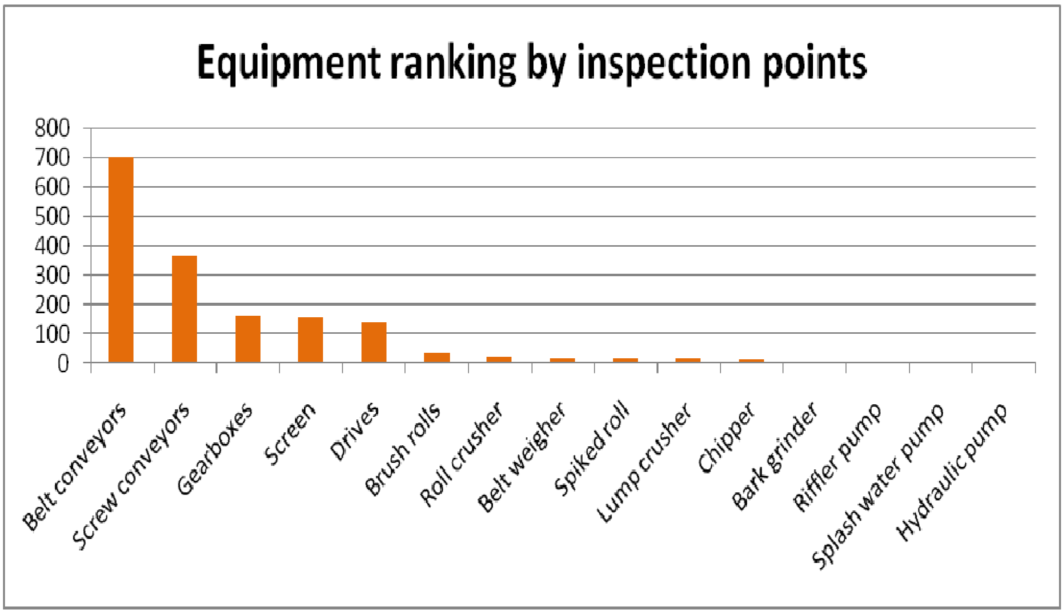

Figure 4-3: Ranking of equipment at MFR by inspection points

Conveyors are mainly rotating devices with a big amount of bearing. Therefore, the inspection and lubrication effort is very high in these areas.

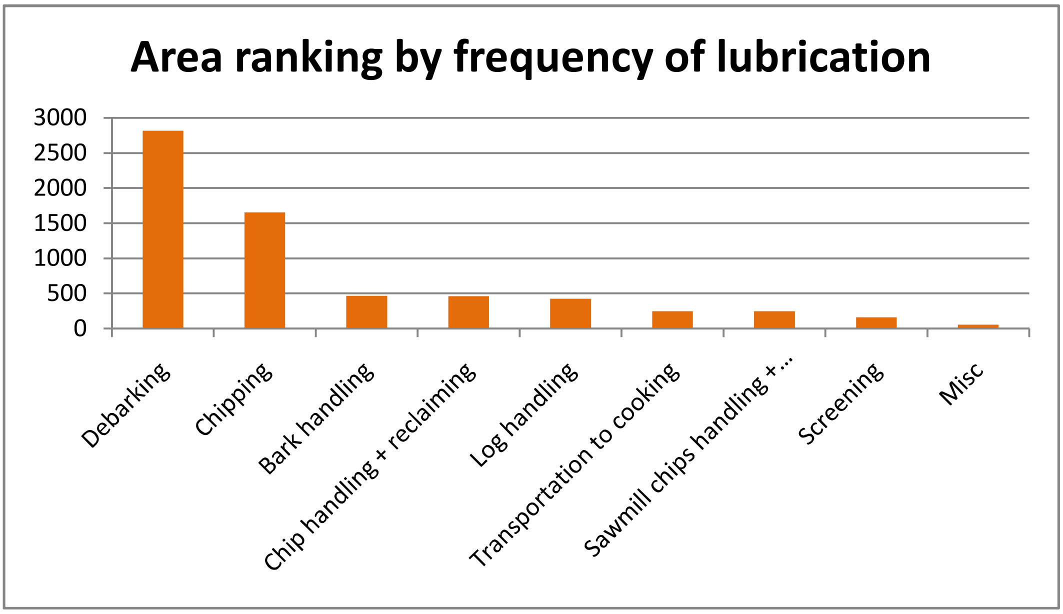

Figure 4-4: Ranking of process areas by frequency of lubrication

Most of the devices in the debarking area are treated by a central lubrication unit, gears and bearings for conveyors in the chipping area as well. The labyrinth bearing of the chipper has to be lubricated by hand on a daily basis.

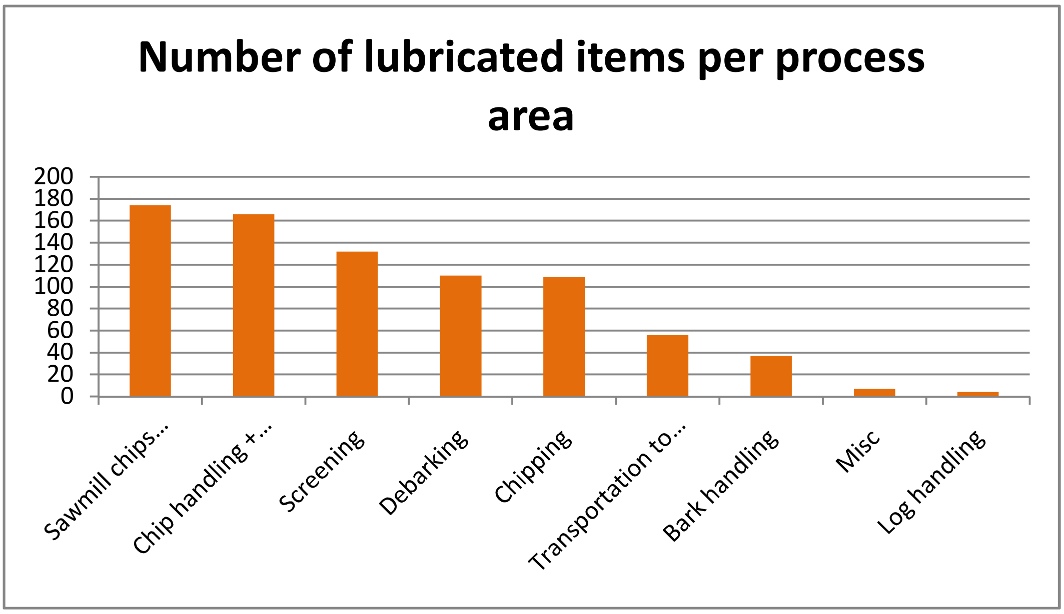

Figure 4-5: Lubricated items per area at MFR

Most items that need to be lubricated are in the chip handling areas, which consist mainly of belt conveyors, screw conveyors, etc. These rotating devices themselves are consisting of a big amount of bearings. Also the pile reclaimer and the silo reclaimer are part of the chip handling areas. Chips are moved to the screening by these devices. Thus they can be defined as key equipment.

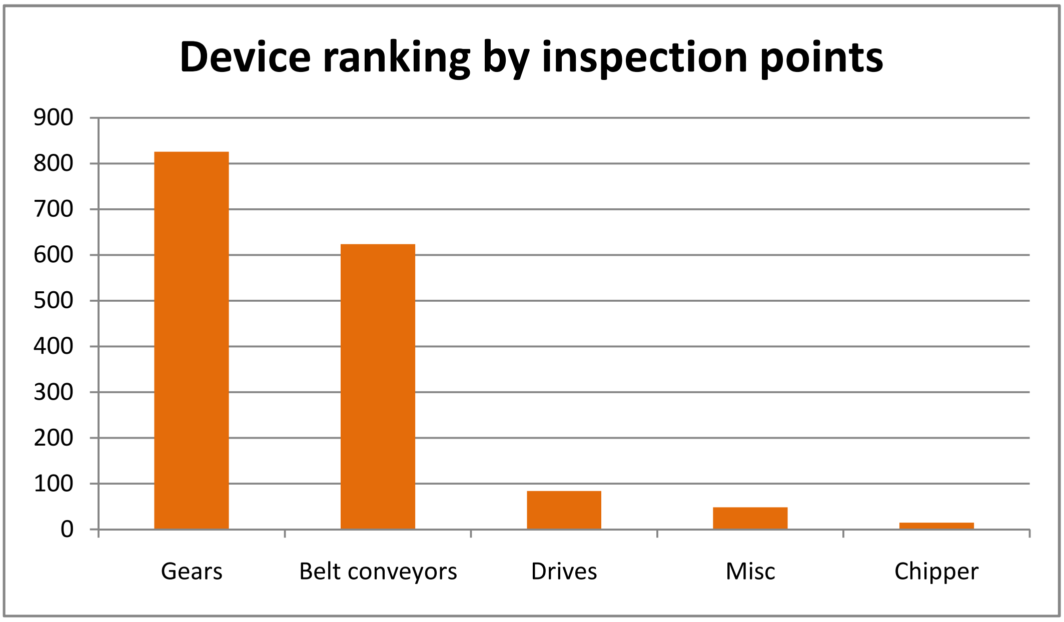

Figure 4-6: Ranking of devices by inspection points at MFR

Gears and drives are the most inspected devices in the process, together with belt conveyors. This is not surprising, since these devices also represent the highest amount of rotational equipment at a wood yard.

4.2.2 Zellstoff Poels

Zellstoff Poels is located in Austria and is the largest manufacturer of elemental chlorine free (ECF) bleached softwood sulfate pulp in Central and South East Europe. (Pöls, 2007)

Wood demand	2.000.000 solid m3/a	Softwood
Market pulp production	400.000 t/a	
Kraft paper	14.000 t/a	40 – 140 g/m2

Table 4-5: Key figures Zellstoff Poels

Zellstoff Poels has a KPI-controlled maintenance concept, with a strong focus on planning, condition monitoring, and root cause analysis. Total Productive Maintenance (TPM) principles are partly in use. The operators at the wood yard (49 employees) are doing the machine care (e. g. recommended service) and the inspection work (including all vehicles). The maintenance department is just called for repair work. 7% of the total maintenance costs can be allocated to wood yard maintenance. It must be considered that maintenance costs are not the same as repair costs. Repair costs are expenses just for repair and replacement work, and are one part of the maintenance costs.

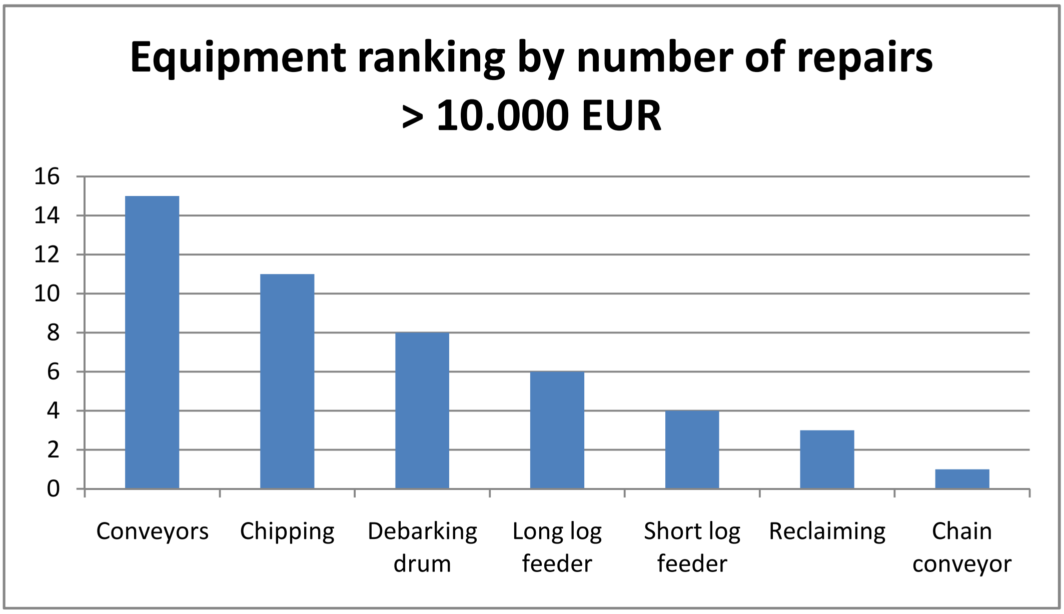

Figure 4-7: Ranking of equipment by the number of repairs at Zellstoff Poels (1999 – 2009)

Conveyors, most of whom are in the chip handling area, have a lot of wear parts which have to be changed at certain times. Drives and gears have caused most of the repair work at the chipper.

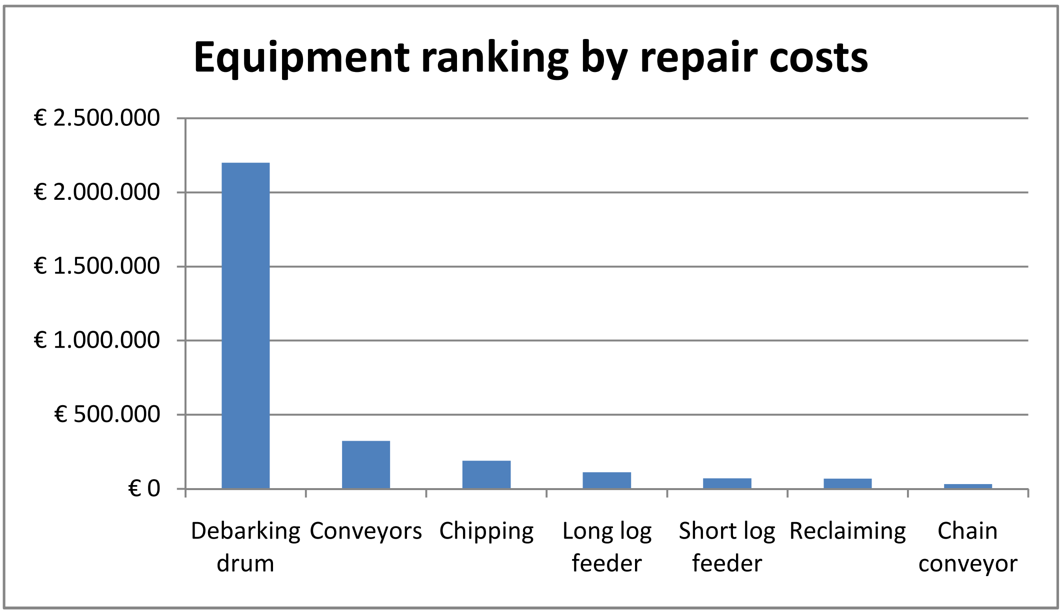

Figure 4-8: Ranking of equipment by repair costs at Zellstoff Poels (1999 – 2009)

The high costs at the debarking drum are due to the replacement of the first drum section in 2005.

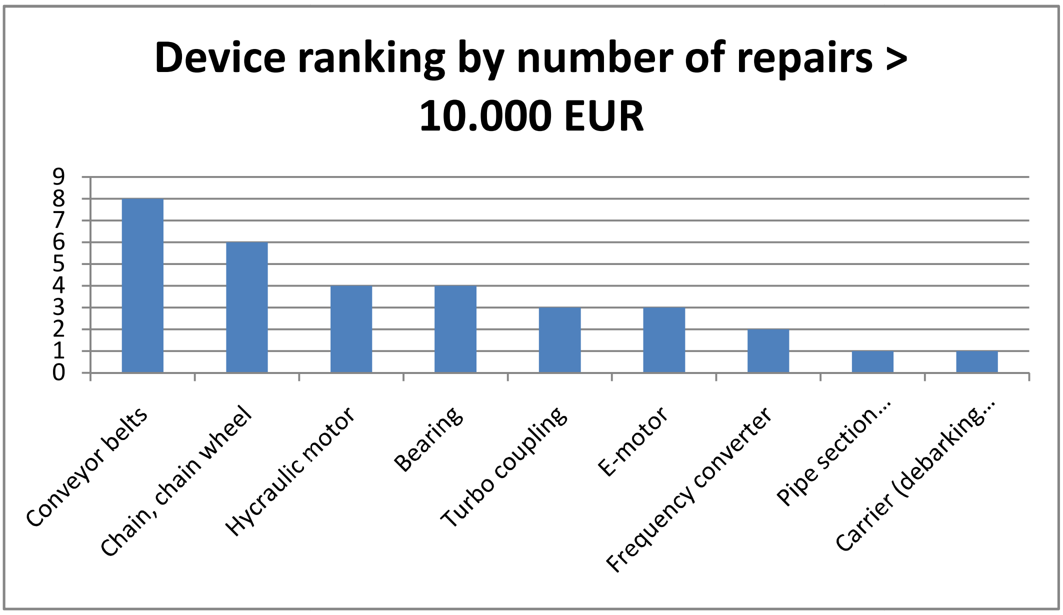

Figure 4-9: Ranking of devices by repair frequency at Zellstoff Poels (1999 – 2009)

There are a lot of wear parts at conveyors that have to be replaced at certain times. Thus it is almost clear to have high repair costs at these devices and items.

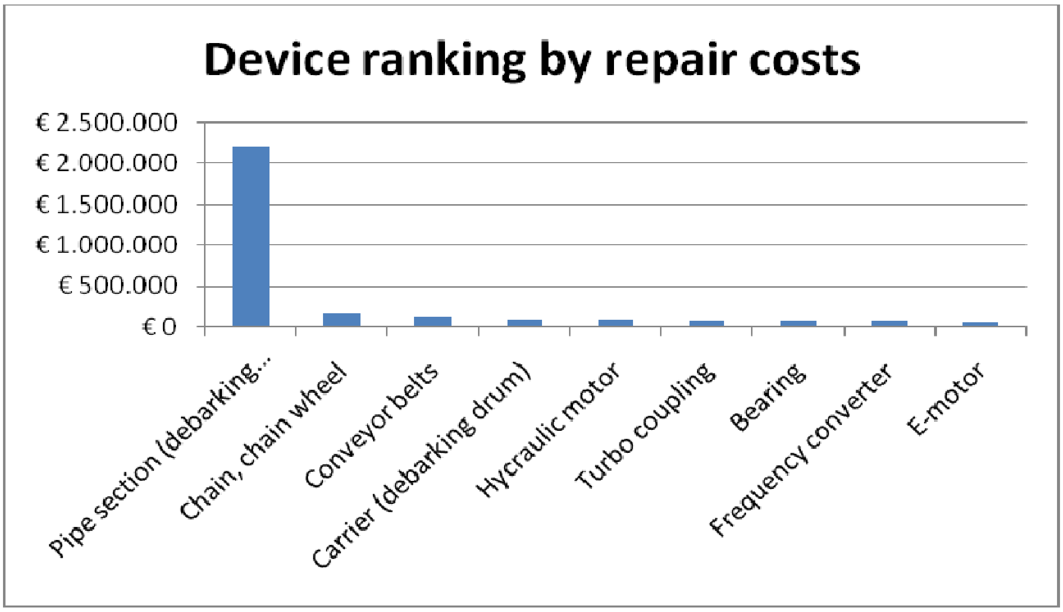

Figure 4-10: Ranking of devices by repair frequency at Zellstoff Poels (1999-2009)

Zellstoff Poels defines the chip conveyors (after the screen) to the cooking plant as key equipment. In case of failures at these conveyors, there is too little buffer time between the plants to ensure an undisturbed cooking process.

4.2.3 Mondi Ruzomberok

Mondi Ruzomberok (MRU) is located in Slovakia. The wood demand can be split into 88% hardwood (HW) and 12% softwood (SW). Most of the wood is delivered by trucks.

Wood demand	2.000.000 solid m3/a	Softwood, Hardwood
Pulp production	450.000 t/a	
Wood free printing paper and cardboards	40.000 t/a	100 – 300 g/m2
Wood free printing paper	140.000 t/a	60 – 100 g/m2
Wood free office paper	330.000 t/a	70 – 90 g/m2

Table 4-6: Key figures Mondi Ruzomberok

The mill is using a well developed maintenance concept, which is the result of different projects to optimize and simplify the maintenance organization. Each business unit (wood yard, recovery line, etc.) has its own maintenance department with full responsibility (directives, costs), which gets support from a central maintenance department in diagnostics, special repair (welding) and covering higher demand on personnel. Central maintenance is also responsible for planning and scheduling the regular shut downs. Wood yard maintenance department: 1 maintenance department manager, 4 blue collar people (2 electrical, 2 mechanical), but only in the morning shift.

Equipment	Capacity	Others
Feeding section	340 solid m3/h	
Debarking drum	340 solid m3/h	Diameter 5,3 m; length 39 m
Bark crusher	250 loose m3/h	
Chipper	340 solid m3/h SW, 280 m3/h HW	Disc diameter 3,3 m, max. log diameter 700 mm
Stacker HW	1.500 loose m3/h	
Round pile HW	170.000 loose m3	
Reclaimer HW	730 loose m3/h	
Stacker SW	1.500 loose m3/h	
Round pile (so)	58.000 loose m3	
Reclaimer SW	730 loose m3/h	
Belt conveyor to screening	730 loose m3/h	
Screen	730 loose m3/h	Surface 3 x 26 m2
Thickness screen	400 loose m3/h	
Silo (between screening and cooking)	500 loose m3	Buffer time approximately 30 min
Belt conveyor to cooking	1200 loose m3/h	

Table 4-7: Wood yard equipment Ruzomberok

If one of the equipment (e. g. conveyor, debarking drum, chipper, ...) in front of the chip screening is broken, there are chips for 11 days (on average) on the pile to feed the pulp production. Mondi Ruzomberok is defining the chip screening as critical to be a bottleneck. The buffer time between chip screen and cooking plant is about 30 minutes. The old chip screen is available to bypass the new screen if it is broken, but then the process has to run with lower capacity. A break down with impact on the pulp production occurs one to two times a year. One to two times a day, the chip screen has to be cleaned. This work takes approximately 20 minutes. The chipper itself is very sensible to loadings of hardwood logs with bigger diameters. The higher weight of these logs is pressing on the disk under vibrations. Thus the knife encounters the counter blade, which can result in damages on bearings. The required repair work takes 12 hours with 6 people. This happens once a year. Approximately 70% of the maintenance hours at the wood yard are from preventive maintenance activities. A criticality analysis detected the equipment shown in the following table as most critical.

Equipment	Device
Log feeding conveyor	
Debarking drum	Drives
Bark crusher	
Chipper	Chains inside of chipper discs
	Hydraulic unit of chipper
Belt conveyor to cooking plant	

Table 4-8: Critical wood yard equipment at MRU

One of the reasons of high criticality is the long delivery time for spare parts, which can be more than one month for some items. In the past, the debarking drum had the highest repair costs because of cracks in the shell of the drum, but in summer 2009 the drum was replaced.

4.2.4 Most important process areas

It was not possible to get directly comparable data from the mills. Their maintenance reporting systems and data evaluation by the controlling department are different. To figure out the areas to which maintenance pays the most attention (inspection, lubrication, repairs), ranking results from other mills were used and a weighting systems of the areas was applied. The lower the position in rankings, which means more efforts by maintenance, the higher the weighting of the area (place 1 = 5, place 2 = 4, place 3 = 3, place 4 = 2, place 5 = 1). The weighting points are summarized by each area. The percentage of weighting points an area has achieved from the whole sum of weighting points, is now defining the “importance” of the area.

Process step (area)	MFR Insp.	MFR Lubr.	MFR lubr. Items	ZP nr. of rep.	ZP rep. costs	MR U	Weigthing sum	Ran-king %
Debarking	3	5	3	3	5	3	**19**	**17**
Stacking + storing	3	3	3	5	4	0	**18**	**16**
Chipping	2	4	3	4	3	3	**16**	**14**
Transportation to cooking	3	2	2	5	4	3	**16**	**14**
Reclaiming	4	3	5	2	0	0	**14**	**13**
Screening	4	1	4	0	1	0	**10**	**9**
Log feeding + dei-cing	0	3	1	3	2	3	**9**	**8**
Bark handling	5	3	1	0	0	3	**9**	**8**
Sum							111	100

Table 4-9: Attention by maintenance on process areas – “importance”, in Frantschach, Poels and Ruzomberok

The most important areas of these three mills (Frantschach, Poels, Ruzomberok) from the maintenance point of few are debarking, stacking + storing, chipping and transportation to cooking.

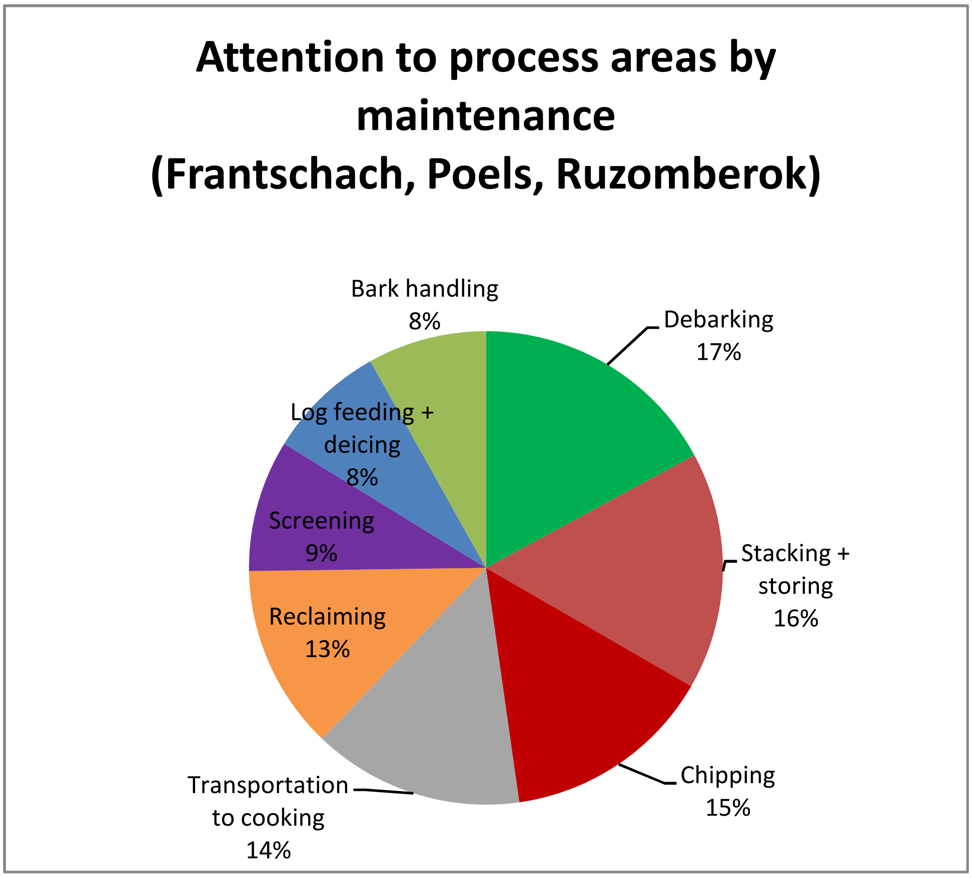

Figure 4-11: Attention by maintenance on process areas – “importance”, in Frantschach, Poels and Ruzomberok

4.2.5 Most important equipment

With data available, it was not very easy to determine the “importance” of equipment and/ or devices. In general, there is a big amount of (belt) conveyors with gears and drives at the wood yard, so these equipments are obviously very often treated by maintenance.

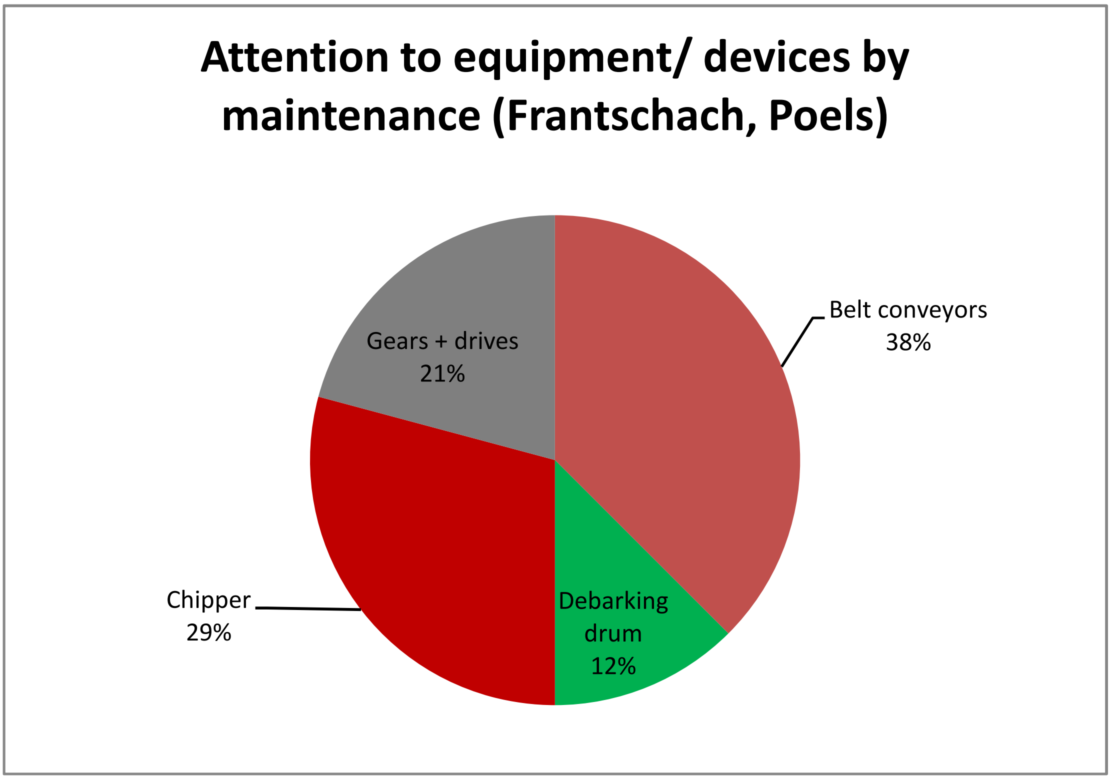

Figure 4-12: Attention by maintenance on equipment – "importance", Frantschach, Poels

The number of belt conveyors in the stacking area and the transportation to the cooking area is very high. So this result fits to the importance of process areas. The same applies to the chipping area.

A mill in Fernandina Beach (United States) has developed 83 condition monitoring routes for its wood yard and pays its attention to each area as follows: log system 19%, bark system 7%, chip system 20% and screening 53%. (Brown, 2004) This example and the results identified by the author show that there is no univocal strategy in setting priorities in maintenance on the wood yard.

4.3 Preselection of critical equipment

It was assumed by Mondi Syktyvkar that the production is running on full capacity and that the process is stable: Continuous loading of logs on the feeding conveyor, full piles and continuous chip demand of the cooking plant. Several (layout) drawings and design information used in this work are property of the Mondi Group. Any kind of use, copy or distribution is forbidden.

4.3.1 Risk assessment by Turnbull

Process step (area)	Potential failure mode	Potential effect of failure	Im-pact	Likeli-hood	Motivation for evaluation	Risk factor
Log feeding + deicing	Chain conveyor doesn´t work	No logs to debark-ing drum	D	W	Robust construc-tion, no complex parts, easy to re-pair, simple availa-ble spare parts	**3**
Debarking	Debarking drum doesn’t work	No logs to chipper	C	W	Robust construc-tion, high repair effort, eventual weak spare part availability	**4**
	Drum discharge conveyor doesn’t work	No logs to chipper	C	W		**4**
Bark handling	Bark conveyors don’t work	No bark removed from debarking drum	D	W	No heavy loads, no complex parts, easy to repair, simple available spare parts	**3**
	Shredder doesn’t work	Bark is not crushed	E	W	No heavy loads, no complex parts, easy to repair, simple available spare parts, bark will be still removed from the wood room - process is not dis-turbed	**2**
	Bark press doesn’t work	Bark ist not pres-sed	E	W	No heavy loads, no complex parts, easy to repair, simple available spare parts, bark will be still removed from the wood room - process is not dis-turbed	**2**
Chipping	Feeding con-veyor doesn’t work	No logs to chipper	D	W	High repair effort, enough buffer ca-pacity (chips for min 10 days on pile) after chipper	**4**

Process step (area)	Potential failure mode	Potential effect of failure	Im-pact	Likeli-hood	Motivation for evaluation	Risk factor
	Chipper doesn't work	No chips produ-ced	C	W	Heavy loads, high repair effort, even-tual weak spare part availability, enough buffer ca-pacity (chips for min 10 days on pile) after chipper	**5**
	Screw conveyor doesn't work	No chips to pile	D	W	No heavy loads, robust construction	**3**
	Belt conveyor doesn't work	No chips to pile	D	W	No heavy loads, simple construction	**3**
	Central lubrica-tion unit doesn't work	Bearings are not lubricated	E	W	Chipper has to be stopped in certain intervals (approx. once per shift) for knife change, dur-ing this time bear-ings can be lubri-cated by hand	**2**
Stacking + storing	Stacker feeding conveyor doesn't work	No chips to pile	D	W	No heavy loads, no complex parts, simple spare parts	**3**
	Pile stacker doesn't work	No chips to pile	D	W	No heavy loads	**3**
	Stacker conveyor doesn't work	No chips to pile	D	W	No heavy loads	**3**
Reclaiming	Reclaimer doesn't work	No chips to screen	C	W	No heavy loads, a lot of drives, rotat-ing and electric equipment	**4**
	Screw discharger doesn't work	No chips to screen	C	W	No heavy loads, a lot of drives, rotat-ing and electric equipment	**4**
Screening	Transfer con-veyor does't work	No chips to screen	D	W	No heavy loads, no complex parts, easy to repair, simple available spare parts	**3**
	Two-way chute doesn't work	Bypassing the screen is not poss-ible	E	W	No complex parts, no heavy loads, not so frequently in use	**2**

Process step (area)	Potential failure mode	Potential effect of failure	Im-pact	Likeli-hood	Motivation for evaluation	Risk factor
	Screen doesn’t work	Chip size not ideal	C	W	A lot of rotating and oscillating parts, possibility to bypass the screen	4
Transportati-on to cooking	Belt conveyors don’t work	No chips to coo-king	C	W	No heavy loads, easy to repair, sim-ple available spare parts, bottleneck	4

Legend: A=1 month breakdown, B=1 week, C=1 day, D=Reportable, E=Minor, V=>10 years, W=Annual, X=Monthly, Y=Weekly, Z=Daily

Table 4-10: Risk assessment of process areas by Turnbull

The process steps that can be defined as most critical are debarking, chipping, reclaiming and transportation to cooking. There is little difference in the risk value between these areas, and none of them requires high interest by maintenance.

4.3.2 Risk assessment by risk portfolio

Process step (area)	Potential effect of breakdown	Consequence	Probability	Explanation
Log feeding + deicing	No logs to debarking drum	2,5	2	Less repair effort. During standard production situation enough chips on pile.
Debarking	No logs to chipper	2,5	3	Could be high repair effort. Complex parts (e. g. drives for debarking drum). During standard situation enough chips on pile.
Bark handling	No bark removed from debarking drum	3	1,5	No complex parts. Easy to repair. During standard situation enough chips on pile. Interruption of process possible.
Chipping	No chips produced	3	3,5	Heavy loads. Could be high repair effort. During standard situation enough chips on pile.
Stacking + storing	No chips to pile	3	2	A lot of rotating equipment. Big stack height. High loads because of wind and snow.

Process step (area)	Potential effect of breakdown	Consequence	Probability	Explanation
Reclaiming	No chips to screen	5	3,4	Could be high repair effort. A lot of drives, rotating and electric equipment
Screening	Worse chip quality	4	2	Could be high repair effort. A lot of rotating and oscillating parts. Negative impact on chip quality. Possible impact on cooking process. Can be bypassed.
Transportation to cooking	No chips to cooking	5	3	Less repair effort. Can stop the whole pulp production.

Table 4-11: Criticality evaluation for risk portfolio

The results of the risk evaluation process are transferred to the risk portfolio or criticality matrix.

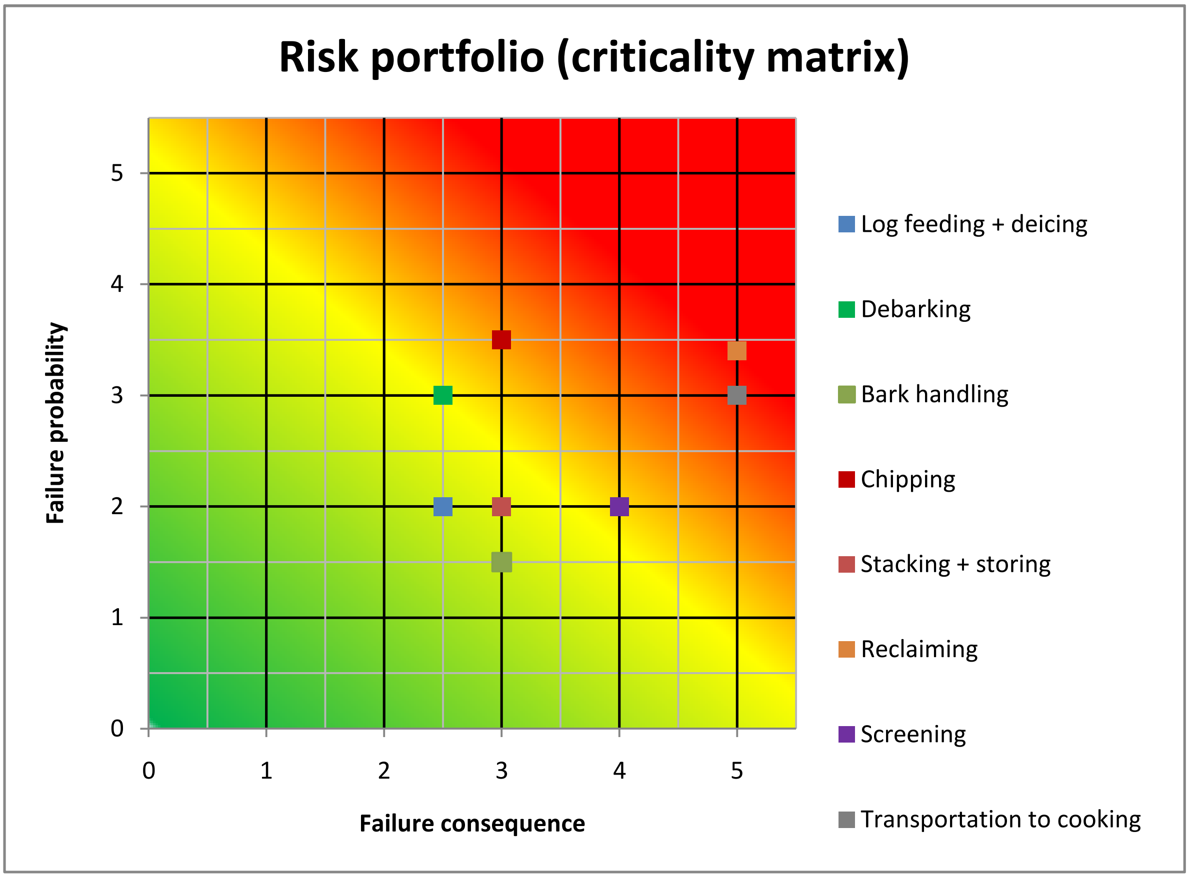

Figure 4-13: Criticality matrix

Now it was possible to identify those process areas with the highest priority for maintenance. Reclaiming and transportation to cooking are most crucial. If the plant is operating under stable design conditions, there are enough chips on pile so that the pile can fulfill its buffer function.

Design data:

HW-pile storage capacity: 142.000 loose m3

Reclaimer: 613 loose m3/h, 24 h operating time

Resulting buffer time: approximately 9,5 days

Maintenance has almost 10 days to repair and fix the break down or failure in front of the piles, without any remarkable influence on the pulp production.

The decision was made to concentrate on those areas by FMEA. As these areas are installed twice (one for SW, on for HW) in nearly the same structure, it is enough to do detailed analysis just for the HW-line.

4.4 FMEA (example): Pile reclaiming system

The following FMEA is just an example of how to use this analysis tool. In general a FMEA is a detailed part of criticality analysis. It should be carried out by a team of experts in operation, maintenance, technology, construction, etc. It was planned to initiate a workshop with experienced people at Mondi Syktyvkar. Because of time reasons and lack of personnel resources it was not possible to do the FMEA together with a team. So the following FMEA was done by the author without assistance. Nevertheless teamwork is strongly recommended.

4.4.1 Operating conditions

Working time: 350 days per year, 24 h per day, 8.400 hours per year

Temperature: -36 °C to +35 °C

4.4.2 Constituent parts

- Reclaimer: To reclaim the chips from the pile and move them to the hopper in the center of the pile into the discharge screw. It is assembled with a rake which is constantly moving along the pile to scrape off the chips. The chips trickle to the screw shaft which moves them to the hopper.
- Electrical equipment for reclaimer
- Screw discharger: To transport the chips out of the hopper to the reclaim conveyor.
- Lump breaker: Is situated above the outlet of the screw discharger. It breaks down frozen lumps of chips.
- Reclaim conveyor: To transport the chips from the screw conveyor to the transfer conveyor.
- Belt scale: To measure the amount of chips reclaimed from the pile.
- Magnet separator: Is situated above the drive drum of the transfer conveyor. It separates magnetic materials from the chips.
- Transfer conveyors: To transport the chips to the two-way-chute in front of the screen.

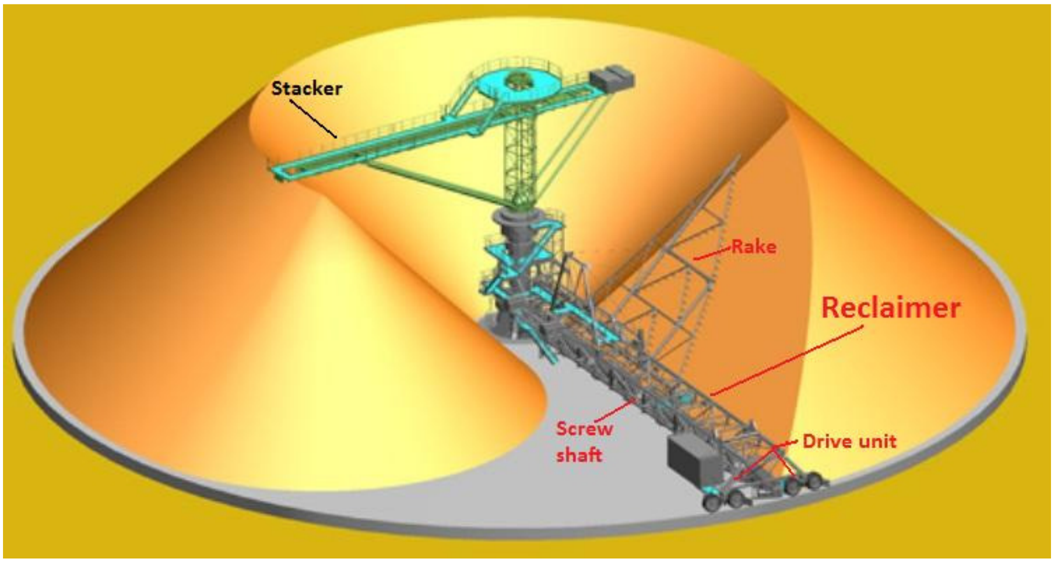

Figure 4-14: Pile stacking and reclaiming system (FMW)

4.4.3 Functional structure

A functional structure and detailed drawings of the reclaiming system can be found in the appendix and on the enclosed CD-ROM.

4.4.4 Analysis table

Failure analysis and risk evaluation are done according to the established scheme in table 3-4 and figure 3-5. Strategies are developed according to table 3-5 and table 3-6.

Item Nr.	Function	Potential failure mode	Potential cause					Potential effect of failure	Severity (S)	Occurrence (O)	Detection (D)	Criticality	RPN	Costs	Criticality rating	Strategy	Task
			Why 1	Why 2	Why 3	Why 4	Why 5										
1000-1350-27-131	Reclaimer	Drive unit is not working	Squirrel case motor (pos. 40/45, 40/46) is not working	No power to motor	No elec-trical connection	Cable connection loose		Reclaimer stops	4	1	1	4	4		B	OEM recommendation sufficient. Preventive: Check cable connections during routes	Check cable connections during routes
			Squirrel case motor (pos. 40/45, 40/46) is not working	Motor over-heated	Motor overloaded	Chips jammed between drive roll	Scraper mounting lose	Reclaimer stops	4	1	1	4	4		B	OEM recommendation sufficient; preventive actions require high efforts	Check scraper mounting from time to time
			Squirrel case motor (pos. 40/45, 40/46) is not working	Motor over-heated	Motor overloaded	Running wheel broken	Crack in running wheel	Reclaimer stops	4	1	1	4	4		B	OEM recommendation sufficient; preventive actions require high efforts	Visual check of the condition of the running wheel
			No power transmission to running wheel	Sprocket belt pulley is not working	Sprocket belt broken			Reclaimer stops	4	1	1	4	4		B	OEM recommendation sufficient; preventive actions require high efforts	Visual check of condition of the sprocket belt during regular inspection routes
			Helical gear motor is not working	Planetary gear is not working	Tooth clutch is not working	Power supply interrupted		Reclaimer stops	4	1	2	4	8		B	OEM recommendations sufficient	Check cabel connections from time to time
		Drive unit is not working without interruption	Helical gear motor is not working without interruption	Planetary gear is not working without interruption	Tooth clutch is not working without interruption	Tooth clutch is dirty		Reclaimer works with interruptions	1	1	2	1	2	1	C	RTF; No planned activities; Awareness of guarantee requirements	Cleaning of tooth clutch during regular inspection routes
	Reclaimer-screw shaft	Drive unit is not working	Sprocket belt broken					Screw shaft stops	4	2	1	8	8		A	Preventive actions	Visual inspection of condition of the sprocket belt, daily
		Leckage at counter shaft	Leckage at floating bearing	Adapter sleeve and V-ring don't seal enough	Contact surface between shaft and ring wear out			Loss of lubricant, high abrasion and wear out, break down or sudden stop possible after some time	4	1	1	4	4		B	OEM recomendation sufficient	Visual inspection of bearing and sealing during regular inspection routes
		Drive unit is not working	Sprocket belt is not running	Sprocket belt pulley is not working	Motor overloaded	Chips and/ or lumps jammed in the screw	Very low temperatures, frozen pile	Screw shaft stops	4	1	1	4	4		B	OEM recommendation sufficient	
	...	...	...	...	...	...	...	...				0	0				

Table 4-12: FMEA sheet for pile reclaimer

The drive unit for the reclaimer screw shaft is marked as criticality "A". The device requires more attention by maintenance than it is recommended by the OEM. Regular preventive activities and inspections should be done. The condition of the device should be recorded in the CMMS.

The FMEA-table above is also available as an Excel-File on the CD-ROM enclosed.

5 Conclusions and recommendations

5.1.1 Lessons from other mills

Mondi Frantschach has well developed inspection and lubrication plans and routes. The mill has a strong focus on condition monitoring. A criticality analysis was still not done at the Frantschach mill. Maybe this is the reason for the big effort in lubricating the bark handling area, which is not crucial for the process. Obviously there is no reason for this big preventive effort in an area which can be treated partly with a run-to-failure strategy (criticality matrix: transition zone green to yellow).

Mondi Ruzomberok has a well functioning maintenance organization and also applied a criticality analysis for the whole mill. The results of this analysis at the wood yard are not congruent with the results of the analysis for Mondi Syktyvkar. If the bark crusher is an equipment of highest priority for maintenance, one should think about a re-design to lower the influence on the production flow by a break down in this area.

If the piles are full, a breakdown of equipment in front of the piles does not influence the production for at least one week. This should be enough time for a maintenance organization to solve the problem, also from a spare part point of view. An empty pile will result in too little time for decomposition of resin during storing. In case of kraft pulping, this impact should be negligible.

At Zellstoff Poels, a criticality analysis of the mill equipment was done, an equipment structure was determined and a detailed breakdown and repair reporting is in use. A big issue for the mill in Poels is the planning and scheduling of maintenance activities.

Potentials:

- Definition of an equipment structure and integration in the CMMS
- Development of a reporting procedure (required data, forms, etc.) and integration in the CMMS
- CA for the whole mill equipment to concentrate on the right equipment with adequate effort
- Strengthen planning and scheduling and utilize the CMMS for these tasks

5.1.2 Lessons from criticality analysis

If the piles are full, which is the case during standard operation, just the equipment after the pile can be critical. The pile reclaiming system is a key element of the process and is absolutely necessary to move the chips from the storage to the chip screen. The chip screen itself can be bypassed in case of a break down. This will ensure a continuous flow to the cooking plant, but will also have a negative impact on the cooking process. A high content of overs can result in incomplete digested wood material, whereas a high content of fines can plug the digester. The next critical aggregate are the conveyors after screening, which transport the chips to the cooking plant. It is recommended to apply a FMEA to the full conveying system to the cooking plant. It should involve the items 1000-1350-27-155, -156, -157 and 1000-1350-27-165, -166, -167.So it is not necessary to put high effort in maintaining devices in front of the piles; it is sufficient to follow the OEM recommendations. After the guarantee period is over, it is also possible to stay below these recommendations for the feeding and deicing conveyor and the bark handling area. Debarking drums and chippers are of significance for the chip quality and should always be treated as recommended by the OEM.

The Turnbull approach is unsuitable for an equipment related risk or criticality evaluation. It is too little to measure the criticality just by likelihood and time based effects. The dimension of the analysis has to be extended to cover all the parameters which can have critical effects: SHE, availability, speed and quality. One can also go further and try to develop a risk evaluation model by a holistic approach, which is considering all stakeholders.

Until today, no one has noticed maintainability and serviceability as single parameters with influence on criticality. Improved maintainability optimizes inspection and repair effort and will help to reduce fixing time. It would be a big advantage for equipment manufacturer and user to dispose of an assessment model for maintainability and serviceability and its impact on criticality. There is a possibility for future research.

Potentials:

- Identification of key equipment
- Optimization of maintenance effort and strategy development
- Consideration of SHE, availability, speed and quality
- Consideration of maintainability
- Identification of improvement potentials on plant layout and equipment design

5.1.3 Lessons from FMEA

Severity is the parameter with the biggest impact on criticality. To weaken the severity, which means lowering the severity rating, big efforts in redesign and reconstruction are needed. For maintenance it is not easily possible to lower the severity. The convenient way of taking influence on criticality by maintenance is by the parameter of occurrence and detection. This leads directly to preventive and predictive maintenance. The success of these actions set by maintenance must be checked by a review of the FMEA or at least of the risk evaluation part.

I propose to extend the FMEA to evaluate the responsibilities for the failure mode and its prevention and detection. Competencies between operations and maintenance must be clear. It will not make sense to hand over the full responsibility for each failure to the maintenance department. A helpful question can be: Who can prevent, detect or correct the failure in the most (cost-) efficient way?

To realize and implement a FMEA, it is absolutely necessary to have a team with experience in maintenance and operation of the equipment. By using this equipment knowledge and brainstorming techniques, the yield of possible failure modes will be much higher than by doing it as a single person. The team approach will also avoid subjective assumptions during the risk evaluation.

Potentials:

- Risk based strategy development
- Review and measurement of results
- Determination of competencies and responsibilities
- Assignment of tasks
- Teamwork between operations, maintenance, technology, etc.
- Detailed investigation of spare part availability and estimation of fixing times

5.1.4 Lessons for maintenance management

In the course of this work it was possible to get an overview of several maintenance organizations. Obviously, maintenance is seen as a “necessary evil” by corporate management and by operations. Maintenance needs to entitle itself a key partner for the operational department to fulfill its tasks. If the corporate goal can be simplified as “making profit by satisfying the customer”, the mission statement of the maintenance organization should be “enable the operational department to produce satisfying products (pulp and/ or paper)". Operations and maintenance should define themselves as partners. Maintenance should supply equipment reliability, whereas operations should supply process reliability. Maintenance costs are related to how the equipment is used, so the responsibility for these expenses is at the operations department. Optimizing maintenance costs means providing equipment reliability and asset preservation in the most cost-effective way. This implies also a lifecycle oriented maintenance strategy development, a detailed reporting system and a high amount of planned work. The latter two will also help to improve safety during maintenance activities.

Potentials:

- Maintenance mission statement based on corporate goals
- Operations and maintenance as a partnership
- Operations (e. g. business unit) responsible for maintenance costs
- Lifecycle orientation in strategy development and budgeting
- Detailed breakdown and repair reports (conditions, loads, detection, historical data, drawings, manuals, evaluation, causes, repair, etc.)
- Increase of planning degree

5.1.5 Future project ideas

Standards for maintenance manuals:

A review of the maintenance manuals delivered by the OEM during this work displayed some weak points in structure and content. For big industrial projects and also for the OEM, a well developed standard for maintenance manuals would help to save time in commissioning, operating and maintaining complex pants and equipment.

Plant knowhow center:

Operations personnel, technologists and maintenance personnel are collecting information and experiences about processes and plant equipment separately. It would generate big advantages for operating and maintaining existing equipment and also for future investment projects, if each of these partners would share their knowledge by creating "plant knowhow centers": regular meetings, CMMS support, etc.

Criticality database:

The results of each criticality analysis at each mill or site should be stored in a central database. It would be an ease for reliability engineers to evaluate or estimate criticality factors for certain equipment or devices.

Methodology training:

The maintenance staff is often not familiar with maintenance terms and their implication on the daily work. It is recommendable to develop a knowledge and mindset training concept for the maintenance staff as well as for the corporate management.

Chipper knife lifetime and conditions of logs:

A detailed analysis of the lifetime of a chipper knife according to the water content of logs (fresh wood, dry wood) and its effect on wood yard maintenance and wood room availability can be done. The results of this investigation should be considered in a new CA of the wood yard.

Influences of low temperatures on operations and maintenance:

The mill is operating during winter for approximately 6 months, whereof 2 months have very low temperatures. It should be observed and recorded in which way the conditions during winter time are influencing the equipment and the process. This information should be considered by maintenance engineering.

Training for "extended" condition monitoring by operations staff:

The operators should be trained to use the data and information delivered by the DCS (distributed control system) as references to the current condition of equipment and devices.

6 Appendix I

6.1 Bibliography

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6.2 List of tables

6.3 List of figures

6.4 Abbreviations

a	Anno, year
CA	Criticality analysis
CBM	Condition based maintenance
CMMS	Computerized maintenance management system
CTMP	Chemo thermo mechanical pulp
D	Detection
DCS	Distributed control system
EBDIT	Earnings before depreciation, interest and tax
EUR	Euro (currency)
FAPET	Finish American paper engineer's text-book
FMEA	Failure mode and effects analysis
FTA	Failure tree analysis
H	Hours
HW	Hardwood
KPI	Key performance indicator
m2	Square meter
m3	cubic meter
MFR	Mondi Frantschach
Min	Minutes

MPL	Mean production loss
MRU	Mondi Ruzomberok
MSY	Mondi Syktyvkar
MTBPL	Mean time between production loss
MW	Megawatt
NASA	National aeronautics and space administration
NBSK	Non bleached softwood kraft pulp
O	Occurrence
OEE	Overall equipment effectiveness
OEM	Original equipment manufacturer
OPE	Overall plant efficiency
RCFA	Root cause and failure analysis
RCM	Reliability centered maintenance
ROA	Return on assets
ROCE	Return on capital employed
RPN	Risk priority number
RTF	Run to failure
S	Severity
S	Seconds
SHE	Safety, health and evironment
SW	Softwood

T	Tons
TPM	Total productive maintenance
UFP	Uncoated fine paper
USD	United States Dollar (currency)
ZP	Zellstoff Poels

7 Appendix II

7.1 Questionnaire

Maintenance Benchmarking Questionnaire

1 General mill overview

1.1 Paper grades

1.2 Wood demand

1.3 Pulp production output

1.4 Pulp internal usage

1.5 Pulp external sold

1.6 Saleable paper output

1.7 Total number of employees

1.8 Energy generation

1.9 Energy consumption

1.10 Geographic location (e. g. industrial environment, …)

2 Maintenance overview

2.1 How is the structure of the maintenance organization?

2.2 Which general maintenance concept (central, local, preventive, outsourcing, …) is in use?

2.3 Since when is this concept working?

2.4 Was there another (additional) reason than cost reduction to change the maintenance concept? (e. g. rebuilds, plant or equipment modifications, …)

2.5 If there was a technical or equipment based change, what was the reason in detail?

2.6 Why was the former maintenance concept no longer feasible?

2.7 Which CMMS is in use?

2.8 What applications of the CMMS are in constant use?

2.9 Which interfaces with other departments (e. g. procurement, spare part management, controlling, …) are considered in the CMMS?

2.10 Which KPI are measured in maintenance?

2.11 According to the specific KPI: How are they composed/ measured/ calculated and why?

2.12 According to the specific KPI: Why are they measured and in which way are they utilized?

2.13 Are periodically maintenance meetings taking place?

2.14 Who is attending these meetings?

2.15 What are the topics which are discussed regularly?

2.16 What are often occurring topics related to certain problems?

2.17 What is the total number of employees in maintenance?

2.18 How does the splitting of the maintenance personnel in terms of skills and function work?

2.19 How does the splitting of the maintenance personnel in terms of work area function (mechanical, electrical, automation, …)?

2.20 Will the operating and maintenance personnel get premiums for achieving certain KPI goals?

2.21 What is the legal situation according to working time? (e. g. 12 hour shift, 4 days on, 4 days off, labor unions, …)

2.22 What are the maintenance department operating costs? (notice: outsourcing!)

2.23 In the case of outsourcing: Who is the outsourcing partner?

2.24 In the case of outsourcing: Which maintenance activities are executed by the external partner?

2.25 In the case of outsourcing: How many external people are working on site?

2.26 In the case of outsourcing: Is the outsourcing partner controlling its maintenance function for itself?

2.27 In the case of outsourcing: In which way is the outsourcing partner integrated in the maintenance organization (e. g. flow of information, reporting, meetings, evaluation …)?

3 Work identification

3.1 Is there a work request process (request – validation – approval - ready to be planned) applied?

3.2 Which KPI are available in this issue?

3.3 Is the KPI “Amount of available man hours for proactive work on whole available man hours (proactive + corrective)” in use?

4 Work planning and scheduling

4.1 Which KPI are available in this issue?

4.2 Is the amount of planned and scheduled work on total effort hours in maintenance known?

5 Work execution

5.1 Which KPI are available in this issue?

5.2 Is the quality of the executed work reviewed?

6 Diagnostic (Predictive/ condition based maintenance)

6.1 How are the diagnostic activities integrated in the maintenance function?

6.2 Is there a schedule for certain diagnostic activities in specific mill areas?

6.3 In the case of outsourcing: Who is the outsourcing partner?

6.4 In the case of outsourcing: Which diagnostic activities are executed by the external partner?

6.5 In the case of outsourcing: According to which schedule are these activities executed?

6.6 In case of outsourcing: What was the main reason for outsourcing diagnostic work?

6.7 Which diagnostic equipment is available?

6.8 Which diagnostic equipment is in constant use?

6.9 Which diagnostic equipment is just rarely used and why?

6.10 Which diagnostic equipment would be useful, but isn’t available at the moment?

6.11 What is the working schedule (shift plan, plant areas, …) of the department?

6.12 What is the number of employees in this department?

6.13 How often do they get trainings in new equipment and technology?

7 Wood yard maintenance

7.1 What are the current key data/ design data of the wood yard? (e. g. capacities, pile storage volume, …)

7.2 How many operating people are necessary at the wood yard?

7.3 What is the maximum sustainable rate?

7.4 Are there some special reasons (operating modes, …) for the characteristics of the sustainable production level curve?

7.5 How many days are they performing the maximum production?

7.6 If the stability profile is poor, what are the main reasons (large amount of downtime, large variations in production rate) for this trend?

7.7 What are the main reasons for downtime?

7.8 What are the main reasons for the variations in the production rate?

7.9 What do you define as key equipment (conveyors, debarking drums, chipper, screens, …) at the wood yard?

7.10 According to key equipment: What are the current key data/ design data? (e. g. supplier, capacities, feed rate, …)

7.11 What is the technical layout of the wood yard?

7.12 How long is the buffer time between wood yard and cooking plant?

7.13 Is there a working schedule for certain equipment?

7.14 What equipment could be a bottleneck and in which cases?

7.15 Were a Failure Modes and Effects Analysis (FMEA) carried out for the plant area or certain equipment? (If yes, pleas provide this information.)

7.16 Which equipment can be defined as “critical” according to failure frequency and failure consequence?

7.17 According to the specific equipment: What are the most common failures?

7.18 According to the specific equipment: How often does a certain failure occur?

7.19 According to the specific equipment: Which consequences (effects) are triggered off by a certain failure and how are they valuated?

7.20 According to the specific equipment: How long is the downtime because of a certain failure?

7.21 According to the specific equipment: What are the reasons for the frequent breakdowns?

7.22 According to the specific equipment: Which parts or elements (motors, bearings, chains, …) are responsible for the breakdowns?

7.23 According to the specific equipment: Which actions were taken by the operators relating to certain failures?

7.24 According to the specific equipment and a certain failure: Which actions (preventive, reactive, …) were taken by the maintenance department relating to certain failures?

7.25 According to the specific equipment: What maintenance recommendations were given by the supplier relating to certain failures?

7.26 According to the specific equipment: What are the downtime costs?

7.27 According to the specific equipment: What is the percentage of reactive maintenance hours?

7.28 According to the specific equipment: What is the ration between unplanned to planned shutdowns?

7.29 According to the specific equipment: Is external help (e. g. supplier, specialists, …) needed in certain cases (certain failures) and which cases are those?

7.30 What is the percentage of work orders (relating to the wood yard) assigned to outside companies (external labor, contracted service)?

7.31 What maintenance KPI related to the wood yard are available?

7.32 In which way are they utilized?

7.33 Which improvements in wood yard maintenance were initiated because of certain KPI results?

7.34 In which way (organizational) is the wood yard considered by maintenance?

7.35 How many maintenance people (split: mechanical, electrical, automation) are required at the wood yard during normal operations?

7.36 How many maintenance people (split: mechanical, electrical, automation) are required during the annual shutdown?

7.37 What is the working schedule of maintenance personnel in this area?

7.38 What is the daily work process (starting time, meetings, other tasks, …) for maintenance personnel (engineers, supervisors, blue collar workers, …) in this area?

7.39 Pictures of critical equipment and/ or parts?

8 Evaporation plant maintenance

8.1 What are the current key data/ design data of the evaporation plant (e. g. liquor flow rate, dry solids content, …)?

8.2 How many operating people are necessary at the evaporation plant?

8.3 What is the maximum sustainable rate?

8.4 Are there some special reasons (operating modes, …) for the appearance (characteristics) of the sustainable production level curve?

8.5 How many days are they performing the maximum production?

8.6 If the stability profile is poor, what are the main reasons (large amount of downtime, large variations in production rate) for this trend?

8.7 What are the main reasons for downtime?

8.8 What are the main reasons for the variations in the production rate?

8.9 What do you define as key equipment (heat exchanger, pumps, …) at the evaporation plant?

8.10 According to key equipment: What are the current key data/ design data (e. g. supplier, capacities, feed rate, …)?

8.11 What is the technical layout of the evaporation plant?

8.12 How long is the buffer time between pulp washing and evaporation plant?

8.13 How long is the buffer time between evaporation plant and recovery boiler?

8.14 Is there a working schedule for certain equipment?

8.15 What equipment could be a bottleneck and in which cases?

8.16 Were a Failure Modes and Effects Analysis (FMEA) carried out for the plant area or certain equipment? (If yes, pleas provide this information.)

8.17 Which equipment can be defined as “critical” according to failure frequency and failure consequence?

8.18 According to the specific equipment: What are the most common failures?

8.19 According to the specific equipment: How often does a certain failure occur?

8.20 According to the specific equipment: Which consequences (effects) are triggered off by a certain failure and how are they valuated?

8.21 According to the specific equipment: How long is the downtime because of a certain failure?

8.22 According to the specific equipment: What are the reasons for the frequent break-downs?

8.23 According to the specific equipment: Which parts or elements (motors, bearings, valves, …) are responsible for the breakdowns?

8.24 According to the specific equipment: Which actions were taken by the operators relating to certain failures?

8.25 According to the specific equipment: Which actions (preventive, reactive, …) were taken by the maintenance department relating to certain failures?

8.26 According to the specific equipment: What maintenance recommendations were given by the supplier relating to certain failures?

8.27 According to the specific equipment: What are the downtime costs?

8.28 According to the specific equipment: What is the percentage of reactive maintenance hours?

8.29 According to the specific equipment: What is the ration between unplanned to planned shutdowns?

8.30 According to the specific equipment: Is external help (e. g. supplier, specialists, …) needed in certain cases (certain failures) and which cases are those?

8.31 What is the percentage of work orders (relating to the evaporation plant) assigned to outside companies (external labor, contracted service)?

8.32 Which maintenance KPI related to the evaporation plant are available?

8.33 In which way are they utilized?

8.34 Which improvements in evaporation plant maintenance were initiated because of certain KPI results?

8.35 In which way (organizational) is the evaporation plant considered by maintenance?

8.36 How many maintenance people (split: mechanical, electrical, automation) are required at the evaporation plant during normal operation?

8.37 How many maintenance people (split: mechanical, electrical, automation) are required during the annual shutdown?

8.38 What is the working schedule of maintenance personnel in this area?

8.39 What is the daily work process (starting time, meetings, other tasks, …) for maintenance personnel (engineers, supervisors, blue collar workers, …) in this area?

8.40 Pictures of critical equipment and/ or parts?

9 Recovery boiler maintenance

9.1 What are the current key data/ design data of the recovery boiler (e. g. pressure, liquor capacity, dry solid content, …)?

9.2 How many operating people are necessary for the recovery boiler?

9.3 What is the maximum sustainable rate?

9.4 Are there some special reasons (operating modes, …) for the appearance (characteristics) of the sustainable production level curve?

9.5 How many days are they performing the maximum production?

9.6 If the stability profile is poor, what are the main reasons (large amount of downtime, large variations in production rate) for this trend?

9.7 What are the main reasons for downtime?

9.8 What are the main reasons for the variations in the production rate?

9.9 What do you define as key equipment (boiler banks, steam drum, superheaters, …) at the recovery boiler?

9.10 According to key equipment: What are the current key data/ design data? (e. g. supplier, capacities, feed rate, …)

9.11 What is the technical layout of the recovery boiler?

9.12 How long is the buffer time between recovery boiler and recaustizising?

9.13 Is there a working schedule for certain equipment?

9.14 What equipment could be a bottleneck and in which cases?

9.15 Were a Failure Modes and Effects Analysis (FMEA) carried out for the plant area or certain equipment? (If yes, pleas provide this information.)

9.16 Which equipment can be defined as “critical” according to failure frequency and failure consequence?

9.17 According to the specific equipment: What are the most common failures?

9.18 According to the specific equipment: How often does a certain failure occur?

9.19 According to the specific equipment: Which consequences (effects) are triggered off by a certain failure and how are they valuated?

9.20 According to the specific equipment: How long is the downtime because of the certain failure?

9.21 According to the specific equipment: What are the reasons for the frequent breakdowns?

9.22 According to the specific equipment: Which parts or elements (pumps, valves, …) are responsible for the breakdowns?

9.23 According to the specific equipment: Which actions were taken by the operators relating to certain failures?

9.24 According to the specific equipment: Which actions (preventive, reactive, …) were taken by the maintenance department relating to certain failures?

9.25 According to the specific equipment: What maintenance recommendations were given by the supplier relating to certain failures?

9.26 According to the specific equipment: What are the downtime costs?

9.27 According to the specific equipment: What is the percentage of reactive maintenance hours?

9.28 According to the specific equipment: What is the ration between unplanned to planned shutdowns?

9.29 According to the specific equipment: Is external help (e. g. supplier, specialists, …) needed in certain cases (certain failures) and which are they?

9.30 What is the percentage of work orders (relating to the evaporation plant) assigned to outside companies (external labor, contracted service)?

9.31 Which maintenance KPI related to the recovery boiler are available?

9.32 In which way are they utilized?

9.33 Which improvements in recovery boiler maintenance were initiated because of certain KPI results?

9.34 In which way (organizational) is the recovery boiler considered by maintenance?

9.35 How many maintenance people (split: mechanical, electrical, automation) are required at the recovery boiler during normal operation?

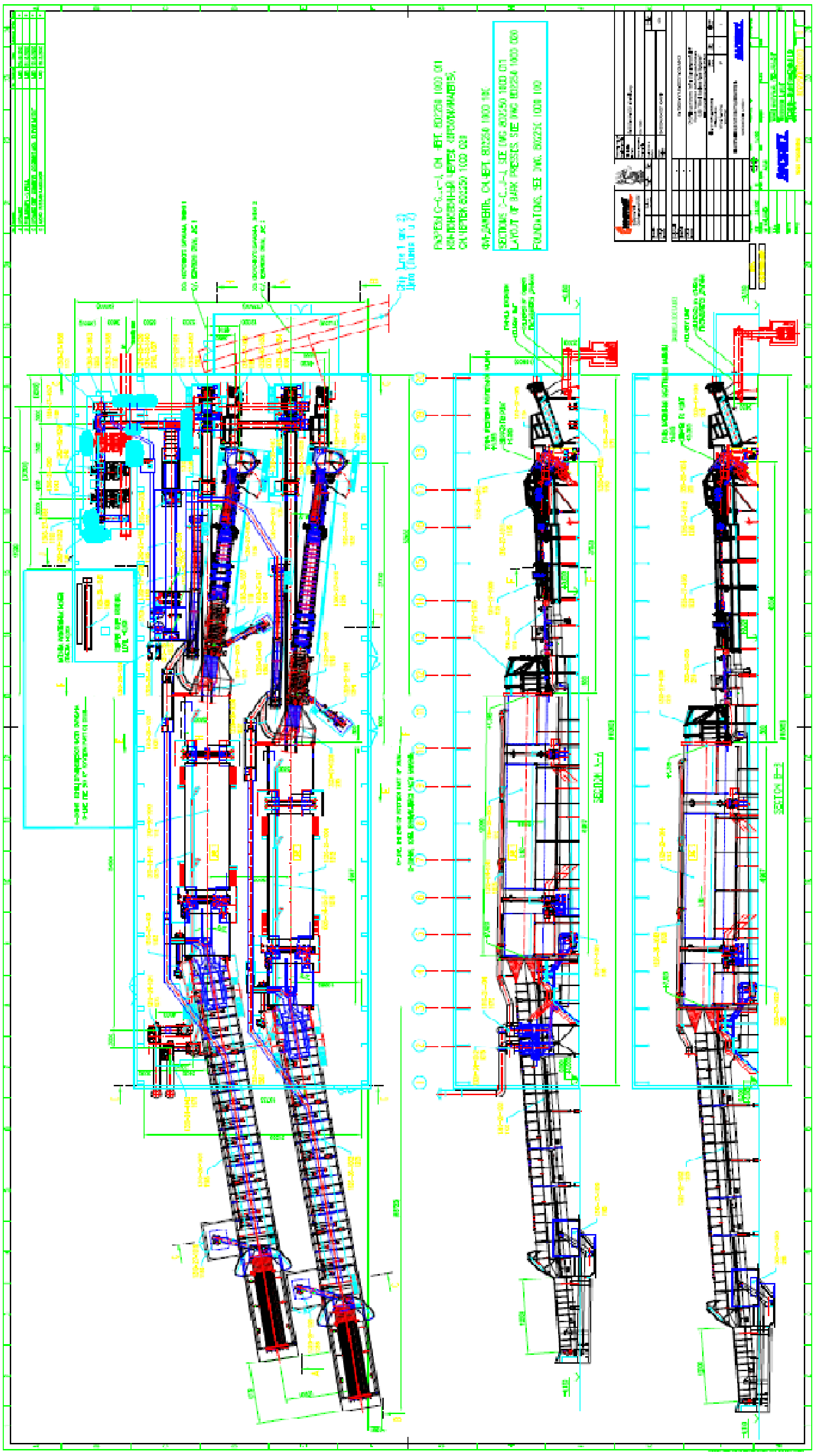
9.36 How many maintenance people (split: mechanical, electrical, automation) are required during the annual shutdown?

9.37 What is the working schedule of maintenance personnel in this area?

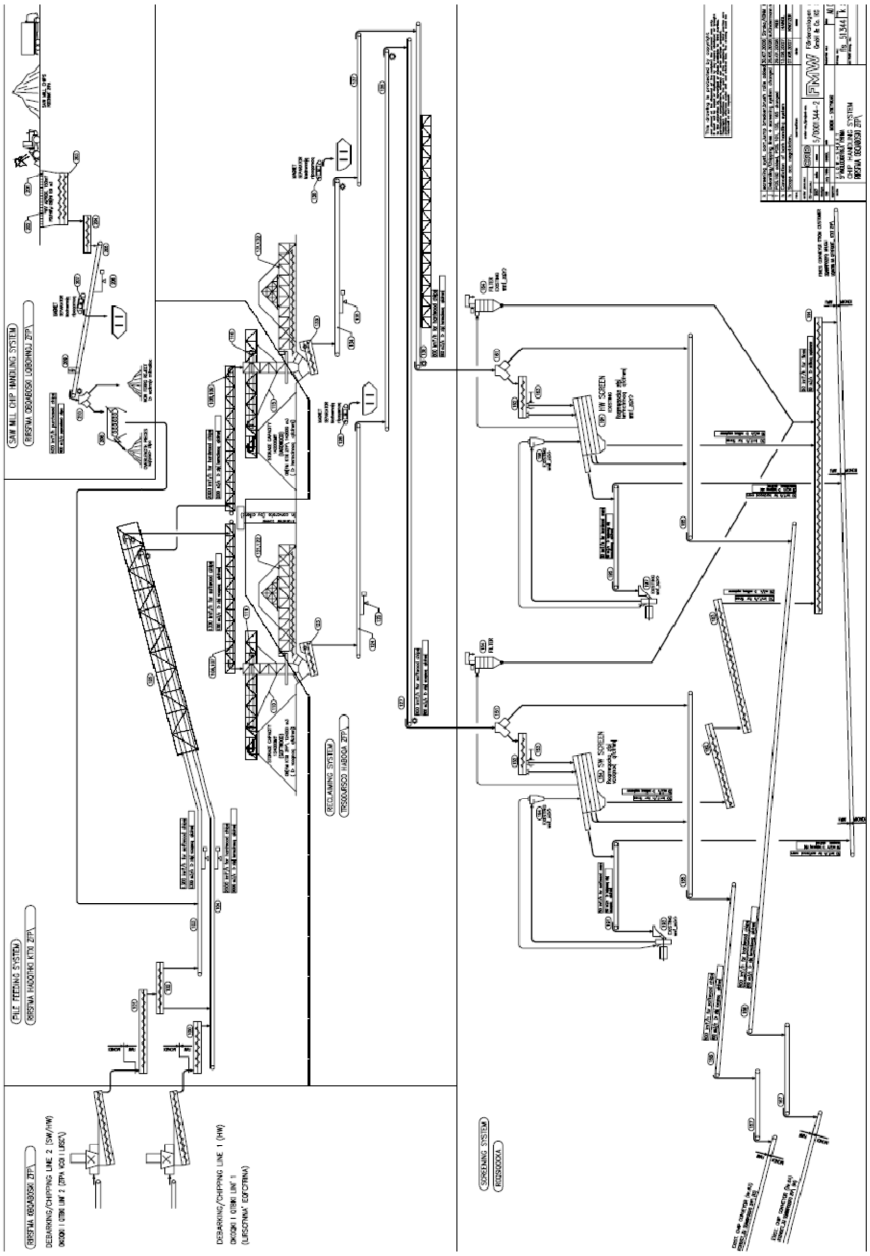
9.38 What is the daily work process (starting time, meetings, other tasks, …) for maintenance personnel (engineers, supervisors, blue collar workers, …) in this area?

9.39 Pictures of critical equipment and/ or parts?

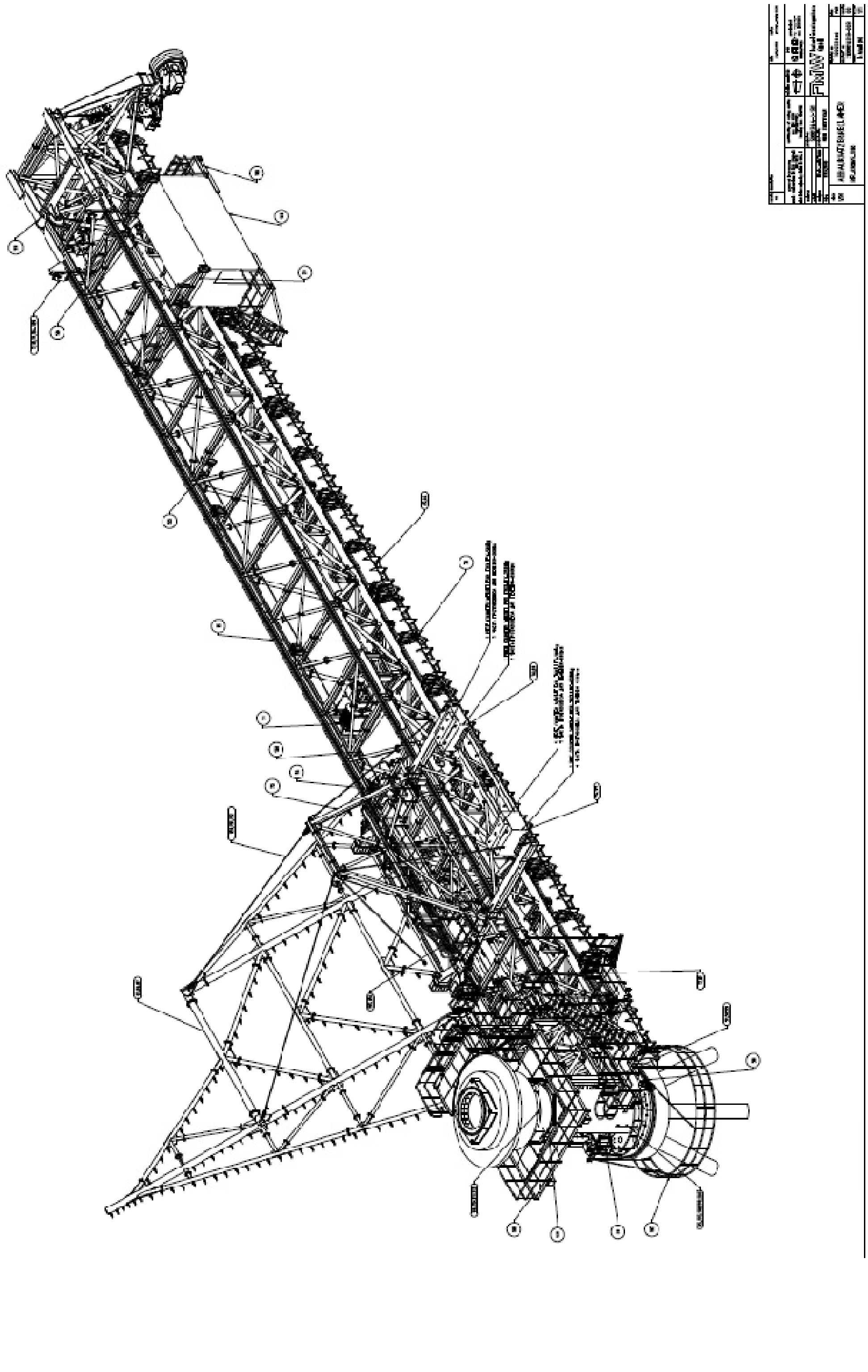
7.2 Layout drawing: Woodroom



7.3 Layout drawing: Chip handling



7.4 Drawing: Reclaimer



7.5 Other drawings

Because of clarity, several other drawings are not displayed on hard copy and are available on the CD-ROM enclosed.