Kaunas University of Technology
Faculty of Mechanical Engineering and Design

Analysis and improvement of reliability of particleboard production line

Master's Final Degree Project

Gintarė Nislaitytė
Project author

Assoc. prof. Kazimieras Juzėnas
Supervisor

Kaunas, 2018

Kaunas University of Technology
Faculty of Mechanical Engineering and Design

Analysis and improvement of reliability of particleboard production line

Master's Final Degree Project
Industrial Engineering and Management (621H77003)

Gintarė Nislaitytė
Project author

Assoc. prof. Kazimieras Juzėnas
Supervisor

Assoc. prof. Sigitas Kilikevičius
Reviewer

Kaunas, 2018

Kaunas University of Technology
Faculty of Mechanical Engineering and Design
Gintarė Nislaitytė

Analysis and improvement of reliability of particleboard production line

Declaration of Academic Integrity

I confirm that the final project of mine, Gintarė Nislaitytė, on the topic „Analysis of improvement of reliability of particleboard production line“ is written completely by myself; all the provided data and research results are correct and have been obtained honestly. None of the parts of this thesis have been plagiarised from any printed, Internet-based or otherwise recorded sources. All direct and indirect quotations from external resources are indicated in the list of references. No monetary funds (unless required by law) have been paid to anyone for any contribution to this project.

I fully and completely understand that any discovery of any manifestations/case/facts of dishonesty inevitably results in me incurring a penalty according to the procedure(s) effective at Kaunas University of Technology.

(name and surname filled in by hand) (signature)

KAUNAS UN IVERSITY OF TECHNOLOGY

FACULTY OF MECHANICAL ENGINEERING AND DESIGN

Study programme INDUSTRIAL ENGINEERING AND MANAGEMENT 621H77003

TASK ASSIGNMENT FOR FINAL DEGREE PROJECT OF MASTER STUDIES

Given to the student: Gintarė Nislaitytė

1. Title of the Project:

Analysis and improvement of reliability of particleboard production line

Medienos drožlių plokštės gamybos linijos analizė ir patikimumo didinimas

Approved by the Dean Order No. V25-11-6, 12 April 2018

2. Aim and Tasks of the Project:

To analyse particleboard production line, to establish the most frequent failure, analyse it and give recommendations for reliability improvement.

3. Initial Data:

25th of May, 2018.

4. Main Requirements and Conditions:

To analyse existing maintenance strategies, to give recommendations how to improve reliability of equipment.

5. Structure of the Text Part:

1. Introduction 2. Literature review 3. Analysis of the company 4. Analysis of downtimes 5. Influence of the failure to the product quality 6. Recommendations 7. Conclusions 8. List of references

6. Structure of the Graphical Part: Not obligatory.

7. Consultants of the Project:

Student.....
(Name, Surname, Signature, date)

Supervisor.....
(Name, Surname, Signature, date)

Programme Director of the Study field Assoc. Prof. Regita Bendikienė
(Name, Surname, Signature, date)

Table of content

List of figures

List of tables

Gintarė Nislaitytė. Analysis and improvement of reliability of particleboard production line. Master`s Final Degree Project / supervisor assoc. prof. Kazimieras Juzėnas; Faculty of Mechanical Engineering and Design, Kaunas University of Technology.
Study field and area (study field group): Production and Manufacturing Engineering, Technological Sciences.
Keywords: reliability, particleboard, maintenance, downtime, intermediate belt.
Kaunas, 2018. 61 pages.

Summary

In this Master`s Final Degree Project the production line of particleboard was analysed. Reviewed maintenance management of the company, analysis of downtimes and the most frequent failures. Survey of operators, production and maintenance managers, and mechanics indicates equipments groups where failures occur more often, than in the others. Respondents rated failures by 3 criteria and evaluation showed that the most critical equipment for the production process is intermediate belt.

Failures and downtimes caused by the intermediate belt were analysed. The failure has direct impact on the product quality. The defected particleboard cannot be corrected and is classified as non-conformity product.

Recommended to use preventive maintenance method for the intermediate belt and replace it with new every two months, consider using only specified belts for moist environment. The maintenance tool for assuring the reliability is FMEA, suggested to implement modified worksheet according company’s assets.

In order to eliminate all possible causes for the intermediate belt failure, an experiment was conducted during which it was detected the right amount of steam, which is not causing failure. The work procedure of evaporation of steam head created, it eliminates human factor from operating process and enables to avoid mistakes that are resulting in failure.

Gintarė Nislaitytė. Medienos drožlių plokštės gamybos linijos analizė ir patikimumo didinimas. Magistro baigiamasis projektas / vadovas doc. Dr. Kazimieras Juzėnas; Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas.
Studijų kryptis ir sritis (studijų krypčių grupė): Gamybos inžinerija, Technologijos mokslai.
Reikšminiai žodžiai: patikimumas, medienos drožlių plokštė, techninė priežiūra, prastova, tarpinė juosta.
Kaunas, 2018. 61 p.

Santrauka

Šiame magistro baigiamajame darbe išanalizuota medienos drožlių plokštės gamybos linija. Apžvelgta įmonės techninės priežiūros strategija, prastovų analizė ir dažniausiai atsirandantys gedimai. Ekspertinė operatorių, gamybos ir techninės priežiūros vadovų, bei mechanikų, apklausa parodė, kad gedimai, kai kuriose įrengimų grupėse atsiranda dažniau. Respondentai įvertino irengimų grupes pagal 3 kriterijus, didžiausią balų skaičių surinko tarpinė juosta, kuri turi tiesioginę įtaką gamybos procesui.

Tarpinės juostos gedimų prastovų laikas išanalizuotas ir nustatyta, kad turi tiesioginę įtaką produkto kokybei. Medienos drožlių plokštės pagamintos tarpinės juostos praslydimo metu yra klasifikuojamos kaip neatitiktinis produktas dėl nepataisomų defektų.

Rekomenduota tarpinei juostai taikyti prevencinės techninės priežiūros metodą ir keisti ją kas du mėnesius. Techninės priežiūros skyriui pateiktos rekomendacijos naudoti juostas pritaikytas eksploatacijai drėgnoje aplinkoje. Vienas iš geriausių techninės priežiūros įrankių yra gedimų rūšių ir pasekmių analizė, todėl sukurtas darbalapis, pritaikytas įmonės turimiems ištekliams.

Siekiant pašalinti visas priežastis įtakojančias tarpinės juostos gedimus, atliktas eksperimentas, kurio metu nustatytas tinkamas garo kiekis, neįtakojantis produkto kokybės ir gedimų. Sukurta garo galvos išgarinimo procedūra, kuri padeda išvengti žmogiškojo faktoriaus klaidų, kurios sukelia gedimus ir prastovas.

Introduction

In the area of manufacturing industry, there is a high degree of competition, and companies are confronted with problems caused by potential equipment failures. Therefore, it is important for companies who wish to become competing, to ensure continuous operation of the technical equipment used. The demand for current production is growing and capital investments in new equipment are delayed due to satisfy customer.

The modern equipment design is complicated and repairs require more time. Reliability of equipment is very important for companies, in order to ensure stable production process and quality of the final product. Downtime for businesses is unprofitable, so the challenge is to reduce them.

Companies install and implement different techniques of maintenance management, regarding type of frequent failures and available resources. One part of company's budget is dedicated to maintenance activities and management team makes decisions about which method of maintenance to choose for their processes. The asset management play a significant role in maintenance management system and together with preventive and reliability based maintenance methods can reduce maintenance costs up to 30%. [1]

Objective – to analyse downtimes and maintenance methods of the particleboard production company, and develop recommendations for improvement of equipment reliability.

Tasks:

1. To analyse maintenance strategies and methods.
2. To review methods of maintenance those are applied at the company.
3. To analyse downtimes and causes of them.
4. To detect the most critical failure for the production process and make recommendations for improving reliability of equipment.

1. Maintenance management

1.1 Purpose of maintenance management

In general, maintenance management is a process that includes all technical, administrative and managerial actions to ensure the proper exploitation of equipment. Successful maintenance management generates profit of a business and enables savings. The process of maintenance management is defined in LST EN 17007:2018 “Maintenance process and Associated indicators” standard.[2] This standard defines all procedures, terms, actions and principles of maintenance management. The maintenance process consists of three processes:

1. The management process – this process includes all actions related to strategy, human resources, continuous improvement, etc.
2. The realization processes – fundamentally, all actions carried out during repair and prevention processes; the item restoration in required state, implementation of maintenance method, improvements.
3. The support processes – the widest process that includes personal health and safety requirements, budget, documentation, improvement of results, data collection and analysis, provide services and human resources, delivery of spare parts.

The main three processes may be adjusted depending on company’s strategy and type of production. The maintenance management consists of several types of methods and tools, which enable company to integrate them successfully. Above mentioned processes includes activities, such as:

- Human resources management;
- Financial resources management;
- Material resources and their maintenance management;
- Information processing.

Activities are divided into levels and each level is consisted of group of information and data, this way enables easier analysis of information. In the standard for maintenance management all maps of every maintenance process is given, those maps are useful tool for management, because they indicate how to form the tasks, responsibilities of the personnel and expectations.

Maintenance management is related with asset management, because maintenance actions are directly related to physical and financial assets. A good maintenance management guarantees long life cycle of equipment and smooth process of production. Two processes are regulated by standard as “Maintenance – Maintenance within physical asset management”.[3] During last decades the physical asset management became a more essential part of company’s activities, because of the

fast growth of competition in the market. Third world countries are fast developing and produce high quality products, but the price is lower, than in economical developed countries, that are increasing competition.

Stakeholders are pushing management teams to deliver higher profit, but with the same assets, demand is to reduce maintenance costs to as lowest as possible level, so it's important to manage assets and maintenance on the right way. Physical asset management has a number of benefits, but the main one is that it builds up the required link between maintenance management and company's strategic plan; it gives direction to maintenance activities. LST EN 16646:2015 standard explains all steps and activities for the physical asset management and gives directions.

The maintenance management and physical asset management are documented and required forms of documents are explained in LST EN 13460:2009 standard "Maintenance – Documentation for maintenance".[4] The standard specifies which documents must be in the company; it indicates minimum requirements for documentation. LST EN 15341:2007 standard specifies how to evaluate quality of the maintenance management.[5] Basically internal and external indicators are evaluated and grouped: economic, technical and organisation indicators, the latter are judged by indicator levels.

Standards specify the minimum requirements for processes in the company; customers can do audits at supplier company and use standard as documented form for audit. Governments regulate companies by the law, standard helps to adjust law for all companies in the country.

1.1.1 Maintenance strategies

Maintenance of equipment is a significant part of total company's operating costs in production industry. Total cost of maintenance concludes from direct and hidden costs, the "Iceberg Model" (see Fig.1) highlights both.[6] Part of hidden costs are the biggest one, that means direct costs doesn`t show the real losses of company's finance. Management of the company has to find solution how to reduce hidden costs and this reason has come down to switch maintenance strategy from traditional reactive approach to a proactive reliability based approach. The reactive approach is to "fix it when it breaks", that results in longer time of downtime, higher cost of spare part, shorter life cycle time of equipment, higher labour need and etc. All those factors together increase losses.

In order to successful implement a proactive reliability based strategy; a main basic elements must be completed:

- A clear strategy and policies to support it;
- Procedures and processes to enable implementation, tools to support;

- Controlled maintenance business process.

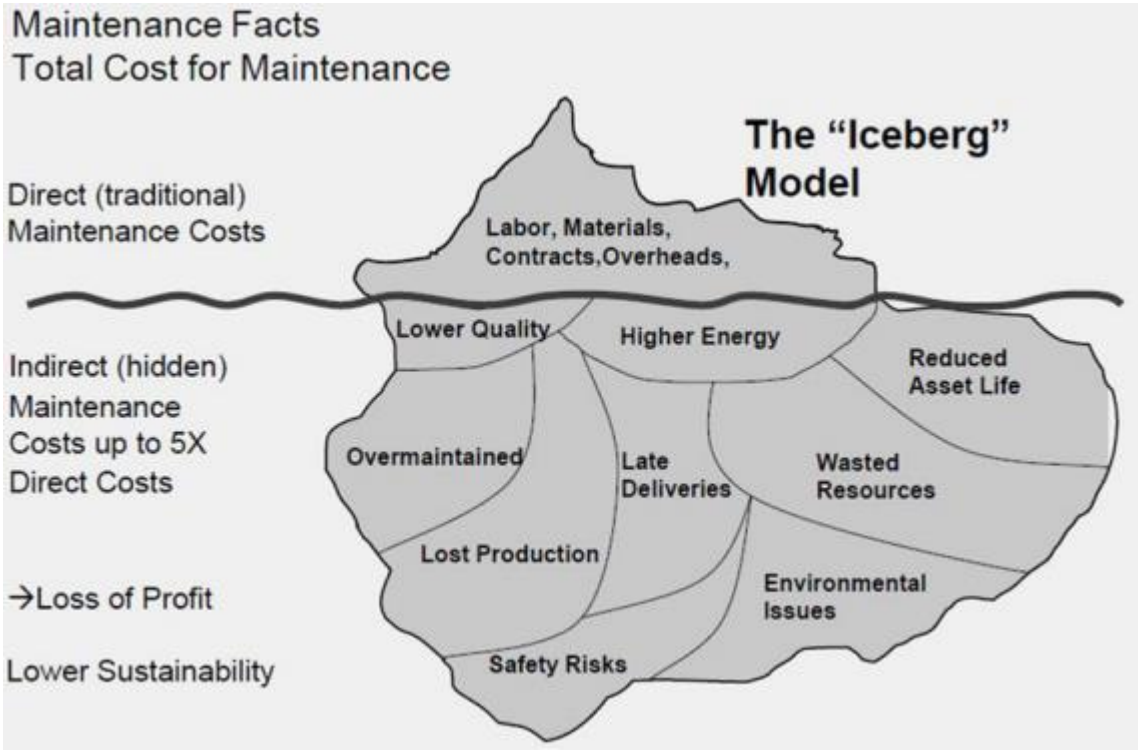


Fig. 1 Total cost of maintenance – the Iceberg Model [6]

Hidden costs are the major part of total cost of maintenance and affects company's financial ratios, in order to be competitive company must have confidence in the customer, lower quality and late deliveries are the main factors that reduce confidence. Two directions of maintenance strategies can be distinguished: reactive and proactive. The reactive maintenance strategy requires a large amount of financial resources unless unencumbered initial investment; the proactive maintenance strategy can save finance. The proactive maintenance management includes several methods of maintenance:

- Preventive maintenance;
- Condition-based maintenance;
- Design-out maintenance;
- Reliability centred maintenance.

In most cases manufacturing companies are using more than one method due to the variety of equipment. For example, rotating parts are managed by the preventive maintenance method, but sensors are managed by the reactive maintenance method, because the major part of sensors is designed to signal when they are damaged.

1.1.2 Preventive maintenance (PM)

Preventive maintenance is carried out at intervals or according to defined criteria and is intended to reduce the probability of equipment failure. Elements or parts of equipment are replaced without reference to their condition, for example; if rotating parts are not worn out, but are in the list of preventive maintenance, personnel will replace them. In some circumstances preventive maintenance is more expensive as reactive maintenance, because equipment broke down unplanned or right before scheduled repair.[7] In some cases the reason of high cost of preventive maintenance may be the wrong periods of changing, when good parts of equipment are replaced. The main advantages of preventive maintenance are:

- Reduction of failure frequency of equipment;
- Reduction of failure costs;
- Improvement of availability of production process;
- Increase of equipment's reliability;
- Increase of equipment's life time.

Seven policies of preventive maintenance can be implemented:

1. Regular – tasks are scheduled in periods.
2. Conditional – depends on wear and saturation of equipment.
3. Systematic – tasks are scheduled on random intervals of time and applicable to all equipment.
4. Cyclical – actions are scheduled on cycles, for example every 30 days.
5. Indicative – time intervals are defined for each machine.
6. Critical – tasks are carried out after indication of probability of failure.
7. Limited – the same as critical, except critical level is different.

Maintenance department has to evaluate machinery, prioritised equipment critical to production process and decide how to process.[8] Production department may give their recommendations and share opinion about the most important equipment for the technological or production process. When a number of machines are related to each other the possibility of production stop, because of the breakdown rises, prevention becomes unavoidable.

The demand for sustainable processes is growing and the Linear Economy is changing to Circular Economy.[9] Industry invests in safety and environment protection, employee's health is important, so the world is changing and manufacturing process has to adapt.

A new model – sustainable maintenance is developed. In particular, the model allows determining the optimal preventive maintenance period that minimizes unexceptional,

environmental, and social costs of maintenance, but limits different type of spare parts influence on environment and social. The main objective of this model is to use remanufactured or used spare parts again, depending on their condition they can be renewing, if it's possible. This method can be applied not for all equipment, function and importance may be taken in consideration.

Periodicity of preventive maintenance is a key to successful management, the algorithm of preventive maintenance was created as scheduling assistant.[10] Its important not just define by who and when actions will be done, but how frequent. Preventive maintenance aimed to prevent failure of equipment, element or part of equipment has to be replaced before failure. The scheduling assistant contains of 5 main steps:

1. Identify the time periods when equipment and technicians are available.
2. Sort the maintenance tasks by importance.
3. Sort the maintenance tasks by due date.
4. Define the scheduling period.
5. Allocation of resources for each equipment.

Those steps may be considered and defined by the maintenance department at the company's level. Implementation of the method can take time, but benefits from it are higher, knowledge and experience of personnel are important factors. One of the benefits is improving reliability of equipment.

1.1.3 Reliability centred maintenance (RCM)

Reliability centred maintenance is the optimum mix of reactive, condition-based and proactive maintenance practices. These strategies are integrated together to take advantage of their strengths in order to minimize maintenance costs and maximize equipment's life cycle. Primarily, RCM was developed in the aviation industry; maintenance and condition of equipment are the most important factors there. Precision is an integral part in maintenance activities.

The logic of RCM is based on three questions [11]:

- How does a failure occur?
- What are its consequences for safety or operability?
- What good can preventive maintenance do?

Those questions are simple and usually maintenance staff is discussing them, but from the RCM perspective, answers to those questions can give directions for methods and tools. The developer of RCM has to go through 10 phases (see Fig.2) and consider various questions and answers about maintenance strategy. Implementation of this method requires resources of good knowledge, in some cases only average knowledge is not enough. First of all the developer has to

define which group of equipment or failures will be most of concern, than he considers which failure modes can result in loss of system function and determines which failure modes are the highest risk.

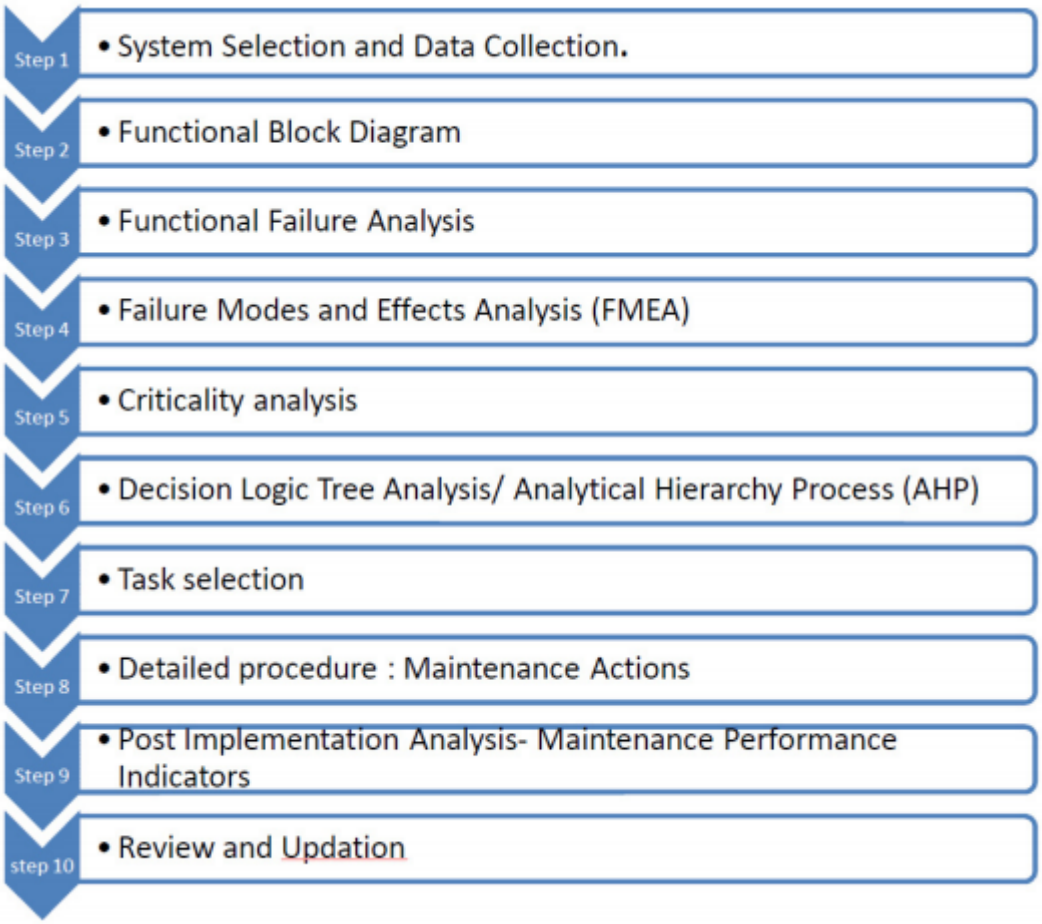


Fig. 2 Implementation process of RCM [11]

In the Step 4 Failure Modes and Effects Analysis (FMEA) implementation is given, this method is one of the most popular at manufacturing companies, used for analysis of failures. A survey study was done in over 70 Swedish company and results show that FMEA is using 33% of companies (see Fig.3).[12] In the first place is the Root Cause Analysis (RCA), probably those methods are combined together.

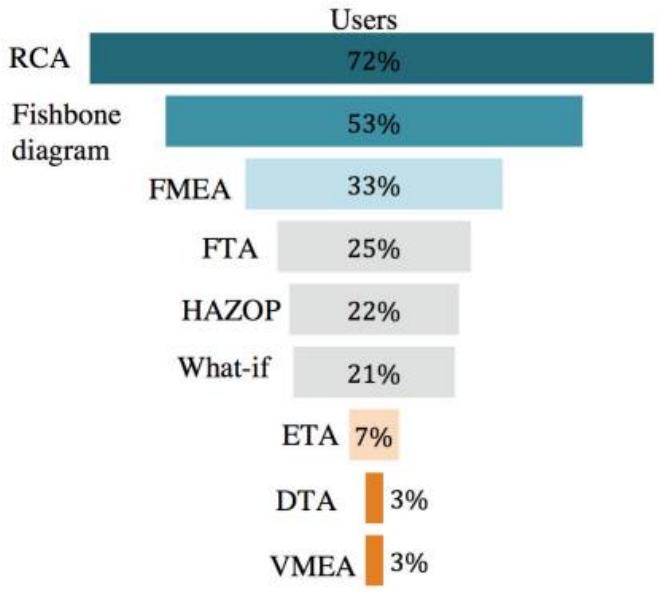


Fig. 3 The use of engineering tools at Swedish companies [12]

Factors affecting wider usage of RCA and Fishbone diagram may be that they are well known and can be applied to almost every process in the company, and FMEA shows the best result in maintenance. Originally FMEA was developed for aviation and ship industry maintenance management and quality assurance. Fault-tree analysis (FTA), a hazard and operability study (HAZOP), maintenance certification (ETA), down tower assembly and variant mode and effect analysis (VMEA) are tools of maintenance methods, but they are not effective and used less in the production companies.

1.1.4 Failure modes and Effects Analysis (FMEA)

FMEA is applicable to a various levels of systems, from the highest level of block diagram, to the functions of components or software commands. Application of this method is a process, defined by IEC 60812:2006 standard as "Analysis techniques for system reliability – Procedure for failure mode and effects analysis (FMEA)".[13] Objectives of the analysis are described as:

- Identifies failures which have unwanted effects on system operation;
- Satisfaction of contractual requirements of a customer;
- Allows improvements of the system`s reliability or safety;
- Allows improvement of the system`s maintainability.

A comprehensive identification and evaluation of all failures that has influence on the system, allows identifying criticality and priority of each equipment, that FMEA is aimed for. The procedure of FMEA implementation consists of four main stages:

1. Establishment of the basic rules, planning and scheduling to ensure that all necessary resources are available.

2. Executing the FMEA using the appropriate worksheet or other.

3. Summarizing and reporting of the analysis to include all conclusions or recommendations done.

4. Updating FMEA as the development activities progresses.

For reaching a positive result of FMEA is important to clarify expectations and dedicate process for one or two members of the team, who can reach all resources and collect data. The standard example of FMEA worksheet is given in Appendix 1.

This worksheet is defined as a basic for FMEA; the maintenance department can modify this worksheet according their equipment, failure modes or other information. A helpful tool before creating the worksheet is questionnaire (see Fig.4).

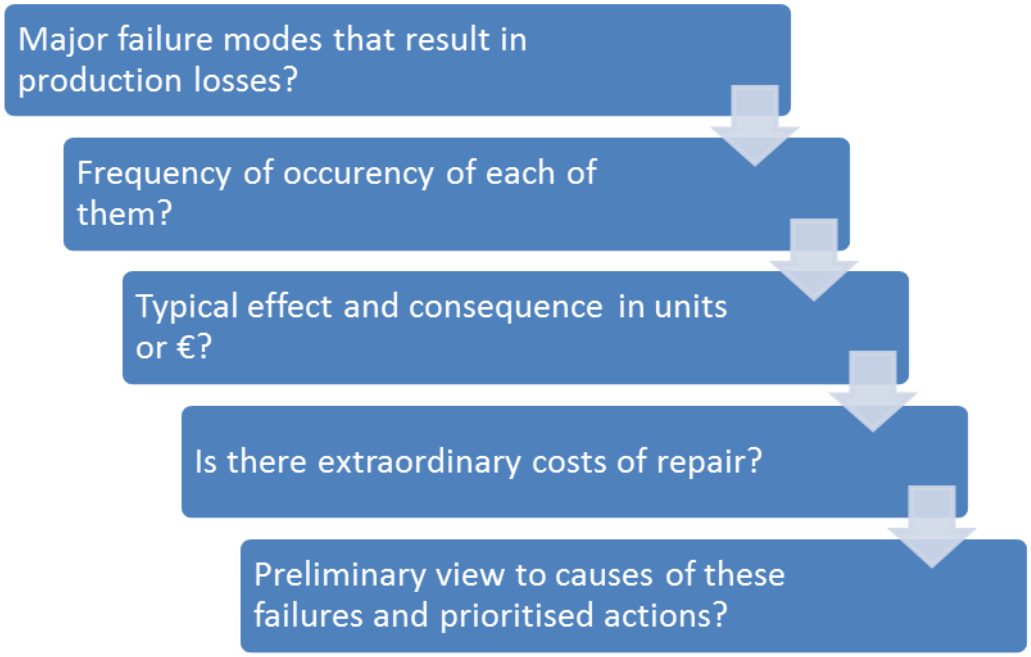


Fig. 4 Standard flow of questions for FMEA

Sequence of questions is important and each question may be considered and discussed with production department. Factor that indicates criticality of equipment is RPN – Risk Priority Number, it's calculated after evaluation of Severity, Occurrence and Detectability ratios, some engineers have doubts about precision of RPN and suggest combining FMEA with other methods in order to achieve the best result. In most cases FMEA is combined with Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and Fuzzy Belief Structure (FBS). [14]

TOPSIS is established upon the concept of positive ideal solution and negative ideal solution concurrently. This method is considered to solve group decision-making problems with multi-criteria and multi-judges with belief structure. TOPSIS has advantages as:

- Is simple to use;
- Takes into account subjective and objective criteria;
- Is rational and understandable;
- The computation process is straightforward;
- The ability to identify the best alternative quickly in a simple mathematical form.

Belief Structure is a tool for combining information from multiple sources. There are two types of belief structures and the first one refer to as fusion, occurs when the information being combined are about the same variable. The result of this type of belief structure is about the variable of interest. The second type refer to as joining, occurs when combined information is about different variables. Field of application outlines which type of belief structure to apply.

1.2 Asset management

In terms of the management of the company an integral part is asset management. Basic definition of asset management is that an asset is an economic resources, anything tangible or intangible that is capable of being owned or controlled to produce value is considered an asset. Plant is an asset from business or company's perspective, which is a sum of smaller assets as: the process equipment, rotating machinery, electrical equipment, automotive equipment, in other words, everything that generates profit is an asset.[1]

Modern companies are deploying asset management systems to increase the operational efficiency. The key drivers for asset management systems are as follows:

- Reliability is becoming a competitive business issue for the successful production. Any unplanned plant shutdowns have the significant impact on the production.
- Quality is a survival issue in most of the markets for better products and the quality of the produced outcome on the financials of the plant is important for the future business.
- Increased production demands on older equipment causes delays on the new capital investment in order to sustain the current production.
- Growing requirements to reduce manpower, to do more with less.
- Cost reductions focus in maintenance and operations.
- Customer requirements are becoming more stringent in various aspects.
- Environmental, health, and safety concerns become a total enterprise issue.
- Value creation is a motivating factor for management decisions.

From operations and maintenance perspective, the asset management systems are available, which help to implement the maintenance strategies, purchase, and cost control. In general, an asset management system manages maintenance scheduling, workflow, inventory and purchase activities of rotating assets, fixed assets and automation assets. There shall be multiple systems for the asset monitoring and management.

Plant asset management can be considered as activities that are provided for sustainable risk over the life cycle of an asset. The asset management focuses on lengthening effective life of assets while guaranteeing availability. It reduces capital tied up in goods by delaying capital investment. In general, asset management is practice to achieve the greatest return and operate with current assets. Maintenance activities are managed by asset management system as well.

An asset management system is a combination of three elements (see Fig.5).

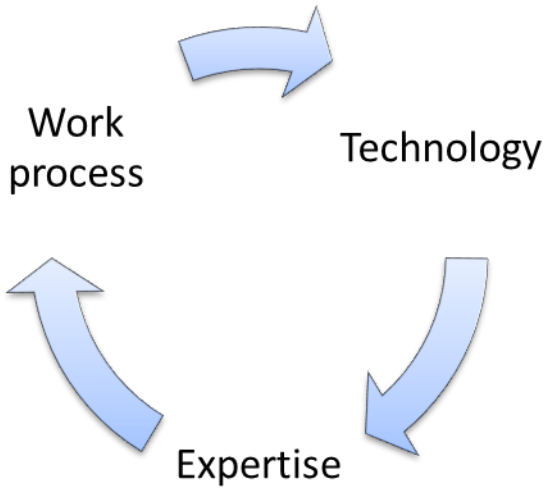


Fig. 5 Elements of asset management system [1]

Those three elements play a role for successful asset management. Company needs the adoption of technologies and expertise from systems and maintenance personal on the ability to diagnose proper and define work process. The company's asset management is a combination of hardware, software and services, which are dedicated to:

- Monitor – to monitor asset condition periodically or in real time.
- Predict – to identify potential problems before they lead to a catastrophic failure.
- Analyse – analysis of potential failures, problems and operator actions.

- Prevent – to provide solutions to protect equipment or process from catastrophic failure.

Different types of assets are classified to levels and have various impacts to the company's operational condition (see Fig.6).

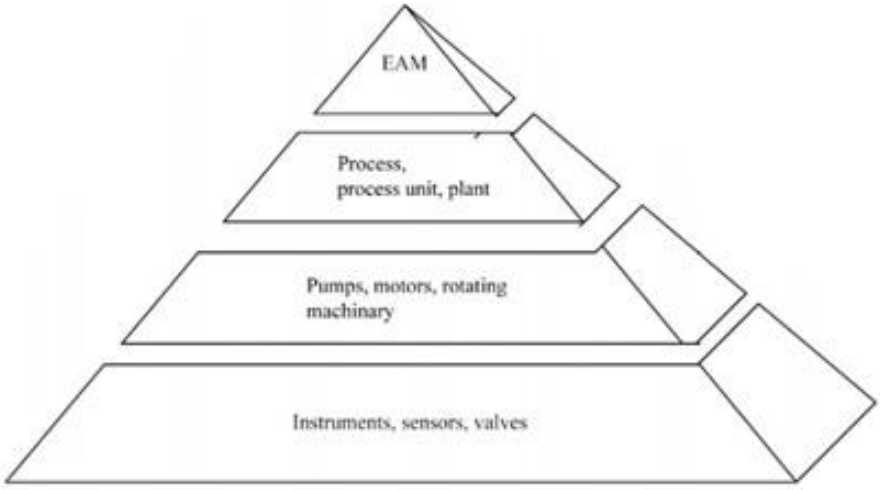


Fig. 6 Types of assets [1]

At the bottom of pyramid there is the biggest number of assets, but they have the lowest value of finance, on the right directions given to visualise how they are managed, by which department. At the top of pyramid are the most expensive assets that need to be protected from failures and requires a good management skills is Enterprise Asset Management (EAM). They generate the highest value for company and have the direct impact to production process. For example, if rotating elements of machine are broken it can't operate and production is stopped.

1.2.1 Instrument asset management systems

Instruments can be defined as equipment, devices or machines. This system monitors and controls life cycle of the equipment and is dedicated to assure it. Maintenance management system is directly related to the instrument asset management system, in order to achieve the highest level and efficiency of maintenance. Generally, instrument asset management system deals with systems for prevention actions. Preventing unplanned shutdowns, reducing downtime, and lowering maintenance costs provide significant financial benefits. The system can be easily adapted to the existing processes.

The aim is to use maintenance methods efficiently and reduce costs of maintenance. This is critical because of the growing concurrency in the market. In some cases company can save itself by producing new products with current equipment.

As discussed earlier, technology, work process, and knowledge are the key elements of the instrument asset management. The maintenance activities of instruments can be categorized as:

- Run to failure: The case where no maintenance activities are presented and equipment is running until failure, elements or parts are replaced with new ones. In some cases this method is applicable.
- Preventive (scheduled) maintenance: This type of maintenance is performed in order to prevent equipment from failure, when it's significant to production process. Maintenance is scheduled with reference to history of equipment or records of failure.
- Predictive maintenance: This is an intelligent method to plan maintenance activities based on production schedule. History of equipment, the root cause analysis makes possibility to reduce costs of maintenance.
- Condition-based maintenance: The condition of equipment is monitored periodically and records analysed by maintenance personnel, if significant changes are noticed than maintenance actions taken. Monitoring can be performed in real time or by using smart device, modern companies are installing equipment with integrated devices that allow monitoring equipment's condition.

From the descriptions above its clear that maintenance needs a clear strategy. Some studies indicated that the trips made by the technicians to equipment may not always conclude the failed equipment. Majority of the times there will be no failure or problem, the instrument asset management help to reduce these efforts and human resources can be dedicated in places where an issue is. Alarms may be standardize in the company, so technicians can plan their work and avoid unnecessarily actions.

1.2.2 Integrated asset management

While the successful implementation of a proactive maintenance strategy together with a performance-based contract can deliver significantly improved results, even more can be achieved if this includes the unique knowledge and capabilities of a global equipment supplier who also has competence in the provision of reliability-based maintenance and service.[15]

In reality the equipment supplier who has designed, installed, constructed and supervised is often not involved in the on-going operation and maintenance. There are many reasons of that, but the main is concern from customer's side that supplier will collect information about internal process and competitors can achieve this information, some suppliers do not have enough resources

to visit or consult customer and at the expiration of the contract ends communication. Because of these reasons a major disconnect is created between supplier and customer during a significant time of equipment life time (see Fig. 7).

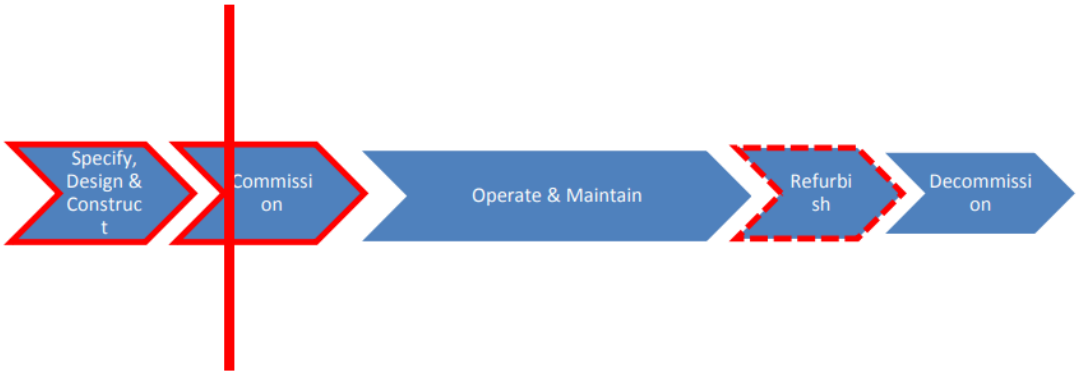


Fig. 7 Disconnection between supplier and customer [15]

The end result of this disconnection is a missed opportunity for both parts:

- Supplier does not receive a feedback which can help to improve equipment according customers need;
- Customer misses the supplier's know-how to optimise the performance and utilise the equipment.

The good example is combination of customers and suppliers knowledge (see Fig.8) that result in a number of benefits to both.

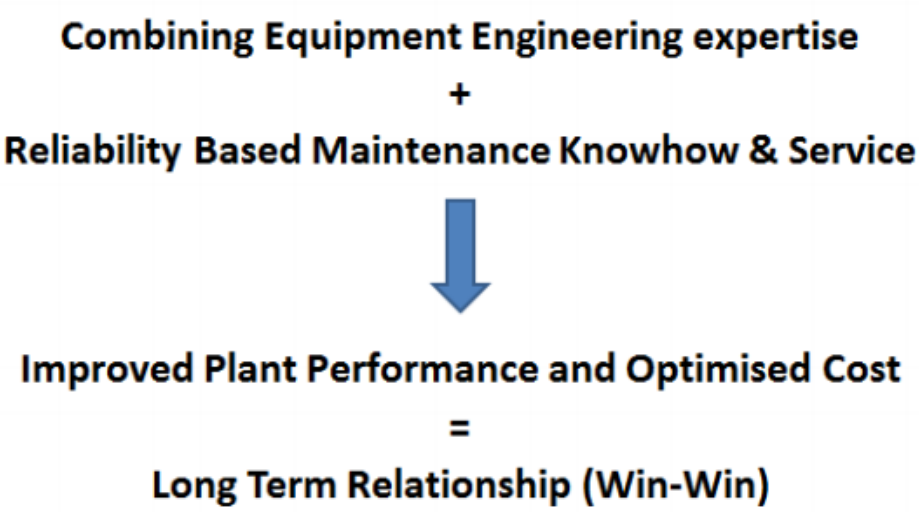


Fig. 8 Combination of customers and suppliers co-operation [15]

The gained benefits can be value added to the specific areas:

- "*An in-depth knowledge of the design basis of both its own equipment and the similar equipment from other suppliers together with the skills and resources for enhancing life cycle services.*
- *Spares optimisation based on its global experience.*
- *Ability to use the on-board systems designed primarily for machine protection to acquire data for maintenance analysis.*
- *Use of the equipment design knowledge to enhance condition monitoring programs by measuring operating variables against design parameters to monitor wear etc. This knowledge is also valuable in choosing the correct location and type of sensors, oil sampling parameters etc.*
- *The development of equipment maintenance plans, in conjunction with the customer, which relate specifically to the particular operation rather than be of a generic basis.*
- *Material enhancements to improve life based on the actual site conditions.*
- *Design modifications to improve maintenance access and cleaning.*
- *Expert oversight and analysis on a regular basis to assist in maintaining plant performance and integrity.*
- *Debottlenecking improvements based on the feedback from operations and maintenance personnel working together.*
- *Shared knowledge and expertise gained from other sites (with appropriate confidentiality) to enable benchmarking of performance.*
- *Training for customer personnel to improve both operations and equipment care.*
- *Life extension projects at the optimum time to minimise cost and maximise the benefits.*
- *Improvements in system documentation through feedback from the site.*
- *Optimisation of energy requirements based on analysis of operating requirements and introduction of the latest design advances where appropriate.*
- *Incorporation of specific site maintenance requirements into future projects. ."* [15]

The global class manufacturers of equipment are always available for advice or helps during exploitation time of equipment.

1.3 Integration of maintenance methods

The maintenance activities are important part of any organisation and are used in manufacturing industry, medicine, health, power and wind supply sectors. Maintenance methods are relevant and carefully analysed. The same method can be applied in manufacturing industry and medicine, without traditional methods there is a new approach – opportunistic maintenance method. [16] Usually maintenance activities are conflicting with production, because customers' demands for product and some repairs are impossible to do without stopping the production. A considerable effort has been introduced regarding the development of policies for a better synchronisation between preventive maintenance and production operations. The main task of opportunistic maintenance method is to reduce the impact of maintenance operations in manufacturing process.

The idea is that maintenance tasks can be done during windows when production is stopped regarding process. Two types of windows were defined: Passive and Active Opportunity windows (PMOW and AMOW). Passive window is defined as the idle time caused by the downtime of other machine in the production line. Active window depends on inventory buffer, when maintenance activities can be carried out without interrupting material flow. A case study was accomplished in the furniture production with purpose to calculate PMOW and AMOW. The results showed that daily production rate may be increased by 5% due to opportunistic maintenance method.

Researchers are deeply looking at the connection between preventive maintenance and quality. For example, in manufacturing companies which are manufacturing medical equipment the quality of final product is critical. The manufacturing system was analysed and the results showed that there are imperfect maintenance methods, which results in frequency of failures. [17] As a solution the preventive maintenance method proposed, because it can reduce frequency of failure and number of non-conforming items. Reworking process of defected items is not effective.

The global warming is a big problem caused by increasing level of CO_2 emission; still induction motors are widely used. Industries are using a majority part of electricity and 80% are used by motors. [18] Efficiency monitoring of motors are concern of maintenance personnel regarding to decisions to overhaul the old motor or install the new one. About 95% of exploitation costs of motors are electricity. The proposed method for cost reducing is the preventive maintenance, because failures of motors cost a lot more, than monitoring and scheduled repair of its components.

As mentioned above electricity is expensive and maintenance of power plants requires a large financial resource, so it's important to choose the right maintenance method that would be effective and costs less. The best defined method for power plant maintenance is Reliability Centred Maintenance (RCM). [19] The RCM process is divided in the steps and each step consists of action group, this method can be implemented step by step, without missing important factors or information.

Wind energy farms aim to replace nuclear energy plants in order to prevent global warming. During a few last year installation of wind power is growing fast in Europe. [20] For this kind of industry maintenance strategy has to be optimised and based on the right decision. The best solution of maintenance method for wind power plant is RCM and predictive maintenance.

RCM was first developed for aviation industry and that shows the precision of this method, for further analysis in this research paper I will use tools of RCM to identify critical equipment and defend the best solution. This maintenance method enables quick analysis and has a clear flow of

actions to be done step by step. A lot of case studies are done in the field of maintenance strategy, because it's important for company's finance and production process. The good synchronization between maintenance activities and production process may increase efficiency up to 30%.

2. Description of analysed company

The company's story began more than 50 years ago, during that time period it becomes one of the biggest manufacturer in wood industry at Lithuania. Since 2008 company is a part of the biggest furniture producer in Europe. International company is divided in a separate divisions by the production process, in Lithuania there are furniture and particleboard factories.

The particleboard production line is designed to produce 500 000m³ of particleboard per year. The production process is continuous, the line is operating 24/7, 4 shifts are working, the duration of one shift is 12 hours, in the particleboard factory works ~200 employees in total, that number includes management team and administrative personnel.

Production machines are manufactured by the best and well known company's in Europe (see Table 1.).

Table 1. List of machine manufacturers

Pneumatic and electric automation	Festo
Forming machine	CMC Texpan
Cold press	Siempelkamp
Steam	Imal
Hot press	Siempelkamp

Suppliers of machines make recommendations for operating and exploitation of equipment, gives advises about causes of faults and failures, makes repairs. Machinery is divided into separate groups by the technological process flow; for example wood shredding and screening of wood chips are located in the different buildings. Technological process before hot pressing is preparation of wood mix. Equipment for gluing, forming, pressing and cooling are located in one line.

The process of particleboard production starts in the forest, because it's important to buy a high quality timber, safety and sustainability is a priority, and forests have to be certified. The company carries out audits and verifies how the requirements are met. Technological flow (see Fig.9) starts by cutting logs and preparation of chips, moisture content of chips is 80%, further processes requires 2% of moisture, company is using 4MW power dryer for drying the wood chips. Wood chips and dusts are mixed with resin and then matt formed; the most important process is hot pressing. After the pressing process boards are cut to size and then stay in a cooling station before forming a stacks. Surface of particleboard is sanded, because of better adhesion of finishing materials.

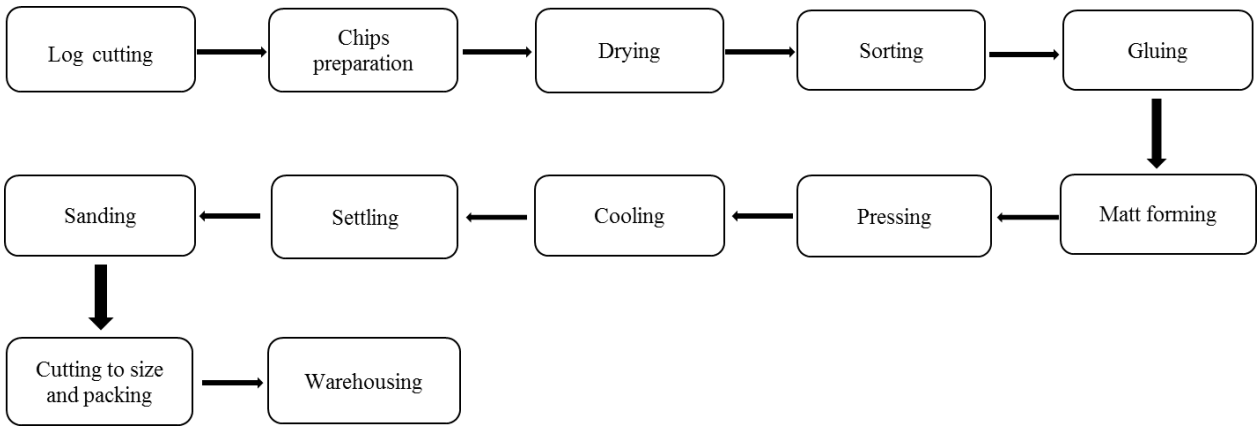


Fig. 9 Technological flow of particleboard production

Company has a foiling line, where finish foil or balanced paper are glued to the particleboard surface, the finish foils forms final quality of the surface, and the balance papers are used for painting, both type of papers are adapted to customers' needs. Customer receives a big format of the board, and then cut to size. The foiling line is operating only 3 days a week and duration time of downtimes are out of interest field for further analysis.

3. Maintenance management at the company

Maintenance department is responsible for analysis of downtime, for repair, for control of failures, for prevention and all actions connected to technical support. Maintenance manager is coordinating middle management team which responsibilities are allocated according to the process (see Fig.10).

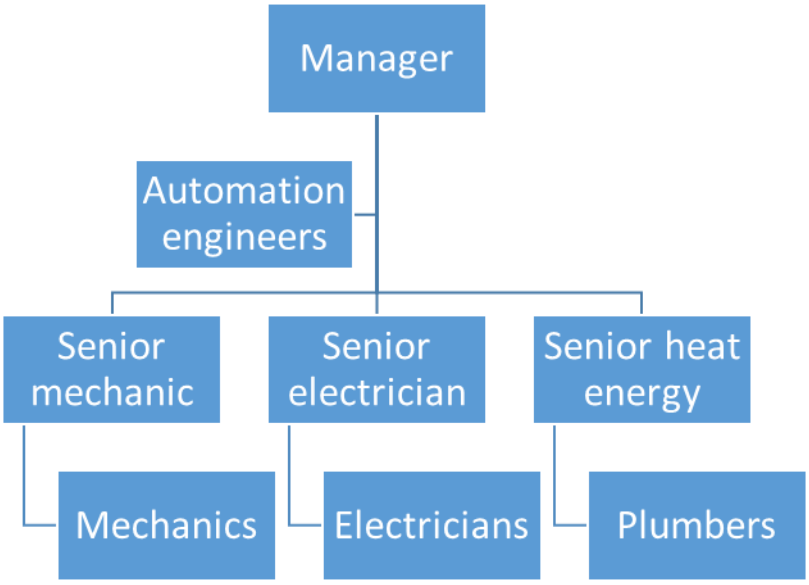


Fig. 10 Structure of maintenance department

Responsibilities are divided in pursuance to achieve the best supervision of equipment. Senior mechanic is supervising mechanics, ordering spare parts, planning repairs during stops, coordinates weekly and monthly repairs, analyses failures and the root causes of them.

Senior electrician coordinates electricians who are responsible for supervising electrical part of machinery. One of his obligations is to order spare parts and control safety stock in warehouse. Electricians' team are doing all repairs that are related to electrical part of equipment.

Senior heat energy supervises plumbers and controls boiler house. This team carries out technical management and repairs of heat and water supply systems.

Automation engineers do not have a directly subordinate employee, but they play important role in the technical support. System and IT failures, automated actions are controlled by them.

Maintenance team is available 24/7 and is responsible for the fastest as possible repair of equipment. Preventive maintenance method is in use now, but in the future achievement of Total Productive Maintenance (TPM) by 100% is desirable. The department collects all data about failures, downtime and repairs. In order to better control and analyse failures ProdIQ software is installed, it gives a chance to register every minute of downtime.

Mechanics has a list of actions that has to be done daily, weekly and monthly. Regular care is carried out in accordance with machinery manufacturer`s operating and maintenance instructions. In the event of an accidental failure, if failure is complicated the manufacturer of equipment is consulted.

Above mentioned personal have rights to make decisions what to repair first by their selves, but in some circumstances they need to get permission. A flowchart of decision making is given in Fig.11.

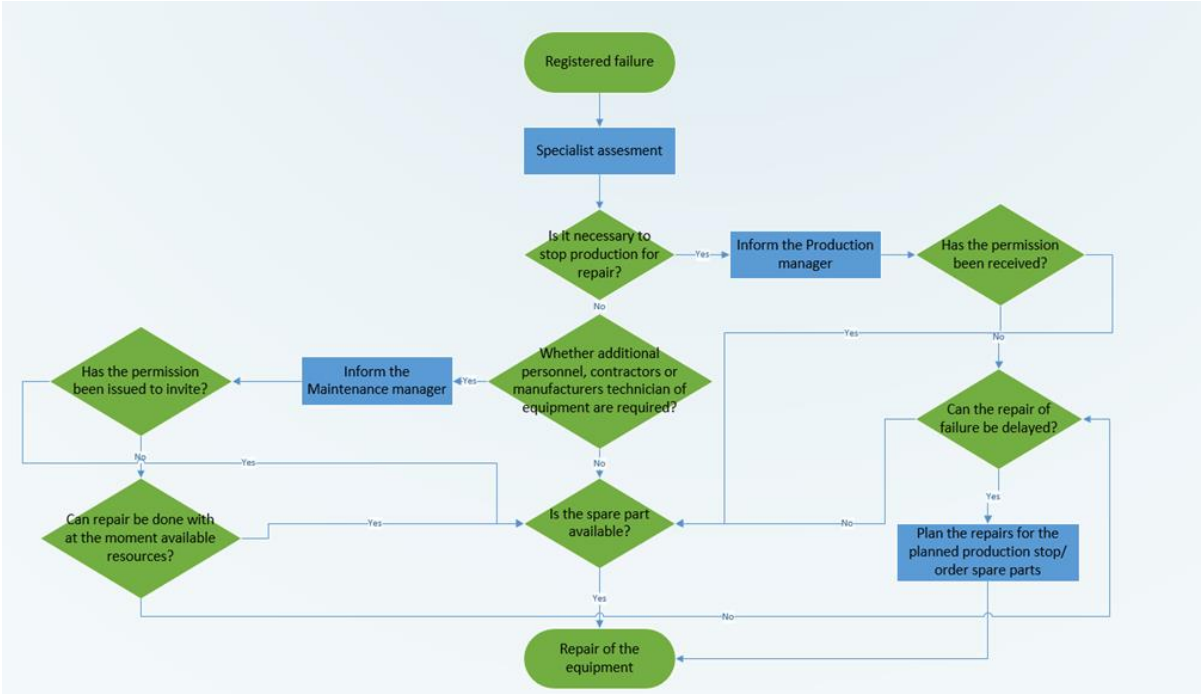


Fig.11 A flowchart of decision making at maintenance department

In some circumstances contractors or technicians from equipment manufacturer are required. Small repairs can be done without asking permission, but if failure requires production stop it has to be aligned with production manager. Extra situations are directly communicated to production and maintenance managers and they make the decision how to proceed, some cases are communicated to the General Manager of the company, especially when long time of production stop is expected, that causes delays in deliveries for customers. In order to maintain a smooth technological process operators are cleaning equipment and stopping the production line, during that time maintenance personnel can make repair. Communication between both departments is at a highest level of importance.

Maintenance and production departments are closely related and works together for the achievement of the best result, every day meetings are organised where repairs are discussed and priorities settled. It`s natural that some repairs can be done later than others, because of staff

availability and access to equipment, they are prioritised. A very important role-plays line operators, they are all the time around equipment and the first ones identify the faults. Every shift registers breakdowns and failures in journal, so maintenance staff can read what needs to be repaired and can leave their record. In the morning, when shifts are switching, the shift leader shares information about downtimes with production manager, technologist, maintenance staff and fire safety specialist, the most important repairs are identified during that meeting, and an action plan is settled.

Maintenance department analyses downtimes and causes of them, identifies where is the most problematic part of equipment and consults with production department what could be done to avoid them in the future. On purpose to control the maintenance processes, the particleboard production line is divided in separate groups by the most important function in that equipment group:

- Infeed pocket – all transporters and equipment that carry out transportation function.
- Dryer section – drying function of the wood chips.
- Screening section – wood chips are made of 3 different fractions, that has to be separated for further process.
- Gluing section – all equipment for mixing wood chips and resin.
- Forming section – formation of the particleboard matt.
- Press section – pressing formed matt into particleboard.
- Trimming, cooling and stacking section.
- Storage and sanding.

Machinery and equipment mentioned above are important for technological process and requires a various specialist supervision. Each section consists of mechanical and electrical devices, rotating parts, transporters; the weakest points in sections are identified and assigned to the group of downtimes, which are described below:

- Mechanical – equipment or it`s part is broken mechanically;
- Electrical – electrical part of equipment is broken;
- Production – the reason of downtime could be contaminants;
- Changes – changing of batch can cause a stop;
- Lack of raw material – direct influence;
- Planned – downtimes are planned due to small repairs or cleaning.

Production line and downtimes are divided into several groups and that allows identifying and controlling the most frequent failures. Recommendations will be made based on the most critical and frequent failure to the production process.

4. Analysis of downtimes

The maintenance department is analyzing downtimes, in order to prevent and control failures, which are divided into different groups. Every group can be analyzed separately and downtimes are assigned to the group. As an example, data of year 2017 (see Fig.12) will be used. In this graph we see actual hours of downtimes divided by the separate groups of production line, even *force majeure* and planned maintenance are involved. Maintenance staff can identify which section fails most of all and can make deeper analysis of it. As mentioned above, sections are divided into smaller parts by equipment or devices, having this graph and more accurate data, downtimes can be divided into mechanical and electrical (see Fig.13 and 14).

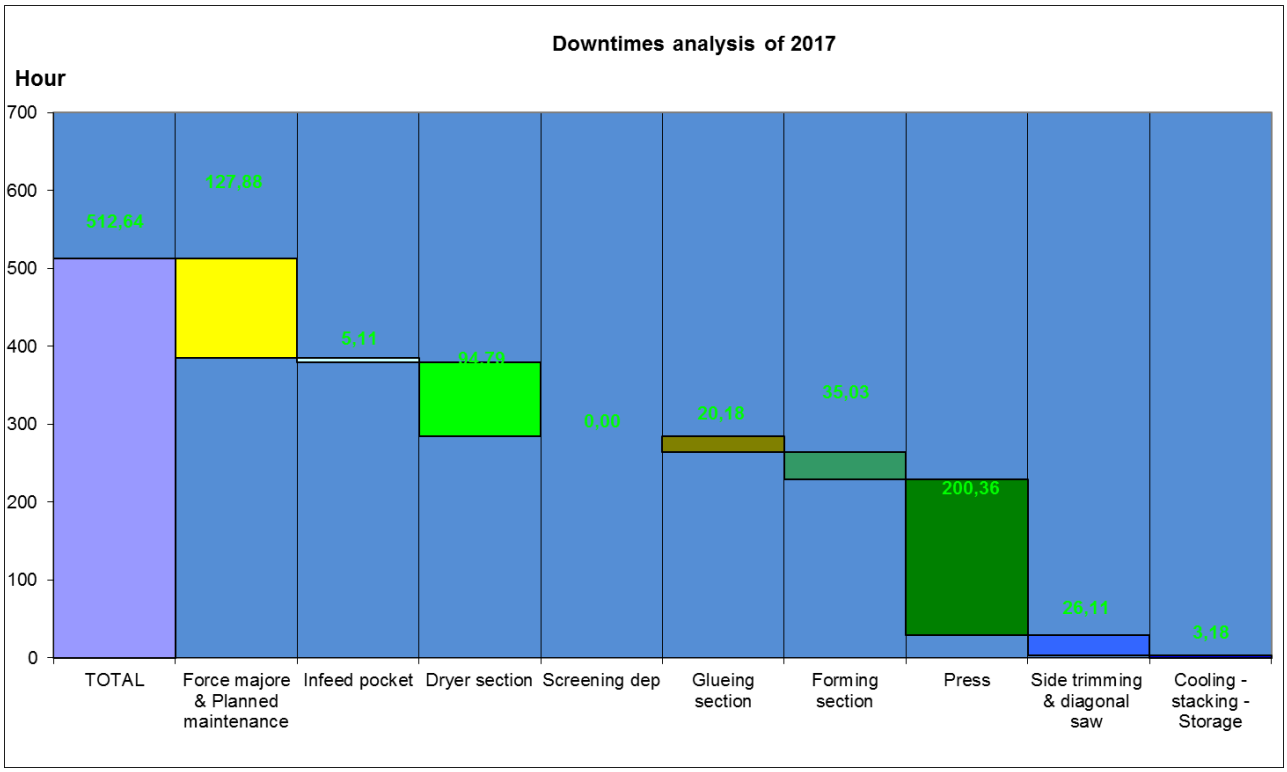


Fig. 12 Time of downtimes in hours by the section

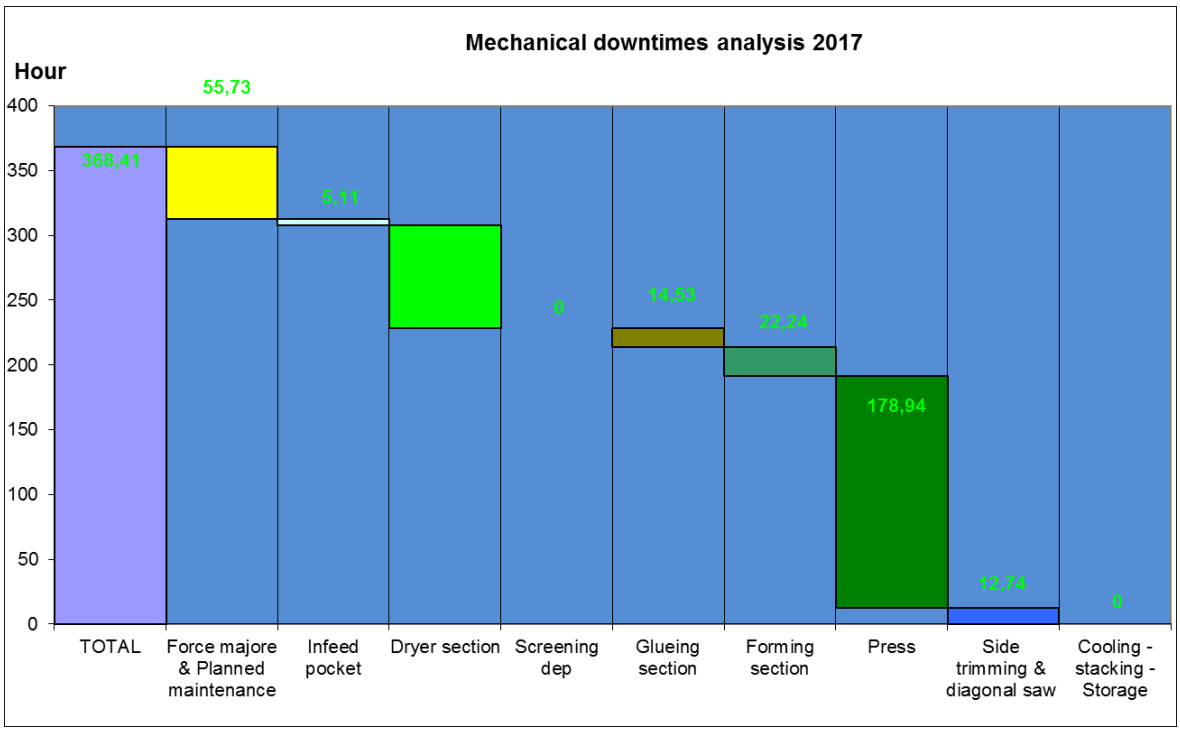


Fig. 13 Time of mechanical downtimes by the section

This graph illustrates how much time has been spent due to mechanical failure and in which section the most. It can be seen that most of the idle time is caused by the press section, which means this section should be analyzed more deeply.

Electrical downtimes (see Fig.14) shows that the most time, it`s caused by *force majeure* and planned maintenance, in this case *force majeure* has to be identified as the main cause, because planned maintenance has no connection with electrical failure. *Force majeure* in the most cases is external disturbances of electricity supply. In the press section indicators are high, so mechanical and electrical failures can be related.

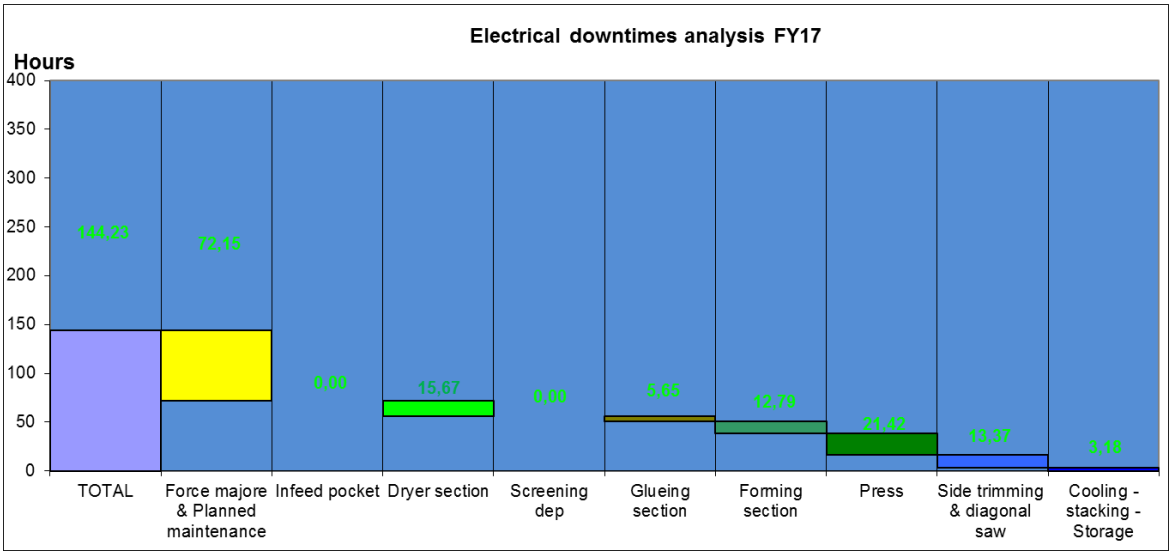


Fig. 14 Time of electrical downtimes

Electrical and mechanical failures can be analysed more accurate by dividing them into groups by the type of failure, machine or part. As the above mentioned downtimes are registered using ProdIQ software, time is recorded automatically, but the line operators must specify the reason of downtime, its type and add comments if necessary. Maintenance staff can analyse them using a filter and collect data for each type of problem. Every morning records are checked and information transmitted to responsible personnel about them.

The particleboard production line consists of several types of machines by their function in the technological process. Usually faults depend on type of machine and its function. Parts of machine is inspected periodically, for example bearings are exanimated every month and results recorded in journals, maintenance staff can monitor them and prevent from failing, nor not always it is successful. Damages, failures or faults are divided in separate groups by the type of cause (see Table 2):

Table 2. List of failure causes

Part of machine	Cause of failure
Rotating parts	Worn-out, physically damaged, not lubricated
Sensors	Physically damaged, contaminated
Transporters	Worn-out, physically damaged
Pneumatic parts	Physically damaged, electrical failures
Hydraulic parts	Physically damaged, electrical failures

Worn-out parts can be replaced or renewed, that depends on level of wear, sensors always are replaced, transporters can be repaired as well as pneumatic and hydraulic parts, but sometimes they have to be sent to producer's plants. For example, the steam injection head can be disassembled or repaired only at the manufacturer's plant, otherwise it's treated as not repairable.

In this research paper I will analyse data of two past years about downtimes and failures. In Fig. 15 it is visible hours of downtimes decrease in 2017 compared with year 2016.

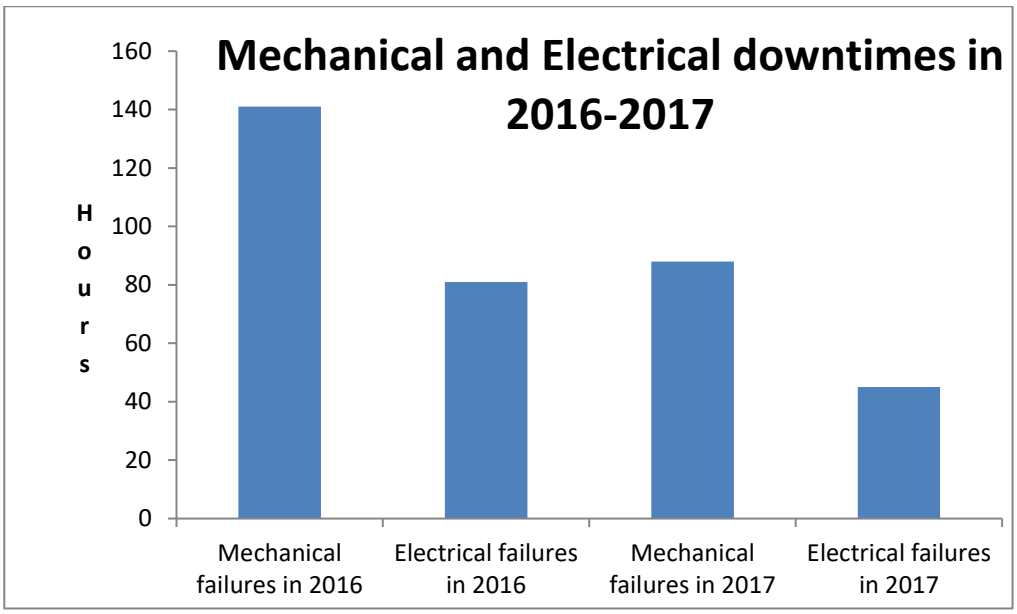


Fig. 15 Hours of downtimes in year 2016-2017

Hours of electrical failures decreased double, but mechanical failures is still not managed as electrical, that shows existing problems in this field. As seen in the graphs the most sensitive part of downtimes are mechanical failures, which are occurring in the press section. Equipment of the press section has a different purpose; the most problematic device has to be identified for further research.

Setting up a priority device

Devices need to be prioritised in order to achieve the highest level of maintenance. Mechanics, line operators, production and maintenance managers can have different opinion about priorities, in order to avoid that I interviewed employees.

For my investigation I choose to interview 2 senior operators with more than 10 years of experience, 2 mechanics, one is working on working days from 8 to 17h and another one is working in shifts (day and night shifts,8-20h;20-8h), production and maintenance managers, senior mechanic. I asked them to specify the most important and frequent failures in the particleboard production line, after making a list they were asked to evaluate downtimes importance by 3 main criteria's:

- Influence to production process;
- Influence to quality and efficiency;
- Influence to safety and environment.

Respondents were asked to evaluate the importance in scores from 1 to 5:

- 1 – not important;
- 2 – has small influence;

- 3 – medium important;
- 4 – important;
- 5- very important, direct influence.

Results of expertise interview are represented in Table 3.

Table 3. Results of evaluation of Press section failures

Criteria	**Respondents**	**Equipment**				
		Matt transporter	Forming machine	Intermediate belt	Chains of hot press	Cold press
Influence to production process	Operators	3	4	5	5	3
	Mechanics	3	3	3	4	2
	Production manager	4	4	5	5	3
	Maintenance manager	3	3	4	3	2
	Senior mechanic	2	3	4	3	2
Average		**3**	**3,4**	**4,2**	**4**	**2,4**
Influence to quality and production efficiency	Operators	4	4	5	5	4
	Mechanics	2	3	3	3	2
	Production manager	4	4	5	5	4
	Maintenance manager	2	3	5	3	2
	Senior mechanic	2	3	5	3	2
Average		**2,9**	**3**	**4,6**	**3,8**	**2,8**
Influence to safety and environment	Operators	3	3	4	4	3
	Mechanics	3	2	5	4	3
	Production manager	4	3	4	4	3
	Maintenance manager	4	2	5	4	3
	Senior mechanic	3	3	5	4	2
Average		**3,4**	**2,6**	**4,6**	**4**	**2,8**
Total average:		3,1	3	**4,5**	3,9	2,6

Respondents assessed on their own experience and perspective. Intermediate belt scored the most and respondents were asked why, few reasons appeared:

- Intermediate belt failures are indicated as the highest rate of interest;
- Mechanics does not know the root cause of failures;
- It has direct influence on the product quality and production efficiency;
- Impossible to predict failure, no indicators showing it.

The highest score of importance were proven by statistical data of downtimes cause by intermediate belt failures in time period of 2016 and 2017 (see Fig.16). Failures of intermediate belt are attributed to mechanical.

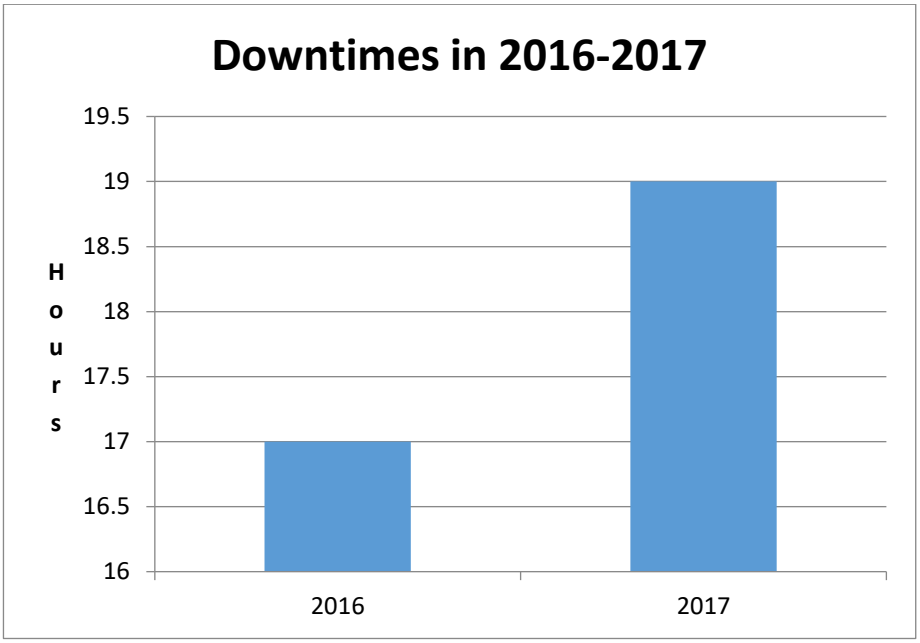


Fig. 16 Downtimes caused by the intermediate belt

Compared with mechanical and electrical downtimes it occupies a big part of them (see Fig.17).

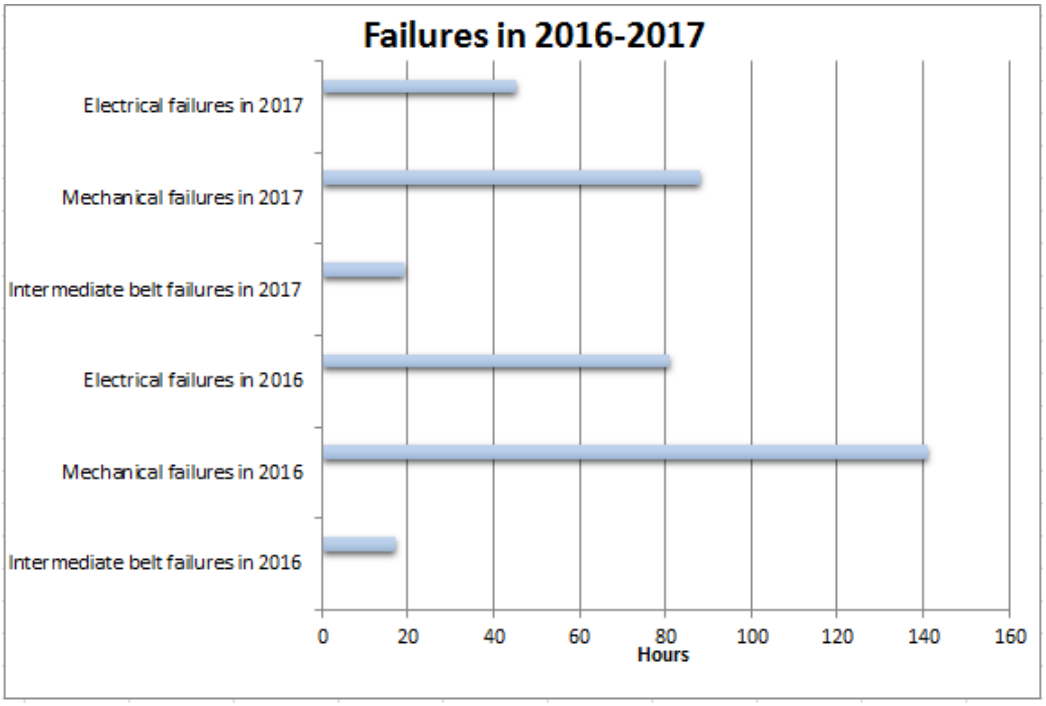


Fig. 17 Intermediate belt failures compared with mechanical and electrical in 2016-2017

An expert interview found that the intermediate belt is important for the production process and quality of the final product. The result indicates that the employees are involved in the quality

control activities and participates actively. In the next chapter influence on quality of the failures of intermediate belt is explained.

Intermediate belt influence on the surface quality of particleboard

A failure of equipment has direct influences to the product quality and increases cost of quality ratio. Intermediate belt failure causes damages in the particleboard surface. Fixed particleboard production line utilization index is 92,3%, it can be higher but not lower, process has to be stable and effective. Repetitive downtimes caused by the same equipment have effect on utilization and efficiency rates, and are more important when directly influence the product quality.

When intermediate belt is slipping it damages surface of formed matt (see Fig.18) and all boards with this defect are classified as a scrap. In order to save resources and money company has fixed rate for scrap, opposite to the utilization index this rate cannot be higher than 0,63%.

Fig. 18 a) Surface of particleboard after intermediate belt failure b) Surface of A quality particleboard

Company focuses on customer satisfaction and profit, each department has budget for financial year and repetitive failures cost a lot of money. Intermediate belt at this time is prioritized equipment and maintenance department task is to control failures and protect from appearing in the future. Summary of intermediate belt failure is given in Table 4.

Table 4. Summary of intermediate belt failure cost

Downtimes in hours during 2017	19
Cost of one hour downtime	10 000 €
Cost of downtimes in 2017	190 000 €
Number of changed intermediate belts during 2017	8
Price of one intermediate belt	8000 €
Cost of intermediate belt during 2017	64 000 €
Total cost of losses in 2017	**254 000 €**

In those calculations indirect costs as salaries, cost of quality, cost of raw material and others are not included. Company during year 2017 lost 254 000€ on direct costs of failures.

Surface quality of the final product is a very important thing to all customers, because if there are hidden defect, customer is not able to catch it during its own process, and defective furniture is delivered to the retail.

5. Analysis of intermediate belt construction and function

5.1 Function of intermediate belt

The intermediate belt transfers the precomputed matt from the forming belt to the steel belt of the Hot Press. It is a short conveyor belt located right upstream of the Hot Press. The main elements are (see Fig.19):

- A structure made out of welded frames to support the components;
- A tensioning roller fitted with spindles to tension the belt;
- The belt is driven by a drive roller. In order to prevent slippage the driver roller is rubber-lined and itself is driven by a servomotor;
- Pilotable tracking roller with setting unit for belt tracking;
- Lateral belt edge tracers to sense the belt edges. In case of belt displacement belt tracking is initiated;
- Lateral limit switches to sense the belt edges. In case of belt displacement a belt stop is initiated;
- Movable and pilotable slide table with transfer nose.

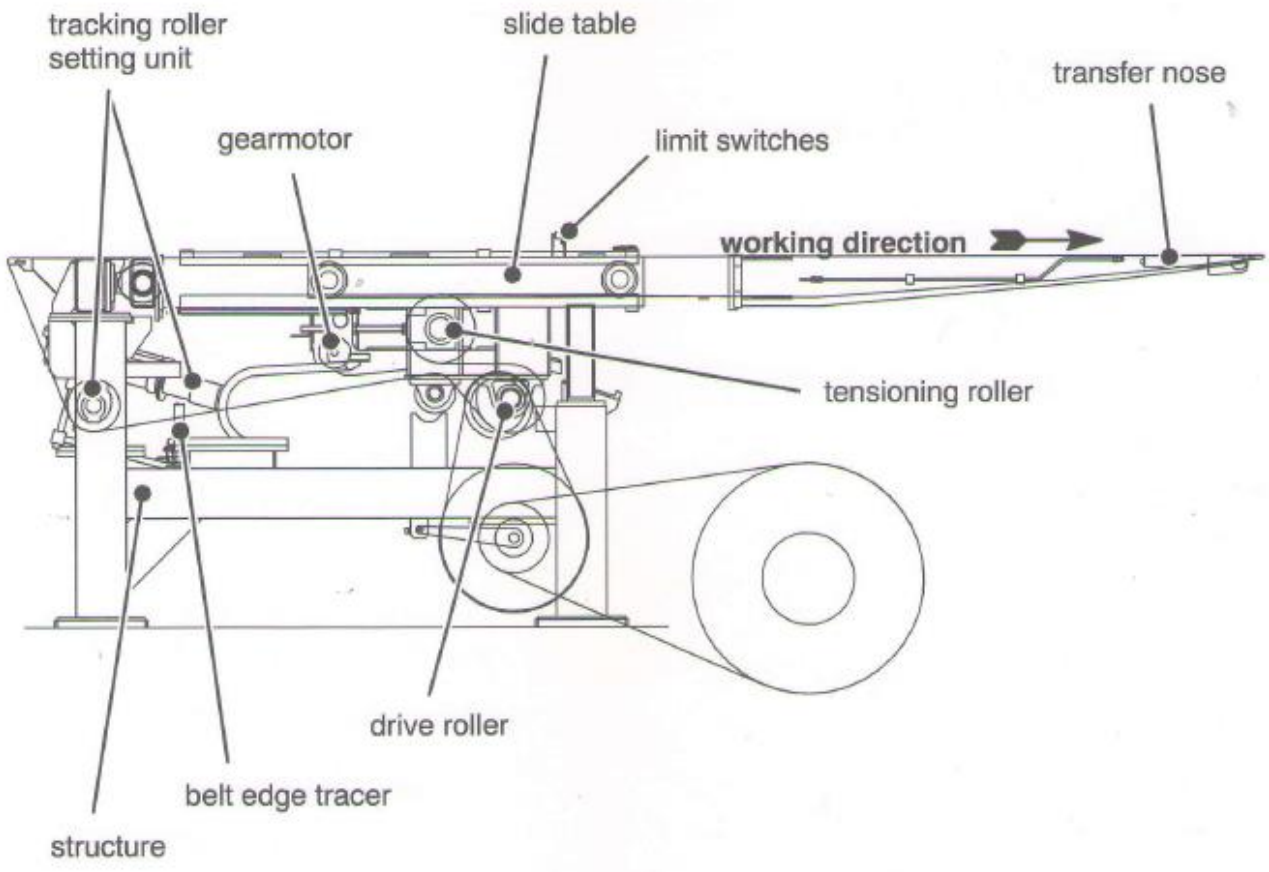


Fig. 19 Design of intermediate belt

To set the optimal transfer point for the matt on the Hot Press the slide table can be shifted horizontally. The intermediate belt reaches into the Hot Press (see Fig.20). The transfer nose rests on sliding elements. The sliding elements are fitted on the left and on the right in the Hot Press infeed drum seat. Setting of the sliding element: in its front final position the transfer nose has the correct distance to the steel belt.

The front position is defined to be the optimal transfer point for the matt on the steel belt.

When the slide table moves into its rear position the transfer nose automatically lifts off the steel belt.

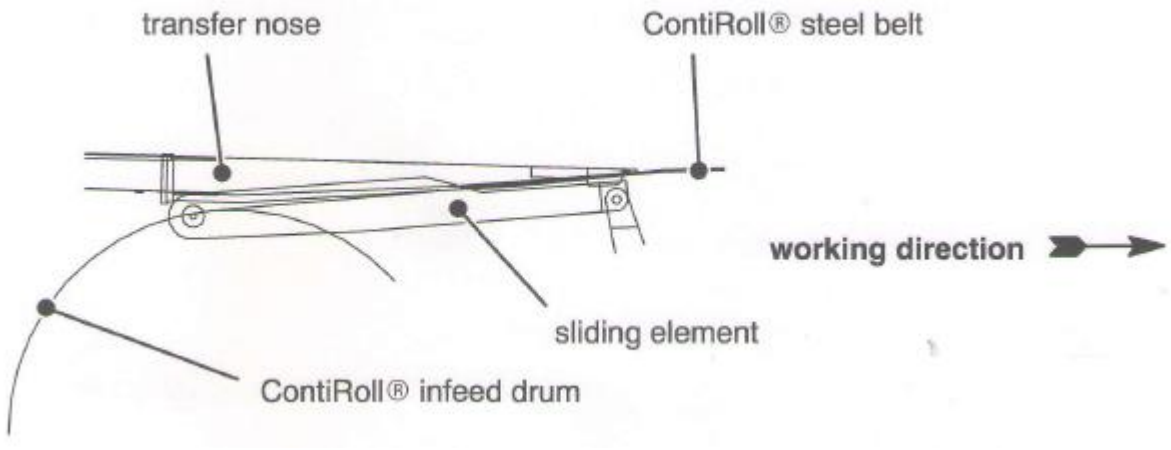


Fig. 20 Illustration of intermediate belt function

To ensure proper operation of the intermediate belt the transfer nose at intermediate belt is fitted with a groove blow-off device. To reduce amount of dust which may be conveyed from the matt edges into the Hot Press a belt edge extraction system is installed at the transfer point from the forming belt to the intermediate belt.

In order to understand how intermediate belt is working its sub-elements has to be known as well. The most often breaking element is gearmotor, because of the equipment construction repair requires time up to two hours, the moving parts are worn out, but doesn`t not significantly influence repairs, their replacement can be planned in advance. The gearmotor may be inspected periodically due to the preventive maintenance method.

5.2 The side table

The slide table serves to determine the transfer point of the matt from the intermediate belt onto the steel belt (see Fig.21). The rollers of the slide table run on a movable rail, the rail is fixed to the rack of the intermediate belt. The main elements are:

- Rigid frame with rollers on either side;

- Transfer nose with lateral sliding elements. The transfer nose is bolted to the frame of the slide table;
- Gear-motor, universal joints with toothed wheels to drive the slide table.

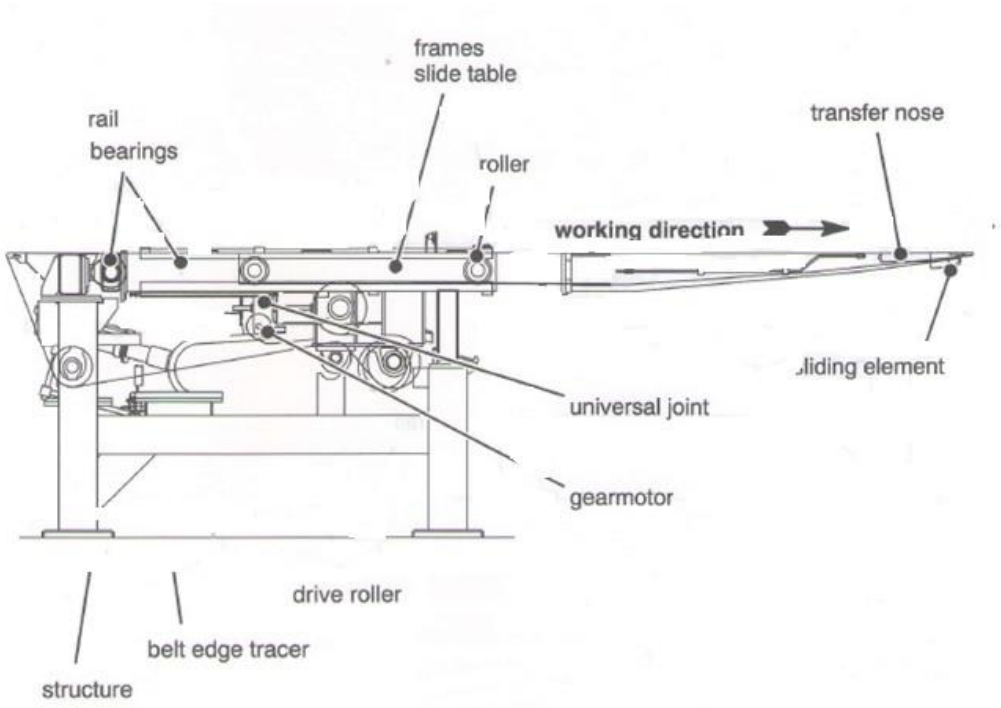


Fig. 21 Design of intermediate belt slide table

Rollers wear out and bearings are inspected periodically, contractor is measuring vibrations in order to prevent failure.

Function of the slide table

The slide table rests with its sliding elements on the sliding elements skids of the bottom Hot Press infeed drum seat (see Fig.22).

The universal joints with their toothed wheels transmit the rotation of the gear motor.

Toothed racks are fixed underneath the rails. The toothed wheels catch into the toothed racks to move the slide table.

The slide table rollers run on guides fixed inside the rails:

- Each side of the rail is fitted with a top and bottom guide.
- Depending on the inclination of the slide table the corresponding rollers make contact with the bottom or with top and bottom guide.

The final positions of the slide table are checked by limit switches.

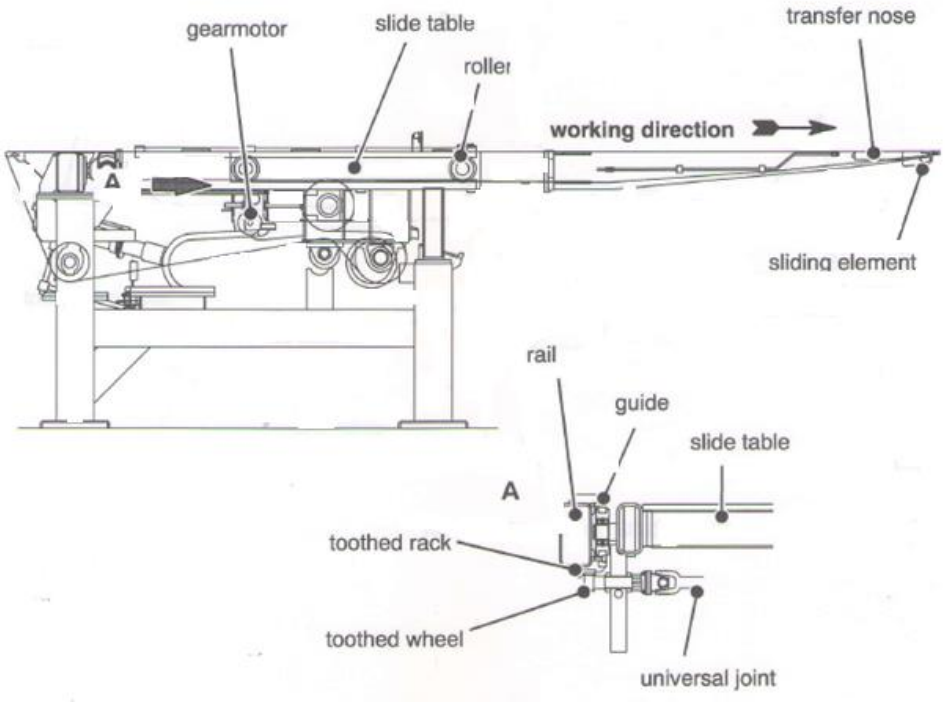


Fig. 22 Function of the slide table of intermediate belt

The toothed rack and wheel are visually inspected every week and if any cracks are detected, they are added to the replacement list.

5.3 Intermediate belt drive

The drive station is a separate unit which is positioned next to the intermediate belt and is bolted to the intermediate belt structure. The main elements are (see Fig.23):

- Servomotor with coupling and brake for the drive;
- Gearbox with two shaft ends for speed transmission;
- An overriding clutch serving as a mechanical safety system to limit the belt speed;
- A universal joint transmits the rotation to the drive roller of the intermediate belt. At the same time the universal joints makes up for the offset to the drive roller.
- A pinion shaft with chain pinion on both sides.

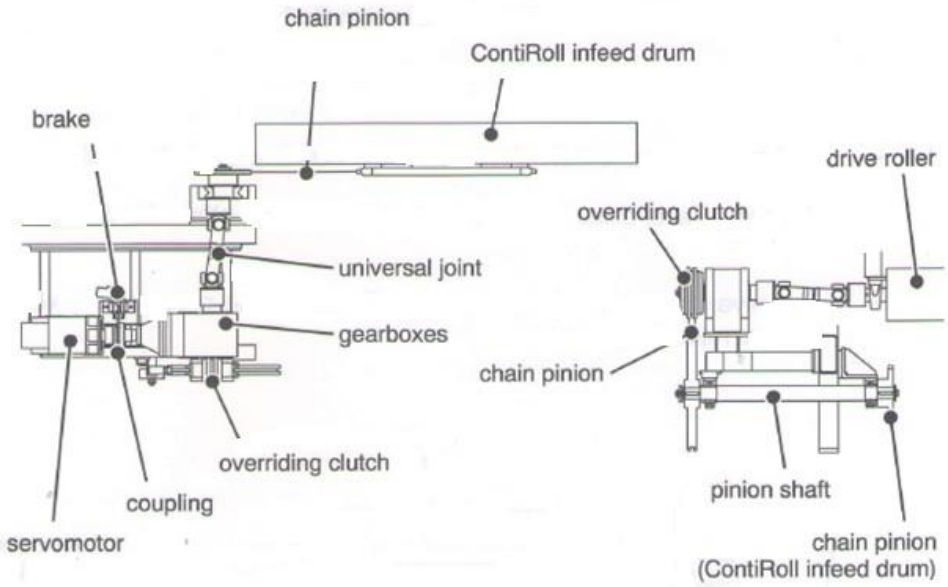


Fig. 23 Intermediate belt drive

Angle encoders monitor rotation and slippage of the bottom infeed drum of the Hot Press and the deflection roll of the intermediate belt.

The chain pinion of the pinion shaft links the bottoms infeed drum of the Hot Press with the overriding clutch at the gearbox. This system arrangement from a mechanical stopper for the servomotor:

- The transmission of the chain pinion is set so as to limit the intermediate belt speed to max. 103% of the corresponding Hot Press speed.

The servomotor is integrated in the drive control system of the Hot Press its actuation is synchronized to the main drive system. The speed is electrically limited to ±1% of the Hot Press speed. From the max. speed of 103% the servomotor is mechanically limited by the overriding clutch, if the electrical limitation fails:

- The clamping elements of the overriding clutch wedge locking wheel and race. This is to block the direction of rotation. In opposite direction the clamping elements remain floating.
- In addition a synchronization failure is signaled to the plant control system.

After a failure (e.g. error indicated by the peak detector) the furnish on the intermediate belt may be rejected:

- To this end the direction of rotation of the servomotor is changed;
- The max travel distance should not exceed 5.5m otherwise the belt might displace;
- This reversing function is controlled locally. During this process keep watching the matt rejection process.

In this facility node the main problem is the chain pinion, because during operating it extent, if change in length is more than 20mm the chain is cutting off and joined again, the tension of the chain then is acceptable. For the chain periodical measurements may be done in order to avoid downtime because of the extension.

6. Recommendations for reliability improvement

6.1 Steam injection equipment

Above explained how intermediate belt is operating and why its important part of process and equipment, without this element transfer to steel belt is nearly impossible. Costs of downtimes are too high and company needs solutions in a cheapest and most efficient way.

Structure of the line and equipment's around intermediate belt are important factors and need to be analysed, one of the important part is steam machine, located above intermediate belt. First of all mat is transported through cold press and transferred on intermediate belt which transports it to Hot Press (matt is transferred from intermediate belt on steel belt, because of the high temperature in hot press only steel transporter is possible), but before entering hot press temperature of matt has to be raised. The fastest way to raise temperature is to use hot steam, whose temperature is 180^{o}C. The best result can be reached when temperature is raised right before hot press, because of the line and equipment construction special mechanism is used called Dynasteam (see Fig.24 and 25).

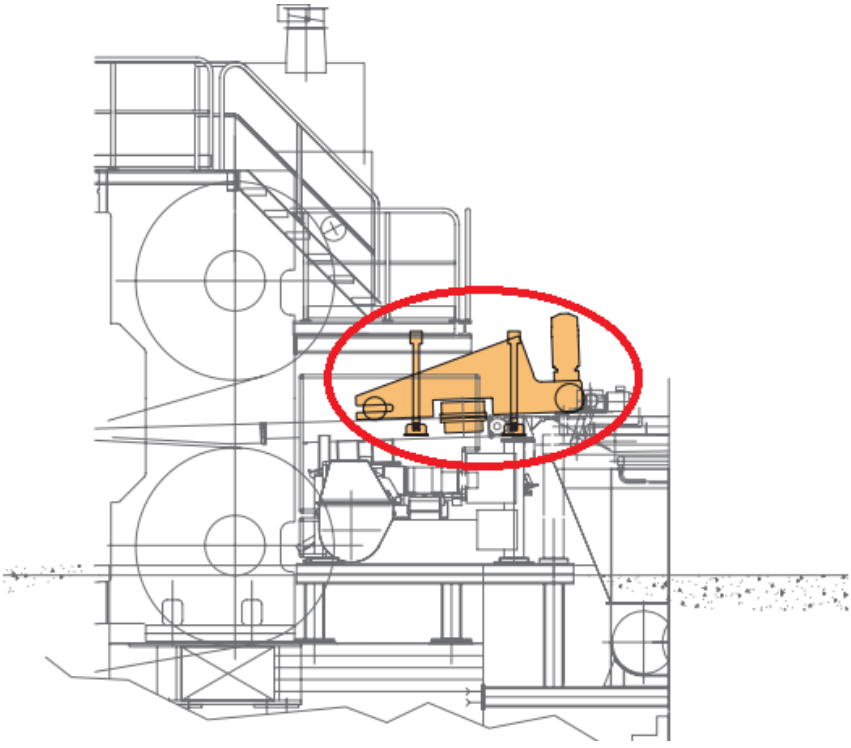


Fig. 24 Scheme of steam injection equipment in the particleboard production line

Fig. 25 Real picture of the steam injection equipment

Advantages of hot steam are:

- 15-30% increase in production capacity;
- Improved board density profile;
- Less pressure required at continuous press infeed, resulting in less wear on the chains and steel belt;
- No condensation spots on the mat;
- Glassy surface for lacquering.

Exploitation of this equipment requires special knowledge and professionalism, because of that manufacturers trained operators and maintenance staff, operating instruction are located in control room. Parts of this machine are very expensive and sometimes irreparable, main element of steam injection is steam head, and can be opened or repaired only at the manufacturer's side.

Operators had opinion that steam can have direct influence on intermediate belt and cause failures; frequently intermediate belt is slipping after changed amount of steam. Several trials were made and one of them showed positive result. Two shifts participated in trial; senior line operators shared their opinion and suggested how to proceed. Results of trials are given in Table 5.

Table 5. Results of steam trials

Shift	Thickness of particleboard, mm	Size of batch, m³	Amount of steam at the beginingg, g/m	Final amount of steam, g/m	Amount of steam per minute	Duration, min	Does intermediate belt slipped?	Quality of the particleboard surface, OK/NOK
A	16	500	20	55	4	8	No	OK
A	18	550	25	60	4	8	Yes	NOK
C	18	250	20	55	5	7	No	OK
C	24	300	25	60	7	5	Yes	NOK
C	30	400	15	50	7	5	Yes	NOK
A	24	600	15	45	5	6	No	OK
A	18	450	15	60	5	9	No	OK
C	19	800	15	55	7	6	Yes	NOK
A	12	400	15	30	3	5	No	OK
C	16	600	15	45	8	4	No	NOK
C	15	550	15	45	5	6	No	OK
Average	**19**	**490**	**17**	**51**	**5**	**6**		

Trials were done during daily production process and quality of the final product were carefully checked, final decision was made with reference to the surface quality and steam amount per minute, which indicates how fast amount of steam can be increased without any impact on the quality. The right amount of the steam increase line speed and output per hour, which is from 70 to 110m³. Operators are interested in producing more, because their salary's part depends on the quantity produced.

- The best result is obtained using from 15g/m to 45g/m of steam and increasing from by 5g/m per minute.

During trials different ways of evaporation were detected, each line operator has his own manner, in order to avoid human factor and mistakes procedure of evaporation of steam head were created (see Fig.26). This procedure is based on the operating recommendations of the equipment manufacturer and the experience of the operators. Actions must be carried out sequentially, in order to avoid error and loss of time. After a long stop operator is trying to start the production quick and not follow all rules, this procedure is confirmed by production and maintenance managers, and operators are obligated to use it. The procedure is presented for each shift operator and they are trained step by step according procedure document. The benefit of the procedure will probably arise after the first long stop. This type of procedure is an auxiliary tool for new employees at the start of their work.

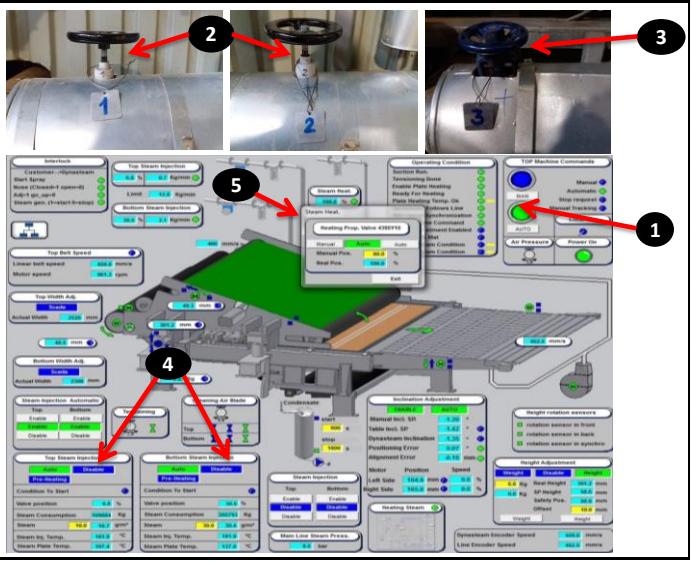
Evaporation of Dynasteam		
Description		Illustration
The evaporation procedure has to be done before planned downtime, longer than 4 hours or when downtime last longer than planned and is more than 4 hours.		
1	In Dynasteam vizualization turn on manual mode.	
2	Fully close the upper and lower steam drain valves for the steam supply line.	
3	Fully open the hotplate hand valve.	
4	In the visualization, turn off the upper and lower steam feed.	
5	In the visualization, turn on the heating manual mode and set the proportional valve opening 20-30%.	
6	After the evaporation procedure is completed, return to the automatic mode: open the manual valves p. 2, enable auto mode in visualization p. 4 p. 1 and p. 5	

Fig. 26 Procedure of evaporation of Dynasteam

The procedure must be followed up step by step in order to avoid mistakes and loss of the time. Every operator can reach and use it.

6.2 Exploitation of intermediate belt

During year 2017 company has changed 8 belts and spent 64 000 €, I recommend to change predictive maintenance method to preventive and change intermediate belt every two months during monthly maintenance stop, calculations are simple and company needs only 6 belts, saves 16 000 € only on the belt and downtimes can be refused to 30%. Analysis of intermediate belt change frequency indicates (see Fig.27) that the longest time period of one belt operating is 2 months, if belt is in use longer than 2 months, the belt changes dimensions in length and causes aberration from normal direction. Otherwise, if belt is in use shorter than 2 months, it's because of the slipping effect, when belt slips more than 5 times per shift, maintenance staff decides to change it. Under these circumstances, when the root cause of failures is not known, the easiest and fastest way is to prevent intermediate belt from failure, also company can save money, because no additional resources are required. Intermediate belt may be changed during monthly maintenance, an additional personnel participates already, and senior mechanic can maintain a safe balance of intermediate belt in the warehouse. The mechanics can get new trends in the production of the intermediate belt and plan trials with different type of them, in order to find the best balance between parameters, operating time and price.

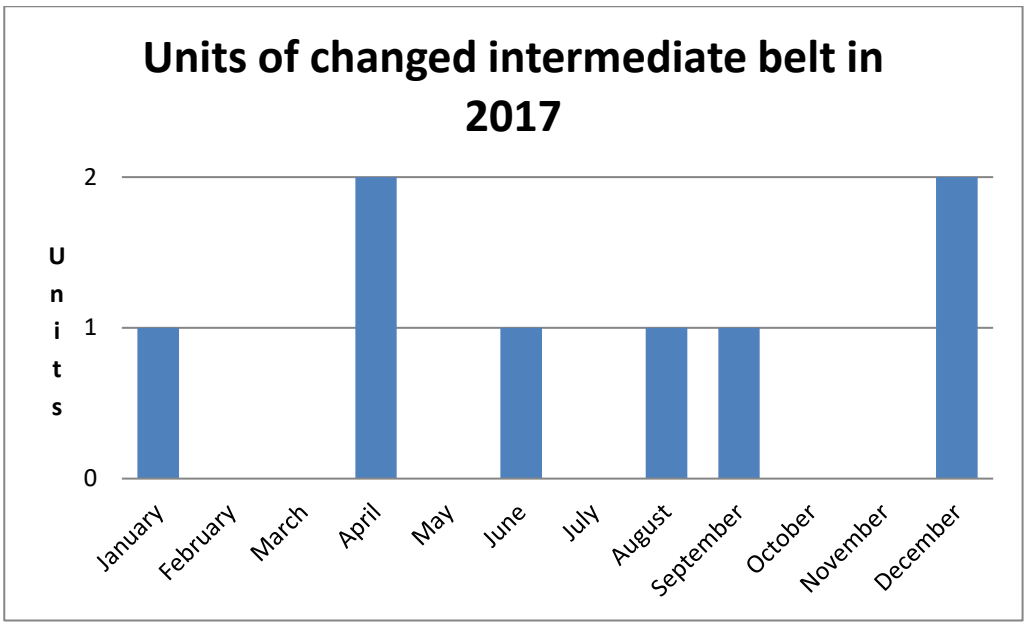


Fig. 27 Frequency of intermediate belt change in 2017

Some manufacturers of particleboard are operating without steam injection and there are several types of intermediate belt. In Fig.27 is visible that total number of changed belts in 2017 is 8, and the longest operation time is 2 months, after deeper analysis it turns out that the type of intermediate belt were different. The company shared their concerns about intermediate belt failures with belt manufacturer, and received proposal to try another type of it. In January and September company changed intermediate belt, which is dedicated to use in the moist environment, other belts were regular. The specified belts result in longest operating time and the price difference is not very significant. Two different manufacturers of regular belts were tested, but the result was the same – failures occurs after 1-1,5 month of operating. The positive result showed intermediate belt produced by Albany manufacturer, they suggested to try "Primaclean 7C 500NT" belt, which is dedicated to moist environment, its air permeability is higher – 500cfm (parameter of regular belt is 200cfm), during manufacturing process additive materials are added to the purpose to reach anti-contaminant and moisture resistance effect.

Another useful tool is tension of intermediate belt; trials proved that tension of the new belt may not be higher than 4kN/m and only after one month of operating tension can be raised to 5-6kN/m. The manufacturer of the intermediate belt recommends average tension from 3kN/m to 5kN/m, depending on the condition of the belt tension can be increased to 6kN/m, but at the beginning recommended tension is lower, because the new belt is stretched enough by itself.

6.3 The journal for failures registration

The paper journals for failures registration are still in use, mechanics have to come to the operating room and check the records; such an operation reduces the effectiveness of the fast repair.

Every employee can use a computer and internal company's server, which is created to keep important document, maintenance and production departments can use that server and create a table for the failures registration, this journal in the server is available for all authorised personnel. For the best result, journal can be implemented and responsible person can be informed about the failure by email, immediately when it was registered. This improvement will shorten the chain of information transmission between shift leader and responsible maintenance personnel increase the effectiveness of repairs and reduce time of them. Communication between departments improves as well, because information will be reachable for all interests.

6.4 Failure mode and effects analysis method

The Failure Mode and Effects analysis method is a good tool for better analysis of the downtimes. It helps to identify the potential failure modes and their causes on process or system performance. FMEA is a systematic procedure of analysis and data collecting, it is based on rating each equipment and failure from less important to the most important, and Risk Priority Number may be calculated in order to prioritise equipment.

The FMEA method is recommended for companies whose equipment's are separated into groups by the process, function or location. The standard objectives of method are identification of failures which has unwanted effects on process, fulfilment of customers' requirements, improvements of process reliability and safety.

Procedure of FMEA implementation is explained step by step in the standard, but there are some field for modification, because the worksheet is recommended, not mandatory. Company can modify worksheet by their process, equipment and important factors on which failure has effect. Modified worksheet is given in Appendix 2, its modified according process and groups of equipment. Just because of the format circumstances worksheet is divided in two tables and both are filled at the same time, ratings of failures are given in Appendix 3.

This recommended worksheet is created according to equipment group and the most important criteria at the company; mechanics were involved in creation process and shared their insights. Tables are not fully filled because of the confidential information of the company. Implementation of the FMEA can last from few months to few years, depends on how much human and knowledge resources company has, worksheet may be modified after deeper analysis and depending on demand of maintenance personnel.

The benefits of worksheet are:

- The visual information and identification which part of the equipment's group demands careful monitoring;

- It can be used during maintenance department meetings, in order to track actions;
- Identification of responsible persons;
- Better maintenance management;
- Higher level of information share.

The company can generate goals that they want to achieve within a certain time frame.

A quick FMEA analysis showed that intermediate belt is very important equipment and actions must be carried out as soon as possible. Recommendations can be implemented without a large monetary investment. Recommended actions may be improved in a short and long time perspective, without changing the design and construction of the equipment. It is useful to first try cheap methods and, if they prove ineffective, to introduce more expensive ones. In some cases, the most frequent failures occurs, because of the very simple cause, which can be eliminated quickly.

Conclusions

1. The most popular maintenance strategies and methods applied in the manufacturing industry are reviewed, highlighted useful tools and the relation between maintenance and asset management is described. Reliability centred and preventive maintenance methods are widely used in manufacturing companies. The company has implemented predictive maintenance strategy, but the goal is to reach 100% of Total Productive Maintenance. The preventive maintenance tools may be applied to one equipment, instead of implementing full strategy. The best results are achieved by combining several maintenance methods.

2. Analysis of downtimes indicates that the longer time of downtimes is because of mechanical failures in Press section, which is critical to the production process. During the expert interview, operators, maintenance and production managers, as well as mechanics, pointed out the main equipment groups that most often failures, these groups were assessed on the basis of 3 criteria, evaluation showed that the critical device is an intermediate belt. The intermediate belt has direct influence on the production process and affects the product quality.

3. Construction and function of the intermediate belt was analysed and proposed to use preventive maintenance method for this equipment, to change it every two months. An experiment was carried out to define the right amount of steam, according to defined amount of steam it's recommended to order special belts for exploitation in the moist environment. This can save up to 50% of financial by reducing cost of intermediate belt downtimes.

4. The procedure of evaporation of steam head created, in order to equal operator's actions during this process. This procedure is in use at the company for 3 months and during that time period no failures occur connected with steam head, it reduces downtimes of intermediate belt by 20%

5. In pursuance to achieve the highest efficiency of maintenance management paper journals must be changed to electronic journals, which can be reached at any time by the maintenance personnel. The modified FMEA worksheet proposed as useful tool for downtime analysis and prioritised of equipment failures.

List of references

1. B.R.Mehta, Y.J.Reddy. Chapter 16 – Asset management systems. In: *Industrial Process Automation Systems.* USA, Elsevier Inc, 2015, pp. 479-506. ISBN: 978-0-12-800939-0. https://doi.org/10.1016/B978-0-12-800939-0.00016-4

2. LST EN 17007:2017. *Techninės priežiūros procesas ir susiję rodikliai=Maintenance process and associated indicators:Europos standartas EN 17007:2017 turi Lietuvos standarto statusą.* Vilnius: Lietuvos standartizacijos departamentas, 2018.

3. LST EN 16646:2014. *Techninė priežiūra. Techninė priežiūra, susijusi su materialiojo turto valdymu =Maintenance-Maintenance within physical asset management: Europos standartas EN 16646:2014 turi Lietuvos standarto statusą.* Vilnius: Lietuvos standartizacijos departamentas, 2015.

4. LST EN 13460:2009. *Techninė priežiūra. Techninės priežiūros dokumentai=Maintenance-Documentation for maintenance: Europos standartas EN 13460:2009 turi Lietuvos standarto statusą.* Vilnius: Lietuvos standartizacijos departamentas, 2009.

5. LST EN 15341:2007. *Techninė priežiūra. Pagrindiniai techninės priežiūros kokybės rodikliai=Maintenance – Maintenance Key Performance indicators: Europos standartas EN 15341:2007 turi Lietuvos standarto statusą.* Vilnius: Lietuvos standartizacijos departamentas, 2007.

6. MichaelWienker, KenHenderson, JacquesVolkerts. The Computerized Maintenance Management System an Essential Tool for World Class Maintenance. *Procedia engineering.* 2016, pp. 413-420. https://doi.org/10.1016/j.proeng.2016.02.100

7. SandrinaVilarinho, IsabelLopes, José A.Oliveira. Preventive Maintenance Decisions through Maintenance Optimization Models: A Case Study. *Procedia engineering.* 2017, pp. 1170-1177. https://doi.org/10.1016/j.promfg.2017.07.241

8. Luca Fumagalli, Marco Macchi, Alice Giacomin. Orchestration of preventive maintenance interventions. *IFAC papers online,* 2017, pp. 13976-13981.

9. Chiara Franciosi, Alfredo Lambiase,Salvatore Miranda. Sustainable Maintenance: a Periodic Preventive Maintenance Model with Sustainable Spare Parts Management. *IFAC papers online,* 2017, pp. 13692-13697.

10. Patrícia Senra, Isabel Lopes, José A Oliveira. Supporting maintenance scheduling: a case study. *Procedia engineering.* 2017, pp. 2123-2130.

11. Vishnu C. R., Regikumar V.b. Reliability Based Maintenance Strategy Selection in Process Plants:A Case Study. *Procedia Technology.* 2016, pp. 1080-1087.

12. JonBokrantz, AndersSkoogh, TorbjörnYlipää. The Use of Engineering Tools and Methods in Maintenance Organisations: Mapping the Current State in the Manufacturing Industry. *Procedia CIRP*. 2016, pp. 556-561. https://doi.org/10.1016/j.procir.2016.11.096

13. LST EN 60812:2006. *Sistemų patikimumo analizės metodai. Gedimų rūšių ir pasekmių analizė (IEC 60812:2006)=Analysis techniques for system reliability-Procedure for failure mode and effects analysis (FMEA) (IEC 60812:2006): Europos standartas EN 60812:2006 turi Lietuvos standarto statusą*. Vilnius: Lietuvos standartizacijos departamentas, 2006.

14. Behnam Vahdani, M. Salimi, M. Charkhchian. A new FMEA method by integrating fuzzy belief structure and TOPSIS to improve risk evaluation process. *Manufacturing technologies.* 2015, pp. 357-368.

15. Ken Henderson, Georg Pahlenkemper, Olaf Kraska. Integrated Asset Management – An Investment in Sustainability. *Procedia engineering.* 2014, pp. 448-454. https://doi.org/10.1016/j.proeng.2014.09.077

16. Marcello Colledani, Maria Chiara, Magnaninia Tullio Tolio. Impact of opportunistic maintenance on manufacturing system performance. *CIRP Annals.* 2018. https://doi.org/10.1016/j.cirp.2018.04.078

17. A.Gouiaa-Mtibaaa, S.Dellagia, Z.Achoura, W.Errayb. Integrated Maintenance-Quality policy with rework process under improved imperfect preventive maintenance. *Reliability Engineering&System safety*. 2018, pp. 1-11. https://doi.org/10.1016/j.ress.2017.12.020

18. Gurmeet Singha, T.Ch.Anil Kumarab, V.N.A.Naikana. Efficiency monitoring as a strategy for cost effective maintenance of induction motors for minimizing carbon emission and energy consumption. *Reliability Engineering&System safety.* 2018. https://doi.org/10.1016/j.ress.2018.02.015

19. E.Shayesteh, J.YuP.Hilber. Maintenance optimization of power systems with renewable energy sources integrated. *Energy*. 2018, pp. 577-586. https://doi.org/10.1016/j.energy.2018.02.066

20. Mahmood Shafieea, John Dalsgaard Sørensenb. Maintenance optimization and inspection planning of wind energy assets: Models, methods and strategies. *Reliability Engineering&System safety.* 2017. https://doi.org/10.1016/j.ress.2017.10.025

21. *Siempelkamp.* Technical documentation. Operating instructions. Mechanical and Hydraulic system. 2005.

22. *Official website of Imal.* http://www.imalpal.com/en/

23. *Official website of Albany.* http://www.albint.com/business/mc/en-us/ef/corrugator/Pages/default.aspx

List of appendices

Appendix 1. The standard worksheet of FMEA

Item ref.	Item description and function	Potential failure mode	Potential effects of failure	Severity class	Potential cause/mechanisms of failure	Frequency or probability of occurence	Current design controls	Detectability	RPN	Recommended actions	Responsibility and target completion date	Action results				
												Actions taken	New Sev	New Occ	New Det	New RPN

Write down each failure mode and potential consequence of that

On a scale of 1-10 rate the Severity of each failure (10-mostly)

Write down the potential causes and on a scale of 1-10 rate likelihood of each failure

Examine the current design and on a scale 1-10 rate the detectability

Risk Priority Number - the combination of severity, occurence and detectability; RPN = Sev x Occ x Det

Response plan and tracking

Appendix 2. Worksheet of FMEA

		FMEA failure mode and effects analysis		Machine criticality analysis						
				Actual situation						
Areas	Major equipment	Effect of breakdown Longest possible breakdown	Reason of breakdown	Today controll methods to controll this breakdown	Early detection (how likely is to detect this before it will happened) Easy - 1 Difficult - 10	Impact (If breakdown will appear what impact it will bring) Big - 10 Low- 1	Probability to happened (from history, spare parts analysis) Often - 10 Never - 1	Result	Preventive action lowering down the Risk	Responsible
Press	- Dynasteam - intermediate belt - steel belt - press cylinders - hydraulic system - press chain - main drives - minifog system - exhaust system - Ness boiler	4 days			**8**	**10**	**5**	**400**		

Appendix 3. Equipment rating for FMEA

		Machine criticality analysis							
Areas	Major equipment	Actual situation					Result	Criticality value A - Highest B - High C - Average D - Low	Responsible
		Downtime impact for Press production 1 - 0-1 hr. 2 - 1-6 hrs. 3 - 6-12 hrs. 4 - 12-24 hrs. 5 - more than 24 hrs.	Production Quality impact 1 - no impact 2 - low impact 3 - high impact 4 - stop production	Safety / Environmental impact 1 - no impact 2 - low impact 3 - high impact 4 - stop production	Equipment restore value 1 - less than 1.000 E 2 - 1.000-10.000 E 3 - 10.000-50.000 E 4 - more than 50.000 E	Equipment age (reliability) 1 - 0-5 years 2 - 5-10 years 3 - more than 10 years			
Press ContiRoll	Dynasteam	**1**	**1**	**1**	**2**	**2**	**4**		
	Intermediate belt	**3**	**3**	**2**	**2**	**2**	**72**		
	Press cylinders	**3**	**3**	**1**	**2**	**3**	**54**		
	Hydraulic system	**3**	**1**	**1**	**3**	**3**	**27**		
	Press chain	**3**	**1**	**1**	**2**	**2**	**12**		

	Press main drives	**3**	**1**	**1**	**3**	**3**	**27**		
	Reject silo	**2**	**1**	**2**	**2**	**3**	**24**		
	Minifog system	**3**	**1**	**1**	**2**	**3**	**18**		
	Press exhaust system	**2**	**1**	**3**	**2**	**3**	**36**		
	Ness boiler	**3**	**1**	**1**	**2**	**3**	**18**		