Intersnack

Preventive maintenance policy Nuts Packaging line D028

Intersnack Doetinchem

Thesis Intersnack

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Title page

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Title:	Preventive maintenance policy Nuts Packaging Intersnack Doetinchem
Abstract:	This report presents the results of a research project about maintenance in the food industry. An analysis is performed on the current maintenance process in the food-producing industry and the literature. The analysis showed a gap in the maintenance strategy decision tools in literature and practice. Therefore, a redesigned decision support tool is developed to help the user make a solid and thorough decision regarding a preferred maintenance strategy for the machines. A case study is performed to verify the practical appropriateness of the method.
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Preface

This report is the final result of my Master thesis conducted at Intersnack BV for the study Industrial Engineering and Management, track Production and Logistics Management.

With this research, I finish my master Industrial Engineering and Management and my time as a student. I have learned many things in the past few years about the field of research and myself, and I had great pleasure while doing so at the University of Twente.

This thesis is the final milestone, where I had the opportunity to learn about the world of maintenance at one of the largest savior snack companies. I found the subject of the research very interesting and liked the associated complexity. It was challenging to continuously make the right trade-off for the scope of the research, but I think this was done successfully and the final result provides valuable insights and maintenance structure for Intersnack.

This thesis would not have been possible without the help of others, who deserve acknowledgment for their support. First of all, I would like to thank Intersnack for allowing me to do this research within the production facility in Doetinchem. I would like to thank my colleagues at the Nuts Packaging department, who welcomed me into their organization. Special thanks go out to Tim van der Linden and Wouter Sonderen, who allowed me to do this research at Intersnack.

All members of the graduation committee are accountable for this success, so thank you Matthieu, and Engin for all your helpful feedback, insights, support, and time. It improved the thesis and made me learn many new things. I enjoyed working with you.

I would also like to thank all my family, friends, fellow students, and colleagues who supported me during my studies. You have made my time as a student great and very special. I am proud of the result.

Martijn Bakker

Management summary

This research, conducted at Intersnack for a Master's thesis in Industrial Engineering & Management, focuses on enhancing maintenance practices. Currently, with over 80% of man-hours dedicated to corrective maintenance, there's a clear deficiency in preventive measures, resulting in increased breakdowns. The current maintenance strategy at Intersnack's Nuts Packaging department is primarily corrective, featuring external inspections and large-scale maintenance performed intermittently. Lacking specific maintenance tasks for machines or components. This study aims to develop a maintenance concept to aid Intersnack in transitioning from corrective to preventive maintenance strategies.

Production line D028 has encountered unplanned downtime (UPDT) totaling 32% of available time. The reliability KPIs, safety triggers, and maintenance costs indicate challenges, particularly with the Transwrapper machine causing 16% of UPDT, with a mean time between failure of 95 minutes. This downtime translates to approximately €800,000 in lost sales and €100,000 in unutilized resources annually. Such unreliability affects production schedules and customer satisfaction. This research outlines a more proactive maintenance plan to improve reliability, validated through a case study.

Recognizing the limitations of the current TPM maintenance approach, the proposed maintenance concept integrates aspects from Reliability Centered Maintenance (RCM) with a structured 7-step framework. The limitations of TPM are the lack of a structured approach to determine maintenance tasks, with unclear decision rules on which maintenance policy and how to optimize the maintenance tasks. The 7-step framework involves identifying objectives, selecting critical systems, choosing maintenance policies, and implementing a comprehensive maintenance plan. The RCM literature-inspired approach systematically identifies critical equipment with the FMEA method and optimizes maintenance policies based on the failure behavior risk and consequences.

The maintenance concept underwent validation through practical implementation of the constructed framework. The primary outcome was the development of a comprehensive maintenance plan comprising 44 maintenance tasks targeting critical components of the Transwrapper, identified as the most crucial system of production line D028 due to its high impact on UPDT and production cessation when malfunctioning. The critical components, particularly those within the Seal Jaws subassembly, were determined using the FMEA method, which assessed severity, occurrence, and detectability based on the predetermined criteria. Which helped to document and better understand the functions, failure modes, and potential causes of the components. Inputs were gathered from various stakeholders including the line team, operators, and technicians. Components that had previously failed were utilized as input for analysis. Maintenance policies were established for different failure modes using the determined decision trees, and these policies were then translated into specific maintenance tasks by the project team.

The method for establishing maintenance task intervals based on failure behavior is detailed, utilizing descriptive methods and Weibull distribution with failure data as input. However, during the case study, it was observed that available data was unreliable, influenced by human interaction and lacking registration, making it less reliable. Most components lacked data, except for manually recorded time-to-repair (UPDT), which was used to indicate the maintenance task impact. After the task specification, tasks were clustered into work packages based on same criteria to minimize maintenance costs. These work packages constitute the constructed maintenance plan.

The identified maintenance tasks facilitated a transition from corrective to proactive maintenance, reducing "Failure Based Maintenance" (FBM) to only 22% of tasks (see Figure 1). More than 50% of tasks now incorporate proactive measures such as Use Based Maintenance (UBM) and Condition Based Maintenance (CBM). Additionally, a list of suggested changes to eliminate or minimize maintenance requirements was compiled under Design Out Maintenance (DOM).

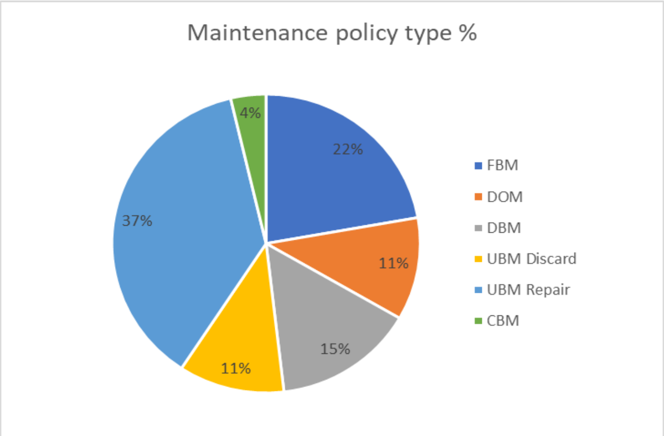

Figure 1 - Maintenance policy type percentages after performing the case study

The implementation of the maintenance tasks is estimated to significantly reduce UPDT, with reductions ranging from nearly 50% to over 80% (see Table 11). These estimations are based on task intervals, failure behavior, and project team estimations. This impact assessment applies to the components with known UPDT, with similar results expected for other machine components.

The maintenance concept not only guides task optimization but also enhance machine reliability and better technical insights. Its implementation at Intersnack, even when adapted later, proves beneficial with estimated downtime reductions. Implementing the maintenance concept selectively, considering current resources, is recommended due to the time-consuming nature of the analysis. Machine and component focus are determined through equipment ranking and UPDT analysis. In conclusion, the maintenance concept offers a structured approach for defining specific maintenance tasks and constructing a proactive maintenance plan.

A primary recommendation is to strengthen the registration process for failure behavior, ensuring thorough documentation of component failures, including causes, repairs, and durations. It is essential to address variations in failure behavior, particularly those related to human factors, to improve data accuracy. Strategies such as excluding data influenced by human factors or implementing work instructions to mitigate their impact should be considered.

Furthermore, initiate the establishment of the maintenance plan at the assembly level rather than the component level. Starting with a high-level maintenance plan enables prioritization of critical maintenance tasks for machines. Utilize recommended maintenance tasks from OEMs for efficient implementation, as these tasks are already established and readily deployable within the high-level plan.

The limitations of this research lie mainly in the lack of (reliable) failure behavior data. Therefore, it is hard to specify the impact on the UPDT. Furthermore, the created maintenance plan remained superficial due to the lack of experience and knowledge within the project team.

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1 Introduction

This research is conducted to advise on how to improve the maintenance process at Intersnack BV. This report was written to complete the Master of Industrial Engineering & Management with a specialization in Production and Logistics Management at the University of Twente. This research has a time frame of six months and takes place at the production location of Intersnack Doetinchem.

In this chapter, we introduce the research design. The company's introduction in section 1.1 briefly explains the production location and department where the research is being conducted. Next are the machines of the nuts packaging line described in section 1.2. The need and motivation for the research is discussed in section 1.3. Section 1.4 explains the problem statement, followed by the formulated research objective in section 1.5. Following this are the research questions in section 1.6. Finally, the scope of the study, research approach, timeline, and data sources are described in sections 1.7, 1.8, 1.9, and 1.10, respectively.

1.1 Introduction to Intersnack Nederland B.V.

1.1.1 Intersnack Group

Intersnack Nederland BV is part of the Intersnack Group, a European manufacturer of snacks with several locations around the world. Intersnack was founded more than sixty years ago in Germany and made its first potato chips in 1968. Since then, they have become one of the market leaders in savory snacks, with operations in more than 30 countries in Europe, Australia, New Zealand, and beyond (Group, 2023).

The Intersnack Group focuses on producing a wide range of snack products, including chips, salty snacks, popcorn, nuts, and other snacks. They have a diverse range of brands, including well-known names such as Chio, Pom-Bär, Kelly's, ültje, and Vico, Figure 1 shows the different brands.

Figure 1 Brands Intersnack Group

1.1.2 Intersnack Nederland BV - Doetinchem

Intersnack Nederland BV employs a total of 450 employees across 3 locations, with ±250 employees in Doetinchem, ±110 employees in Lelystad, and ±90 employees in Hardinxveld-Giessendam. The headquarters of Intersnack Netherlands BV is located in Doetinchem, where the research is conducted.

In Doetinchem, the primary production and packaging activities include peanuts, coated nuts, and peanut butter. Additionally, semi-finished products are supplied to the food industry. The production department in Doetinchem is organized with four self-managing line teams:

- Line Team Coated Nuts & Baking, consisting of five lines for baking peanuts and coated nuts.
- Line Team Nuts Packaging, consisting of four packaging lines for packaging peanuts and coated nuts.
- Line Team Pika Processing, comprising six lines for producing peanut butter.
- Line Team Pika Packaging, comprising three packaging lines for packaging peanut butter.

Each line team is structured with a Line Lead, a Maintenance Lead, and a Process Lead. The research is being conducted on behalf of the Line Team Nuts Packaging.

1.2 Process Nuts Packaging department

The production process at the Nuts Packaging department consists of the following general steps. First, the nuts are brought in, weighed, packed, and wrapped for transport. Different types of nuts are packed for multiple customers. The machines of the nuts packaging line D028 are illustrated in Figure 2. The production process with the machines is in detail explained in appendix A.

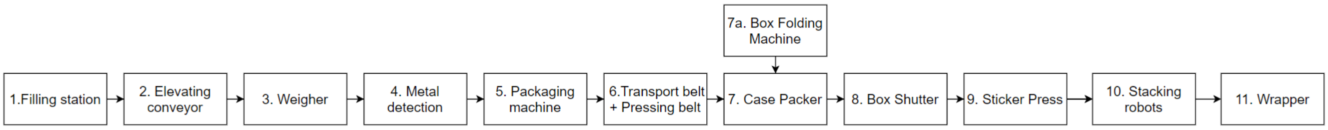


Figure 2 Machines Nuts Packaging

1.2.1 The Technical Department (TD)

Reducing downtime is crucial for minimizing production loss and associated costs. The Technical Department (TD) plays a critical role in achieving this objective at Intersnack. The TD is responsible for both corrective and preventive maintenance. Their activities include:

- (Non)-Critical failures (Corrective Maintenance)
- Long-term failures (Corrective Maintenance)
- Inspections (Preventive Maintenance)
- Periodic maintenance (Preventive Maintenance)
- Modifications (redesigning current machines)
- Projects (Purchasing new machines or production lines)

To carry out all maintenance-related tasks is a team of ±15 individuals available. Additionally, external technicians are hired for specialist work or as extra capacity. Chapter 2 will further elaborate on how the TD executes the maintenance tasks.

1.3 Research motivation

Intersnack's goal is to ensure that each production line can produce a high-quality product at a constant level, with as few (large) production interruptions as possible.

The purpose of this research is to create a preventive maintenance policy for the Nuts Packaging Line D028. This research aims to optimize the performance of the production lines by performing both corrective and preventive maintenance optimally.

At present, the company finds itself in a situation where mainly corrective maintenance takes place, while preventive maintenance does not yet receive sufficient attention. The ratio of corrective to preventive maintenance is currently skewed, with about 80% of the available man-hours spent on corrective maintenance and only 20% on preventive maintenance as can be seen in Figure 3. Even some of the so-called preventive maintenance is limited to repair parts that have already broken down, the non-critical failures, but do not yet need to be replaced immediately. Further specifications of the distribution of maintenance will be analyzed in the first phase of the research.

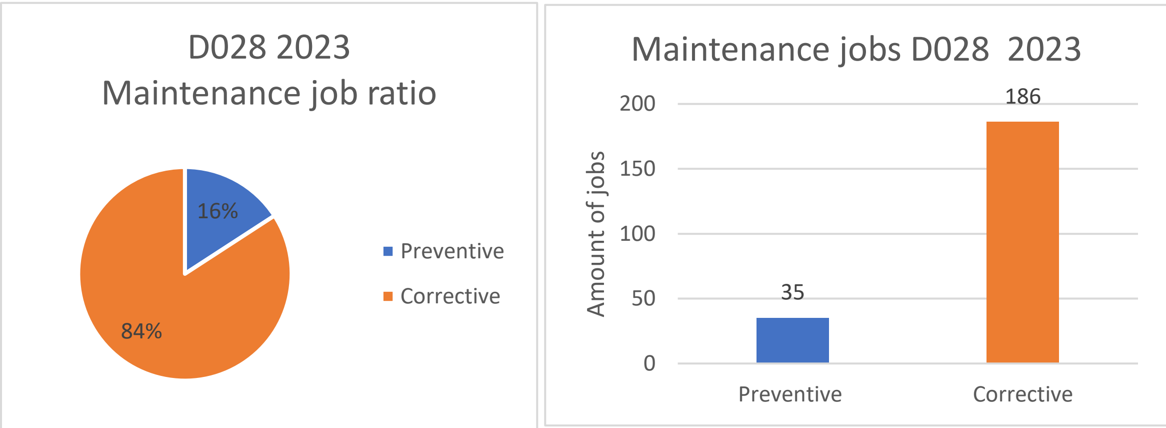


Figure 3 Maintenance job type ratio %

This research has the potential to bring a significant culture shift. Currently, there is a predominant "fire-fighting" culture that prioritizes solving immediate problems instead of proactively preventing them or analyzing their root cause. This research can emphasize the importance of preventive maintenance and demonstrate its benefits. This approach promotes a proactive mindset, prioritizing preventive measures and identifying the root causes of problems, rather than just treating their symptoms.

The current maintenance situation harms the operational efficiency and reliability of the production lines. Lack of understanding of the core problem leads mostly to corrective actions and no preventive actions. This approach increases costs and the risk of production losses, for instance, due to downtime caused by defects and failures.

Therefore, it is important to create a preventive maintenance policy. Where the policy aims to prevent breakdowns and improve the production line uptime. During this study, a preventive maintenance policy for one of the machines in the Nuts Packaging line D028 will be created. The production line D028 has the lowest uptime and highest unplanned downtime (UPD) compared to the other production lines as shown in Figure 4. The UPD is caused by different machines events as shown in Table 19. The event "general" is excluded from the research since this is not caused by a machine. D028 is therefore the focus of this project. Specific causes and problems can be identified that are responsible for the current performances. The possible causes of unplanned and planned downtime are listed in Table 19 appendix A.

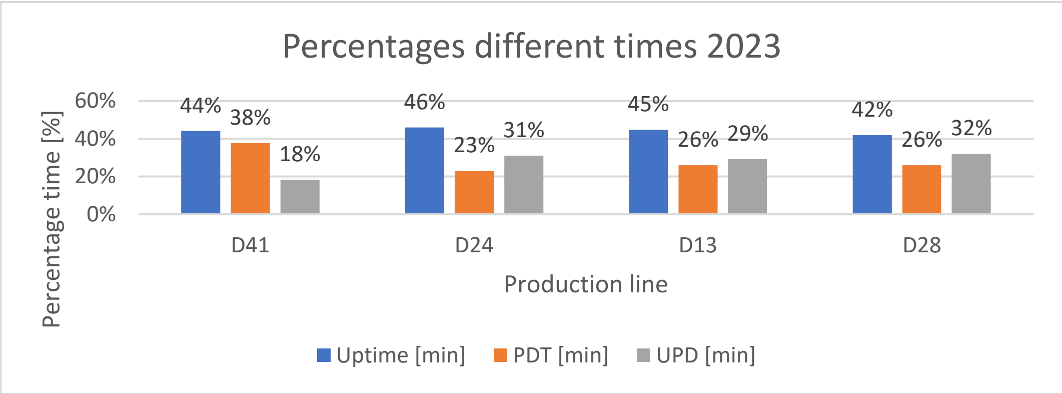


Figure 4 Performances different production lines Nuts Packaging

As earlier specified in section 1.2 consists of the packaging line D028 of different machines. Within this research will the focus be specified on one of the sections of the machine. The specific machine will be chosen after analyzing the performances of the different machines. The machine with the most impact on the unplanned downtime will be chosen to create the preventive maintenance policy.

Another reason for starting this study is the future budget request for the preventive maintenance plan. The Nut Packing Department plans to request a budget next year to implement an improved maintenance policy. Currently, a clear understanding of the required financial resources about the expected efficiency improvements is lacking. After conducting this study, there will be a better understanding of the required investments and operational costs associated with the preventive maintenance policy.

1.4 Problem statement

The current problem situation is indicated in Figure 5. At the nuts packaging line D028 is mainly corrective maintenance performed and a preventive maintenance plan is missing. There is a lack of knowledge on the needed maintenance actions. Which results in an unstable production process with a lot of unforeseen defects and failures. The machines are therefore unreliable regarding their performance. This has a significant negative impact on production efficiency and output. The lack of reliability in the output of products creates uncertainty, which has an impact on planning and the ability to deliver to customers. It is essential to address this unreliability to ensure consistency and high-quality results. Within Intersnack is therefore chosen to create a preventive maintenance plan among others to create a more stable process.

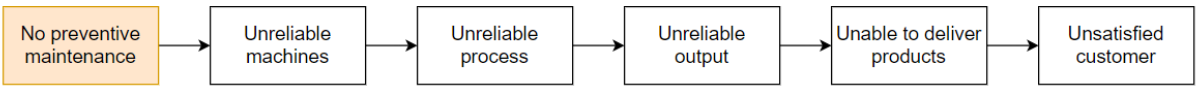


Figure 5 Problem situation

Moreover, there is an urgent need for a better understanding of the financial resources required for preventive maintenance. The company plans to request a specific budget for this purpose next year. Having a clear understanding of maintenance requirements allows for a more precise and supported budget request.

To improve reliability and reduce unplanned downtime, it is essential to optimize the preventive maintenance policy and shift the focus to proactive maintenance. This will improve the operating results, and ensure a more reliable and stable production environment.

1.5 Research goal

The research objective is to achieve the transition from corrective maintenance to preventive maintenance at Intersnack Doetinchem Nuts Packaging department. The objective will be achieved by creating a (preventive) maintenance plan for the machines with the highest unplanned downtime of production line D028. An indirect goal of this research is to decrease the KPI Unplanned Downtime (UPD) with the created (preventive) maintenance model.

As a result of this research, a maintenance model will be created to determine the optimal maintenance policy, indicating which parts/machines require what type of maintenance and when. One of the machines of packaging line D028 will be used to create and validate the model. The model will provide an overview of the maintenance steps to be taken. These maintenance steps and actions will then be used as input for the maintenance planning and scheduling meetings (MP&S). In addition, the research will provide insight into the (financial) requirements for implementing the preventive maintenance policy.

Specifically, the research results will lead to a maintenance model that will indicate the needs of each machine based on the available information. The model provides insight into the critical path. Maintenance will be divided into first- and second-line maintenance, respectively the maintenance that the operator can do himself and the maintenance that must be done by a technician/mechanic.

The model will be tested with the (historic) failure and defect data from the D028 to be validated and verified. As a result of the study, there will be a clear and usable model that will serve as the basis for the transition to an optimal and literature-supported (preventive) maintenance policy for Intersnack's production site Doetinchem.

1.6 Research questions

The research objective leads to the following main research question:

Main research question:
"How can the maintenance for the machine with the highest downtime of the nuts packaging line D028 be optimized with the specific goal of minimizing unplanned downtime?"

The main research question results in several sub-questions, which are structured in 5 phases: current situation, literature research, solution design, analysis of the results, and implementation plan. To answer the main research question, several sub-questions must first be answered to arrive at an answer to the main research questions. Therefore, the following questions to be answered first have been formulated:

Current situation
Before the current situation will be improved is a good understanding of the current situation needed. To know how much the current situation has improved, it is also essential to know its performance. This is investigated through the first research question. Chapter 2 describes the current situation of maintenance and its related performances.

1. What is the current way of performing maintenance on the nuts packaging line D028?
    1.1. What is the maintenance policy?
    1.2. How are the maintenance jobs registered and planned?

1.3. What is the objective of the maintenance plan?
1.4. What is the current performance of the maintenance?
1.5. What are the important decision criteria and constraints for scheduling maintenance?

Literature research

Once the current situation is clear, will the existing knowledge in this specific field be explored. The knowledge and expertise will be explored through the literature review, saving time from reinventing the wheel. Next, will the most suitable maintenance method from the literature study be chosen to solve the maintenance problem at Intersnack. Chapter 3 describes the literature that can be applied.

2. What is the best way to establish a preventive maintenance policy and model in a production environment similar to Intersnack, according to the literature?
    2.1. What are the proposed steps for the execution of the maintenance plan according to the literature?
    2.2. Which preventive maintenance approaches are proposed in the literature, and which is best applicable to the situation at Intersnack?
    2.3. What is the research gap between the literature-proposed maintenance method and the current method?
    2.4. How can the research gap between the proposed maintenance method and the current method be closed?

Solution design

The solution design describes the maintenance model, and discusses which problem it solves, how it works, and what information and data are needed. With the help of an experimental design is the model tested and validated.

3. What should be the maintenance model design for Intersnack?
    3.1. What input data does the maintenance decision model need to use?
    3.2. What does the maintenance model look like?
    3.3. How can the data be initialized?
    3.4. How can the optimal maintenance actions be determined?

Analysis of the results

The outcomes of the case study are analyzed in this chapter. The case study tests the performance of the developed maintenance model. Furthermore, is the quality of the model evaluated.

4. What is the performance of the maintenance model?
    4.1. What are the results of the experiments in comparison with the current situation?
    4.2. What are the consequences of adjusting the input data?
    4.3. What is the quality of the solution of the maintenance model?

Implementation plan

The implementation plan describes how the maintenance model can be implemented at Intersnack Doetinchem.

5. How can the maintenance model be implemented at Intersnack Doetinchem?

1.7 Project scope

The focus of this research is limited to developing a maintenance model that provides insight into the required maintenance actions for the machine with the highest unplanned downtime from the nuts packaging line D028. The created model will enable a (preventive) maintenance policy. The depth of the maintenance model regarding the specific parts of a machine will be according to the provided BOM list in the registration tool Ultimo.

Furthermore, will an implementation plan be provided for further roll-out of the maintenance model for the other machines in the packaging line D028. The execution of the implementation plan within Intersnack is outside the project scope.

The model will be validated by using historic defect and failure data from the nuts packaging line D028. The machines that are used in the process of the packaging line as shown in Figure 2 are in the project scope. The machine with the highest unplanned downtime will be focused on. The process steps and machines before and after the indicated process in Figure 2 are outside the project scope.

During this research will most likely different factors found that are responsible for the reliability and downtime of the process. The focus of the research will be on the machinal factors and less on the human. The human factors that influence the process will be documented and included in the recommendations.

The result of the study will be consistent with the current working methods of Intersnack and in line with the Intersnack Work Systems (IWS) structure as described in Appendix B. This research will be conducted under the two IWS pillars Autonomous Maintenance (AM) and Preventive Maintenance (PM).

1.8 Project approach

Step 1: Process, Machine, and Maintenance Documentation & Analysis

- The process with associated machines of production line D028 will be documented in an overview. The overview is needed for tracking and categorizing different types of maintenance activities. Subsequently, will the defects and failures be analyzed to select the machine with the highest downtime. This machine will be further analyzed and focused on for the maintenance plan. The information sources for the needed data are described in section 1.9.
- The current production performance will be documented and analyzed to get a better insight into the current situation and further specify the research objective percentage.
- The current maintenance approaches within Intersnack Nederland BV will be shortly documented and analyzed. The (preventive) maintenance policy, criteria, and motivations will be documented. Analyzing the different approaches will help to identify best practice examples or any limiting factors for (preventive) maintenance. The information will be used as input to the maintenance model.

Step 2: Literature Review

- A literature review will be conducted to find suitable maintenance policies and methods. The focus will be on field studies to identify relevant and effective maintenance approaches.
- The literature review will be a guide to get insight into the different action steps that need to be performed to create and implement a predictive maintenance policy.

Step 3: Development of the (Preventive) Maintenance Model

- Based on the collected insights and findings from previous steps will a suitable preventive maintenance model be developed. This section will determine what kind of maintenance model is suitable for the company and how to create the model.
- The performance of the model will be validated using historic defect and failure data from the nuts packaging line D028 on the specific machine. The created model will allow an informed trade-off between preventive and corrective maintenance.

Step 4: Implementation plan and Follow-up Steps

- The developed preventive maintenance model can be tested and validated at Intersnack Doetinchem after performing step 3. The maintenance model will be tested for one of the D028 machines. After the test will a review performed to get feedback on the maintenance model. The tested and improved maintenance model will then be generalized for the other machines of the production line.
- The implementation itself falls outside the scope of this research. The needed steps for further implementation of the model, provided strategies and recommendations will be documented and serve as guidance for a successful implementation.

Through this approach, the research will provide a clear understanding of the current maintenance policy, production performance, and the factors that influence the choice between preventive and corrective maintenance. This will ultimately lead to the development of an effective preventive maintenance model, contributing to minimizing machine downtime and maximizing production output within Intersnack Doetinchem.

1.9 Information Sources - Data

During this study are different internal and external information sources required as described in section 2.2. The information sources within Intersnack are the employees, ERP system (Ross), Ultimo, and QlikView. Furthermore, external information sources are used for the case study information. The information is provided by the OEM and external technicians.

2 Current situation

This chapter describes the current situation regarding maintenance at Intersnack Doetinchem. The first research question: "What is the current maintenance policy, important decision criteria, and maintenance-related performance regarding nuts packaging line D028 at Intersnack Doetinchem?" is answered.

2.1 Current maintenance policy

The current situation regarding maintenance at Intersnack Doetinchem will be described in this section. The maintenance objective, tasks, timeslots, plan, and desired state are explained. The focus is on production line D028 with the involved machines as indicated in section 1.2.

2.1.1 Maintenance objective

Maintenance is needed to ensure that equipment continues to function reliably and minimize the chances of defects and failures. Maintenance aims to improve system availability and MTBF (mean time between failure), to reduce failure frequency and downtime (Wang, 2002).

Intersnack indicated that their objective is to ensure equipment reliability, minimize unplanned downtime, enhance safety, and reduce machine ownership costs. Unplanned downtime results in lost unutilized production hours and costs of repair. To minimize unplanned downtime is it important to have more reliable machines. Furthermore, maintenance contributes to the safety of employees and the working environment by ensuring that equipment functions properly and meets safety standards. A safe working environment is the most important aspect indicated by Intersnack. Lastly, effective maintenance can reduce the cost of ownership by preventing costly repairs and replacements. The maintenance goal is therefore stated as follows:

"Maximum reliability and availability while gaining a thorough insight into the technical systems"

The goal should be realized in a cost-effective manner and in accordance with the safety and environmental regulations. The last part of the goal is included because Intersnack wants to have highly skilled employees both operators and technicians.

2.1.2 Maintenance policy - Nuts Packaging Doetinchem

The current maintenance policy at the Nuts Packaging Department Doetinchem consists mainly of performing corrective maintenance. To create basic conditions for the machines are different tasks performed as indicated in section 2.1.1. Furthermore, multiple inspections are executed after which (large) maintenance is planned for the different machines. These are executed by externals in combination with the Technical Department (TD) of Intersnack.

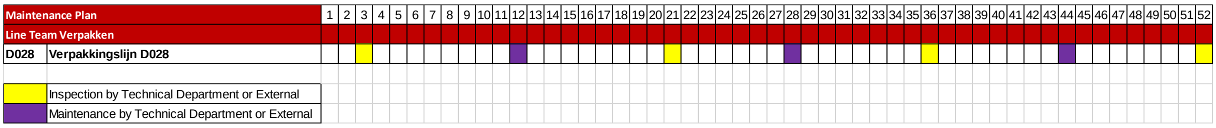
Corrective maintenance is performed when a critical failure occurs. A critical failure is an occurrence where production progress is disrupted or where (food) safety is at issue. Non-critical failures are planned during one of the maintenance time windows, as described in section 2.1.2, most of the time will this be the planned corrective maintenance slot. Depending on the criticality of the non-critical failure is the best timeslot chosen by the Coordinator Preventive Maintenance in consult with the department's Maintenance Lead. For the critical failure maintenance execution are the following actions performed:

1. When an operator encounters a failure or defect that can't be solved without TD's assistance, they call the mechanic who comes to help.

2. The operator creates a work order in Ultimo and prints this registration form for the TD.
3. The mechanic will carry out the needed repair.
   - *When the failure is solved will the operator and failure mechanic both sign the maintenance paper and fill in what the problem was and how it is solved.
4. The mechanic will register the maintenance job in Ultimo with the cause and solution.
   - When the failure causes more than 90 minutes of downtime or a part is replaced will also a PM-card.
5. At the end of a shift, all papers are registered in Ultimo by the Technical Department.

**This is the desired situation, however, in practice signs the technical department the paper without consulting the operator and identifying the underlying issue.*

The machine inspections are currently performed by externals in combination with the Technical Department. After the inspection is executed is an inspection report created. Eight weeks after the inspection took place are the needed maintenance activities from the inspection report executed. The scheduled inspections with maintenance are planned in the maintenance plan of the D028 in Figure 6. As can be seen is there no maintenance task specified. It is only indicated that maintenance or inspection will take place but further specification is not included.



Onderhoudsplan / Productieplan 2023

Week	Combinaties		Totaal stilstand Inspectie	Totaal stilstand Onderhoud / Totaal stilstand Modificatie	Stoptijd TD DAGDIENST Start	Stoptijd TD DAGDIENST Eind	Stoptijd PLANNING start	Stoptijd PLANNING Eind
3	D028 (I)	Thursday, January 19, 2023	6,5+2		7:30	16:00	19/01/23 7:30	19/01/23 16:00
12	D028 (OH)	Thursday, March 23, 2023		6,5+2	7:30	16:00	23/03/23 7:30	23/03/23 16:00
21	D028 (I)	Thursday, May 25, 2023	6,5+2		7:30	16:00	25/05/23 7:30	25/05/23 16:00
28	D028 (OH)	Thursday, July 13, 2023		6,5+2	7:30	16:00	13/07/23 7:30	13/07/23 16:00
36	D028 (I)	Thursday, September 7, 2023	6,5+2		7:30	16:00	7/09/23 7:30	7/09/23 16:00
44	D028 (OH)	Thursday, November 2, 2023		6,5+2	7:30	16:00	2/11/23 7:30	2/11/23 16:00
1	D028 (I)	Thursday, January 4, 2024	6,5+2		7:30	16:00	4/01/24 7:30	4/01/24 16:00

Figure 6 Current maintenance plan D028

The motive for the eight weeks between inspection and maintenance is the average component delivery time which is based on the experience of the Coordinator Preventive Maintenance. The planned timeslots of the Nuts Packaging department are planned on Thursday as can be seen in the bottom diagram of Figure 6. On this day are all the mechanics within Intersnack, about 10 persons, available to perform maintenance. Maintenance has to be executed within this time slot. When maintenance activities are not executed, they will be rescheduled. Depending on the criticality, the task will either be executed immediately or scheduled for the next maintenance timeslot.

2.1.1 Basic conditions of the machines

To keep the machine in Basic condition are there also other activities performed next to maintenance. The different tools to create this Basic condition are the CIL, DH, and CL. The different tools are further explained with examples in appendix A AM Pillar2.1.1. The goal of the CIL (Clean-Inspect-Lubricate) is to clean, inspect, and lubricate the machines. To find and resolve defects during the pitstop to prevent future breakdowns. The goal of DH (Defect Handling) is to ensure that defects are found and fixed on time and that the production line is maintained in basic condition. The goal of the CL (Center Line) is to reduce variation in daily results by creating standard operation settings. The reduction in variation will be achieved by preparing and updating information sheets that document the basic settings. An example of a CL is the changeover settings of the machine (see Figure 42).

2.1.2 Maintenance time windows

In a production environment like Intersnack is it crucial to continuously produce products. Any interruption leads to a loss of productivity and revenue. Therefore, maintenance should be considered as a supportive activity to optimize production output and minimize interruptions. It is essential to plan and schedule maintenance activities carefully, ensuring minimum disruption to production.

The current maintenance policy for the nuts packaging line D028 is mainly corrective maintenance. Furthermore, it is an inspection with (large) maintenance performed. An overview of the maintenance activities that are currently performed is visualized in Figure 7. The progressive maintenance tasks are at the beginning of this research not part of the maintenance activities.

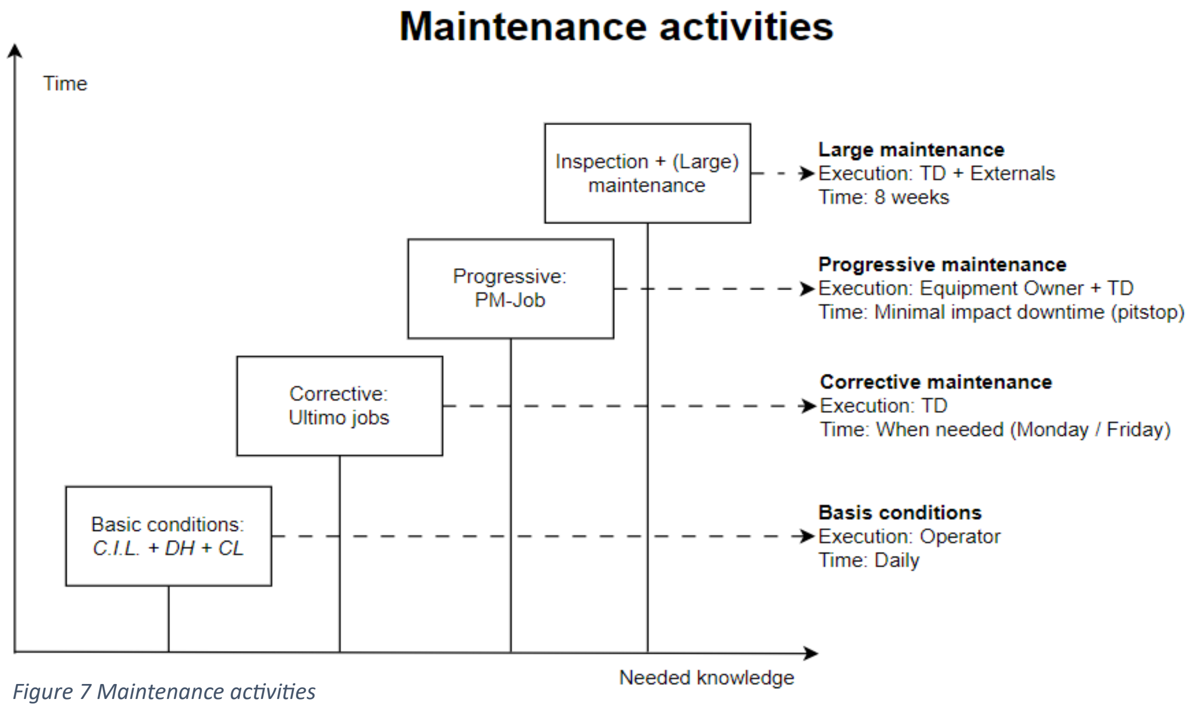


Figure 7 Maintenance activities

The current maintenance time windows can be classified as:

- **Critical corrective maintenance** **1*

Executed immediately when a critical failure occurs, since the production line is already down.

- **Planned corrective maintenance** **1*

The planned corrective maintenance is the non-critical failures. The maintenance is executed when there is the least impact on production. Most of the time it is planned on Monday or Friday since the department technician is available on these days.

- **Pitstop** **1,2,4*

Executed daily between 10:30 - 11:00, the production line is shut down for maintenance to restore the machine in basic conditions in order to reduce failures. The main tasks is cleaning.

- **Inspection in combination with (Large) Maintenance** **3,5*

Every 16 weeks are inspections performed by external suppliers on the different machines. After the inspection are the found defects repaired during the (large) maintenance time slots to restore the machine. The maintenance time slots are 8 weeks after the inspection.

**The numbers correspond with the different maintenance activities described in the next section 2.2.1*

2.1.1 Current and future state maintenance

The current and desired future state of the maintenance indicated by Intersnack is visualized in Figure 8. The maintenance activities of the technician should move from mainly corrective tasks to more preventive maintenance. In a future state would it be desirable if the technician could be more concerned with preventing failures rather than solving them. Also, should the operator help with keeping the machine in Basic condition and not only keeping the machine running to produce products. The operator could execute the first-line maintenance and be the one who notices failure behavior.

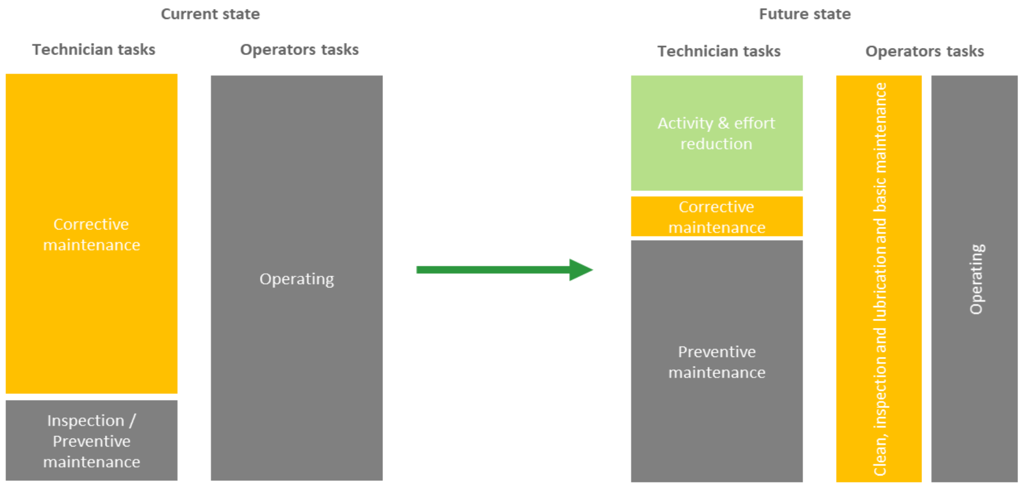


Figure 8 Current and future state maintenance

In the future state of maintenance should the maintenance work structure shift towards the right side of Table 1, in other words, maintenance should be scheduled. Scheduled maintenance is beneficial because it schedules tasks efficiently, minimizes downtime, controls costs, improves reliability, and creates a safer and more predictable production environment.

Table 1 Maintenance work structure

Unscheduled – Unplanned	**Unscheduled – Planned**
There is no structured approach to maintenance. Resulting in high maintenance costs/low efficiency/firefighting culture. Maintenance is carried out without a predetermined plan.	Maintenance is carried out on an ad-hoc basis, whenever an opportunity arises. Which results in higher maintenance costs caused by reactionary work but maintenance is effective in terms of time utilization.
Scheduled – Unplanned	**Scheduled – Planned**
The date and time for performing maintenance tasks are known, but there was a lack of organization. The planned tasks are not executed in an orderly manner, resulting in high maintenance costs and a reactive way of working.	There is a structured approach with a predetermined plan. Resulting in lower/controlled maintenance costs, efficient use of time, and consistent, predictable outcomes.

The changes from unplanned-unscheduled towards planned-scheduled maintenance are visualized in Figure 9. The most important part is that the mean downtime (MDT) becomes equal to the mean time to repair (MTTR). The failure is known so there is no troubleshooting, the workload of the preparation task drops and is already executed.

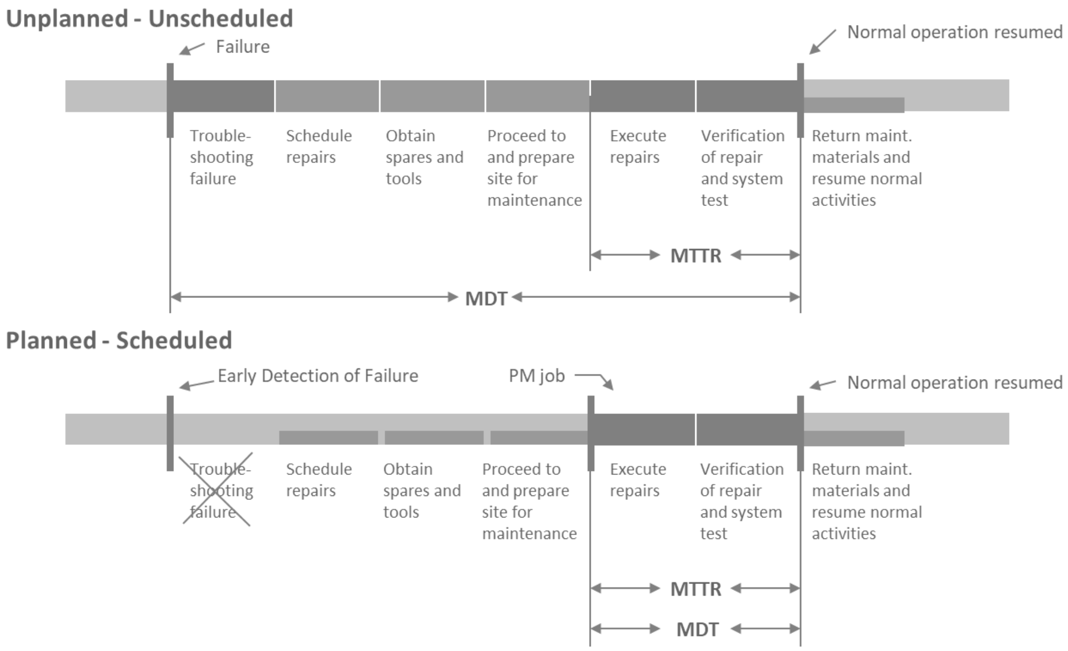


Figure 9 Shift from maintenance Unplanned - Unscheduled towards Planned - Scheduled

2.2 Maintenance registration

In this section is the current method of registering maintenance activities investigated. To provide a better overview of how this process works is the D028 chosen as an example.

2.2.1 Maintenance jobs – Ultimo

Ultimo is the enterprise asset management system of Intersnack. Ultimo holds information related to the management of assets and facilities, including data on asset maintenance schedules, work orders, inventory, asset history, and performance analytics. In Ultimo are the maintenance activities divided into 6 categories. The registered maintenance job types are:

1. Failure (critical and non-critical)
2. Scheduled repair
3. Periodic / Preventive Maintenance
4. Inspection / Condition Monitoring
5. Work out Inspection / Condition Monitoring
6. Modification

Production line operators can only create maintenance jobs for failures type 1. The failures are translated in Ultimo to maintenance jobs as indicated in section 2.1.1. Critical failures need to be handled immediately. Non-critical failures, failures that do not immediately affect the production or (food)safety, are planned by the Coordinator Preventive Maintenance as scheduled repair. Category 2, 3, 4, and 5 jobs can be created by the Coordinator Preventive Maintenance or the Line Team (Maintenance Lead, Process Lead, and Line Lead). Category 3 is a maintenance task that is planned and performed at a specific interval. Job category 5 is created from inspection job category 4. The modifications of job 6 are created by the engineers. At the start of this research are there almost none PM jobs used at the Nuts packaging department as can be seen in Figure 10.

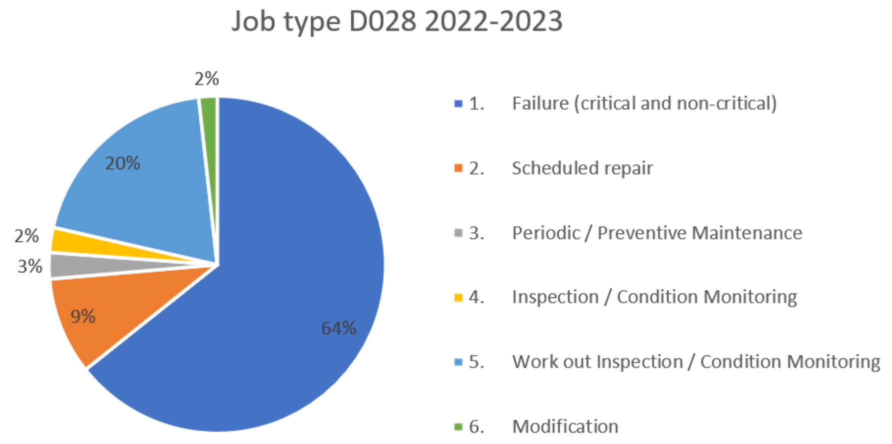


Figure 10 Distribution Job Types D028 2022-2023

The different types of performed maintenance jobs on the D028 in 2022-2023 are indicated in Figure 10. Job type 1 is the most executed job type and job type 4 is (mainly) performed by the external.

2.2.1 Machine structure

To use the Ultimo program effectively, it is important to ensure that all components of your machinery are accurately filled out and that the machine structure is logical. In this way can the maintenance activity be linked to specific machines or components. This allows better assigning and registration of maintenance jobs. As shown in Figure 38 is the current machine structure of D028 in Ultimo restricted to the highest level of the machines. The sub-assemblies or components of the different machines are not indicated. Which makes it difficult to register and analyze specific failures.

2.3 Maintenance decision criteria and constraints

The decision criteria for performing maintenance are determined by the Maintenance Lead of the production line with the Coordinator Preventive Maintenance. The coordinator plans for the different departments of the production site the required maintenance activities. The coordinator determined that the department technician is available on Monday and Friday for the defect handling.

Furthermore, is the Tuesday every 8 weeks planned for the Nuts Packaging Department. On this day are all the technicians of Intersnack available. The eight weeks are determined by the coordinator and are based on an average delivery time of the components based on experience.

When creating a schedule for the maintenance activities are various conditions considered. These conditions can be translated into constraints. There are two types of constraints: hard and soft. Hard constraints are those that must always be satisfied. Meanwhile, soft constraints are those that are wanted to be satisfied as much as possible. The hard constraints are:

- **Safety:** The maintenance activities may not cause an unsafe situation
- **Budget:** The cost of maintenance is not higher than the value it adds.

When the hard constraints are met can the wishes be fulfilled. The solution is preferred based on how many wishes are met (as long as hard constraints are met). The soft constraints are:

- **Downtime:** Maintenance is supportive of production and should minimize downtime
- **Risk Management:** Maintenance jobs must minimize the chance of potential failures
- **Human resources:** The maintenance jobs can be performed by the internal technicians
- **Machine job grouping:** Maintenance jobs of the same machine/grouped

2.4 Maintenance performances

The unplanned downtime is indicated as the best indicator of the reliability of the machine. The reliability helps to determine the machine condition. The analysis starts with evaluating the performances of each machine of the production line D028 with the data of 2022. This data is used to have enough events and a complete year of relevant data to the current situation. From this year until now no large changes made to the machines. Different key performance indicators were used to measure the performance. The machine with the highest unplanned downtime is further analyzed at the assembly component level.

2.4.1 Machine and component performances

The machines, as indicated in 1.2, are analyzed on their performances. The "Transwrapper" in combination with the "Casepacker" is responsible for almost half (47%) of the total unplanned downtime of the D028 as can be seen in Figure 11. The "Transwrapper" has the highest impact on the downtime and will therefore be chosen as the machine to focus on during this research. Another reason is that the production line cannot continue producing if the machine is down since it is one of the critical machines.

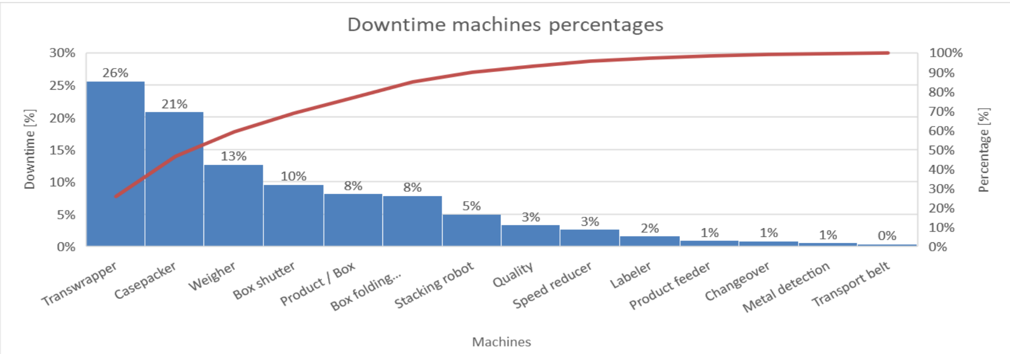


Figure 11 Downtime percentage per machine

The performances of the machines in aspect to the Unplanned Downtime are shown in Figure 12. The red and green cells indicate respectively the worst and best-performing indices of its KPI category. The assets "General" and "D28 (IWS Packaging)" are excluded from the research since these are not related to machine failures but human factors as shown in the underlying events from Table 19 Downtime Events. The event can be caused by different components which are related to the event. To prevent and identify these unplanned events is a more in-depth analysis needed.

Asset Name	Stops [#]	Downtime [%]	MTBF [min/#]	MTTR [min/#]
General	1.280	27%	137,3	20,4
Transwrapper	1.847	16%	95,2	8,6
Casepacker	2.464	13%	71,3	5,3
D28 (IWS Packaging)	128	9%	1.373,1	65,7
Weigher	871	8%	201,8	9,0
Box shutter	908	6%	193,6	6,6
Product / Box	93	5%	1.889,9	54,4
Box folding machine	905	5%	194,2	5,4
Stacking robot	661	3%	265,9	4,7
Quality	387	2%	454,2	5,3
Speed reducer	280	2%	627,7	5,9
Labeler	138	1%	1.273,6	7,2
Product feeder	28	1%	6.277,2	20,4
Changeover	135	1%	1.301,9	3,8
Metal detection	16	0%	10.985,1	20,8
Transport belt	31	0%	5.669,7	8,0

Transwrapper - Event	Stops [#]	Downtime [min]	MTBF [min/#]	MTTR [min/#]
Seal jaws	399	6,427.0	440.5	16.1
Foil transport	783	4,813.0	224.5	6.1
Bag coding	263	2,265.0	668.3	8.6
Blade	102	747.0	1,723.1	7.3
Vertical seal	142	712.0	1,237.8	5.0
Unexplainable downtime	92	615.0	1,910.4	6.7
String belt	41	240.0	4,286.9	5.9
Chute	25	114.0	7,030.4	4.6

Figure 12 Performances D028 machine level (left) + Transwrapper component level (right)

As can be seen, in the orange highlighted cells on the left, is the Transwrapper the machine with the highest downtime. When the Transwrapper is not functioning is it not possible to produce products on the production line. The downtime is mostly caused by the “Seal jaws” (40%) and “Film transport” (30%) events as can be seen on the right. The “Seal jaws” have a high mean time to repair (MTTR = 16 minutes) and the “Film transport” causes the most stops (783 stops).

Furthermore, another interesting aspect, which can be seen in Figure 13, the product class “Salted” has the most downtime (76%) created for the event “Seal jaws”. This indicates that salt affects the Seal Jaws which is in line with what was expected since salted products create extra dirt. When analyzing specific component failures can this information be used to explain the failure behavior.

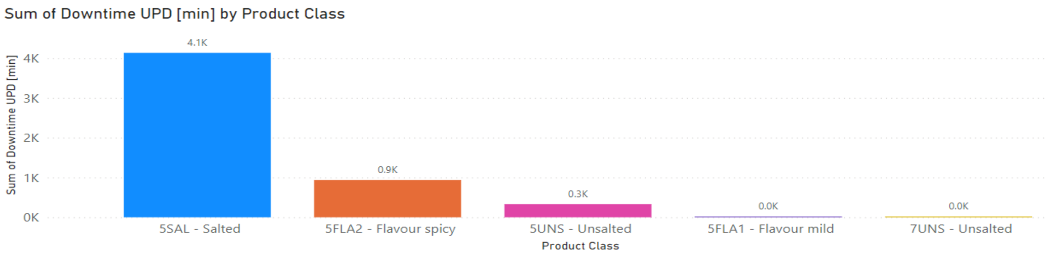


Figure 13 Effect product classes on the "Seal jaws" (Unplanned Downtime)

The seal jaws of a packaging machine are the components responsible for sealing the bag, ensuring that the product is packaged airtight. This is a critical aspect of the product quality. To further analyze the downtime event are the registered maintenance jobs in Ultimo analyzed. There are a total of 46 jobs in Ultimo created in 2022 related to the Seal Jaws event.

2.4.2 Maintenance performance 2022

The maintenance goal of Intersnack can be translated into key performance indicators regarding reliability, safety, and costs. The focus of this project will be on the machine “Transwrapper” of production line D028. The performances of the machine in 2022 are shown in Table 2. These are registered to create insight into the performances and set an objective that can be achieved with the newly developed maintenance plan. The future performances regarding the failure behavior will be compared to control the effectivity.

Table 2 Performances KPI Bosch Transwrapper D028 2022

KPI	**Reliability**				**Safety**	**Maintenance costs**	
Asset Name	Stops [#]	MTBF [min/#]	MTTR [min/#]	Downtime [%]	Triggers [#]	External [€]	Internal [€]
Bosch Transwrapper D028 2022	1847	95,2	8,6	26	0	36.210	30.000

The KPI’s regarding the reliability are explained in section 2.4.1. There are 6 safety triggers, unsafe situation notification, registered in 2022 (D028) as shown in Table 2. None of these notifications are related to the machine Transwrapper.

The external maintenance costs for the Transwrapper are recorded in the purchase orders. The costs for the year 2022 are shown in Table 2. These costs include the parts that were purchased after inspection, along with spare parts for the machine. The internal maintenance costs are registered in Ultimo. Each maintenance job records working hours and material costs. There are a total of 100 working hours and € 26,544 material costs on the D028 Transwrapper registered in 2022. This represents a total cost of ± €30,000.

2.4.3 Improvement potential

The improvement potential of performing optimal maintenance is mainly to reduce unplanned downtime. The machine reliability will be improved through performing maintenance which will reduce a part of the unplanned downtime. In perspective, on the D028 in the year 2022 is a total of more than 1600 hours of unplanned downtime registered which represents a total direct cost of:

- Loss of sales (production loss), missed output of products related to the unplanned downtime on the production line D028.
    - ± €800.000 (1600 missed production hours, 130 products per minute, OEE 40%)
- Labor hour costs / unutilized resources
    - The costs of 2 operators (±60 euro per hour), the total cost of ±€100.000 euro in 2022.

In addition to unplanned downtime are there also other ways in which a failure affects the operational capabilities of the asset. These include:

- End customer satisfaction, the customer service is affected regarding delivery completion. When delivery completion drops below the agreed term can cause financial penalties.
- Emergency maintenance costs, whether the failure leads to an increase in overall operating cost in addition to the direct cost of repair
    - (Higher) Labor costs emergency Technician
    - (Higher) Replacement costs for parts, materials, and tools
- Decrease in employee motivation and productivity
- Administrative costs for failure registration and investigation of the core problem
- (Internal) Supply interruption

2.5 Conclusion

Maintenance objective

The maintenance objective of Intersnack is to improve reliability, improve safety, and reduce machine ownership costs. This objective is the main focus of the maintenance strategy. Measured with the reliability KPIs, safety triggers, and maintenance costs.

The most critical machine D028

The Transwrapper is indicated from the performed analysis as the most critical machine of the production line D028 and will be further analyzed in this research. The machine has the highest unplanned downtime, followed by the Casepacker. The failure event “Seal jaws” and “Film transport” created the most downtime for the Transwrapper. Notably, the failure event of "Seal jaws" is considerably influenced by the product class "Salted."

Failure and defect registration

The failures and defects are registered on the highest (machine) level and not specified per part. To get better insights for instance regarding failure patterns would it be beneficial to divide the machines into sub-assemblies and even some parts at a component level. For this reason, is only the failure event indicated and not the specific component.

Current maintenance strategy

The current maintenance strategy at Intersnack Doetinchem, for the Nuts Packaging line D028, is corrective maintenance. Furthermore, an inspection is performed for the different machines in combination with (large) maintenance. This can be seen in the maintenance register Ultimo (Figure 10) where category 1, (critical and non-critical) failure, is currently the most executed maintenance job. Modifications, preventive, and condition monitoring maintenance are rarely performed.

Desired future state maintenance

In a future state would it be desirable if a technician could be more concerned with preventing failures rather than solely solving them when they already occur. The operator will keep the machine in basic condition and can execute first-line maintenance and notice failure behavior.

Conclusion and next steps

In this chapter is the impact of the unplanned downtime on the production site indicated. The different machine events causing the unplanned downtime are highlighted. These events are only registered on a high machine level. Which are directly linked to the reliability and availability of the machines. The current maintenance activities indicate the corrective maintenance policy. The missing maintenance plan including the specific tasks and technical knowledge are the root cause of the issue.

From the analysis in this chapter is concluded that Intersnack would benefit from a maintenance concept that helps them to determine the various maintenance interventions and a general structure in which these interventions are foreseen. The information about the maintenance concept development and maintenance policies is required and will be obtained in the next chapter.

3 Literature review

In this chapter will the question “What is the best way to establish a preventive maintenance policy and model in a production environment similar to Intersnack, according to the literature?” be answered. Since the current situation is clear, we explore the existing knowledge in this specific field. The knowledge and expertise will be explored through the literature review, saving time from reinventing the wheel. Firstly, will the relevant maintenance concepts and policies be described. Next, we choose the most suitable maintenance concept from the literature study to solve the maintenance problem at Intersnack. Further execution and optimization of the maintenance plan will also be looked into in the literature review. Chapter 3 describes this literature.

3.1 Maintenance concepts

Garg, A., & Deshmukh, S. G. (2006) state: “A maintenance concept can be defined as the set of various maintenance interventions (corrective, preventive, condition-based, etc.) and the general structure in which these interventions are foreseen.” (P. 226). The maintenance concepts that are further looked into are: Total Productive Maintenance (TPM) and Reliability Centered Maintenance (RCM). The maintenance concepts Business Centered Maintenance and Life Cycle Cost are not further analyzed since it is not in line with the maintenance goal and strategy of Intersnack. Within Intersnack is indicated that an effective maintenance concept has to be developed, which has to be considered comprehensive. Intersnack’s current maintenance strategy is included in the Intersnack Work Systems as described in paragraph 2.

3.1.1 Total Productive Maintenance (TPM)

TPM is a program that originated in Japan in 1951 and prioritizes factory maintenance due to the increased need for maintenance personnel caused by automation. Maintenance is a key component in the concept, but TPM include much more than maintenance only. TPM is incomplete as a maintenance concept since it does not provide clear maintenance policy decision rules. Within Intersnack is the TPM concept the foundation for the Intersnack Work Systems (2).

The foundation of TPM is cleanliness, order and discipline, teamwork and continuous improvement process. Two of the main solutions pillars that are proposed by TPM are translated into the IWS pillars:

- **Progressive maintenance (PM).** Plan maintenance instead of waiting for breakdowns. Create the capability to achieve optimal equipment and process conditions in a manner that is efficient and cost effective. To assure the functions of the equipment are satisfactory whenever the equipment needs them at minimum cost.
- **Autonomous maintenance (AM)**. The overall aim of Autonomous Maintenance is to develop highly skilled production operators/technicians and establish proper equipment conditions. Get the operators to do the (easy) first line maintenances. This combination of equipment and people yield an orderly workplace that is effective (zero losses/defects) and efficient (requires minimal effort).

On the foundation of TPM can 5 pillars be built. The first two pillars are PM and AM, the others are:

- Elimination of main problems. Get the factory to a standard level. In IWS is this implemented in the form of a Break Down Elimination. This is a method to analyze breakdowns and find the core problem.
- Early management of new equipment. Get new equipment on time into the factory. This proposed pillar is translated in multiple pillars in IWS.

- Education & training (ET) on the job. Prepare your people for the job in IWS is this pillar ET.

As can be seen in the proposed foundation and pillars from TPM is IWS based on the TPM concept. The execution of TPM is broader than maintenance as can be seen in IWS. This also results in unclear decision rules for the maintenance policy selection and the execution of maintenance. The concept describes on a high level how to reduce the big losses regarding availability, speed, and quality. In order to continuously improve the performance-effectiveness as well as efficiency.

3.1.2 Reliability Centered Maintenance (RCM)

Moubray describes RCM as "A process used to determine the maintenance requirements of any physical asset in its operating context" (Moubray, Reliability-Centered Maintenance, 1999). In other words, what must be done to ensure that any physical asset continues to do whatever its users want it to do in its present operating context. The ultimate goal of RCM is to precisely identify the failure modes for each system and/or equipment and the severity of failure consequence in order to determine the applicable maintenance technique in a cost-effective manner (Gurumeta, 2007).

RCM is more focused on reliability than on economic issues, particularly useful for high tech/risk environment. The RCM analysis starts with system selection and definition of functions. Next is a Failure Modes Effects Analysis (FMEA) per system performed where the severity and probability are indicated. Lastly is a decision diagram created where is described:

1. What routine maintenance has to be done, how often has it to be done and who has to do it
2. Which failures are significant enough to require a redesign?
3. In which cases can failures happen deliberately (run to failure)

The three tangible outcomes of the RCM analysis are:

- Maintenance schedules about what has to be done by the maintenance department.
- Revised operating procedures for the operators on the asset.
- A list of areas where one-off changes must be made to the asset design or the operating procedure.

Less tangible outcomes of the analysis are that the participants learn better how the asset works, and also tend to function better as a team.

3.1.3 Combined maintenance concept

Companies need a customized maintenance concept borrowing ideas from different theoretical concepts, however, there still has to be enough space to create a company-specific and flexible concept (Waeyenbergh G. &., 2002). Intersnack would prefer an easy-to-use maintenance concept that captures the knowledge of experienced personnel without requiring extensive documentation.

The proposed maintenance concept will therefore be a combination of the existing maintenance concept of TPM with additions that are proposed from RCM. RCM helps in identifying the most critical equipment and determines the most appropriate maintenance policy based on the risks and consequences of the failure. By applying this detailed analysis within the TPM framework, would it be possible to execute more targeted and effective TPM activities. The RCM process ensures that maintenance activities are carried out when needed, and resources are optimized to improve equipment reliability and reduce maintenance costs.

3.1.4 Maintenance policy

There are a lot of maintenance policies that can be applied for the failure modes. In the past several decades, maintenance and replacement problems of deteriorating systems have been extensively studied in the literature. The increase interest in academia and the demand in practice for maintenance task optimization is demonstrated by the published works on this topic in Figure 14, both theoretical and applied shows the evolution.

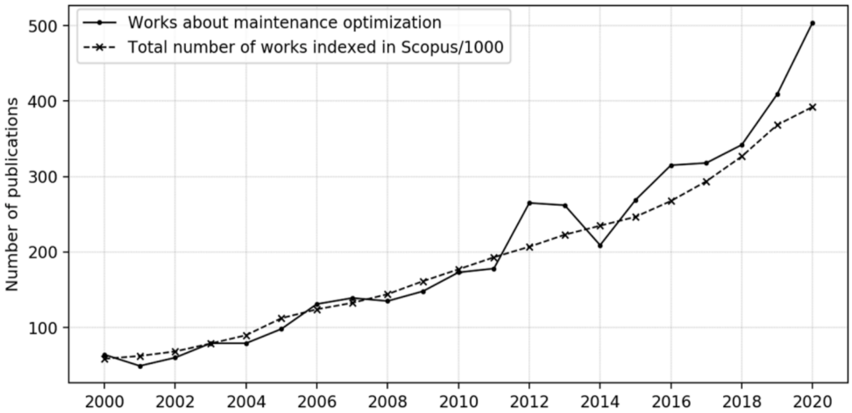


Figure 14 Number of publications about maintenance optimization and total number of maintenance related publications (divided by 1000) indexed in the Scopus database from 2000 to 2020 (Pinciroli, Baraldi, & Zio, 2023)

Since TPM does not provide a clear overview or rules for applying a specific maintenance policy are the proposed maintenance policies from RCM and Waeyenberg used. RCM provides structured rules for selecting a maintenance policy. The overview of the possible maintenance policies from the literature is in Table 3 shown. Each maintenance policy is shortly described. Each policy having their unique characteristics, advantages, and drawbacks.

In the survey of Wang (2002) are these categorized and compared. The classified categories from Wang are similar to the proposed in RCM (2008) and Waeyenbergh maintenance concept development (2002) but with slightly different names. In the survey of Wang are the main policy categories further specified. The maintenance policy names of Waeyenbergh will be used for the maintenance concept development as indicated in Table 3.

Table 3 Maintenance policy types

	Maintenance policy		
	RCM	**Waeyenbergh**	**Short description**
Default tasks	No scheduled maintenance	Failure based maintenance (FBM)	Maintenance after breakdown, “Run to failure”
	Redesign is compulsory	Design-out maintenance (DOM)	Improve design to make maintenance easier/eliminate
	Scheduled failure-finding task	Detective based maintenance (DBM)	Observe degradation, “Detection by operators”
Proactive tasks	Scheduled on-condition task	Condition based maintenance (CBM)	Monitor/measure conditions
	Scheduled discard / restoration task	Use Based maintenance (UBM)	Maintenance is carried out after a specified interval

After a maintenance policy, as indicated in Table 3, is determined for a machines/component can the policy task be optimized. The different policy options are shortly explained. The failure management policies are divided into two categories:

Proactive Tasks
The tasks required to prevent failures can be called proactive tasks. The proactive tasks can be further classified into the following categories:

- *Use Based Maintenance (UBM)*
  - *Scheduled Restoration Task.* The component needs to be restored to the initial capability at/or before a specified interval.
  - *Scheduled Discard Task.* The component needs to be discarded or removed at/or before a specified interval.

A unit is replaced at the predetermined limit (for instance time T which represents production hours or age) or in the case of failure (corrective maintenance), whichever occurs first, where the limit is a constant (Barlow, 1960). The failure behavior of the components is assumed predictable. In this policy, after (preventive or corrective) maintenance, is the component as good as new. An example path of use based maintenance with interval T = 10 is shown in Figure 15. In green is the preventive maintenance action performed and in red corrective. The interval needs to be based on the failure behavior. When the failure behavior is unknown should the historic failures data, information from the OEM, employee knowledge and experience be used.

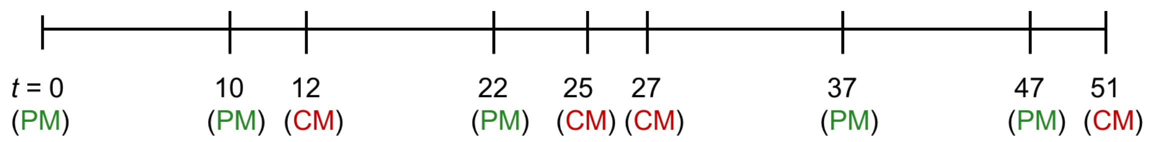


Figure 15 Use-based maintenance policy timeline example

- *Condition based maintenance (CBM)*
  - *On Condition Task.* To prevent functional failure or its consequences, it is important to check for potential failures. A potential failure can be a detectable condition that indicates a functional failure is either about to happen or is currently happening. For instance, with:
    - Visual monitoring involves using senses such as sight, taste, and hearing to assess the condition of the engine.
    - Performance monitoring checks and measures the performance parameters of the machine to ensure they meet the standard.
    - Geometric monitoring helps to identify any deviations in the equipment's geometry, allowing for leveling and alignment measurements to be taken.
    - Vibration monitoring checks and measures the location of vibrations on a routine and continuous basis.

Default Actions
Default actions are automated actions that mostly take place when there is no proactive task chosen or suitable to overcome a failure.

- Detective based maintenance (DBM)
  - Failure-finding: This involves periodic checks of (hidden) system functions to identify whether they have failed or not.
- Design-out maintenance (DOM)

    - Redesign if needed, a one-off change can be made to the built-in capability of a system to prevent future failures. The RAMSHEEP design principles can be used.
- Failure based maintenance (FBM)
    - No scheduled maintenance (run-to-failure): In this scenario, no effort is made to prevent system failure. Instead, the system is allowed to fail and then repaired.

Another option that is mentioned by Waeyenbergh is the policy "Outsourcing". This option is can be an alternative for in-house maintenance work. This option can for instance be included if the knowledge, skills, or time is not available.

3.2 Maintenance concept development

In the literature study are mainly the maintenance concept development of Waeyenbergh & Pintelon and from Gits used to identify the proposed steps for the execution of the maintenance plan. They both propose a decision chart for the selection of the optimal maintenance policy. The framework helps to define the maintenance actions and consists of seven steps:

Step 1: Identification of the objective and resources
The objective of the maintenance should be specified in order to define the optimal maintenance plan. The stated maintenance goal, "Maximum reliability and availability while gaining thorough insight in the technical systems", in section 2.1.1 will be used. The objective still needs to be translated into a requirements list in example materials, people, know-how and money.

Step 2: Selection Most Important Systems
The selection of the Most Important Systems could be based on the Equipment Ranking that is performed per production line. This tool is meant to help evaluate the ranking of the equipment. Since there are no unlimited resources, is prioritization and focus required.

Step 3: Identification of the Most Critical Components
Currently, the identification of the most critical components in the most important system remains unknown. This insight can be gained through the execution of a Failure Mode Effect Analysis (FMEA). Other methods include Fault Tree Analysis (FTA), Markov analysis, and Hazop (especially safety-related). FMEA takes a more qualitative approach, while FTA, Hazop, and Markov analyses require quantified data obtained from databases and quantified (limit) values. In the current situation, acquiring accurate quantified data from existing databases is challenging, hence the application of FMEA. Nevertheless, historical failure and defect data will be utilized as available input.

Step 4: Selecting maintenance policy
A constructed maintenance policy decision tree helps with the selection of one maintenance strategy for a particular part (Waeyenbergh G. &., 2002). The decision tree still needs to be specified for the organization by combining the RCM method with the one of Waeyenbergh.

Step 5: Optimization of the maintenance policy parameters
After a maintenance policy is selected with the help of the decision diagram can the maintenance policy task and parameters be optimized. Maintenance tasks are primarily determined by leveraging the experience and knowledge of operators and technicians, as well as by examining the existing maintenance tasks at similar production locations, such as Hardinxveld or Lelystad. Additionally, OEM maintenance recommendations from manuals are utilized, and input from external technicians is

considered in task determination. To identify maintenance tasks for previously occurring failures, an analysis is conducted on the performed activities.

Step 6: Implementation and evaluation
Next are the actions that are needed to put the maintenance policies into effect. These actions are for instance: clustering maintenance policies into maintenance plans, formulate maintenance schedules, and developing or revising task instructions.

Step 7: Feedback
The maintenance concept is evaluated after execution to ensure that the tasks meet the requirements and objectives stated in step 1.

3.3 Initialize and optimize maintenance tasks

Operationalizing maintenance is the design step in which a maintenance operation is linked to each maintenance task to be specified based on technical effectiveness of the operation, anticipating efficiency considerations and taking into account operating conditions. In order to initiated and put the maintenance concept in action will the approach as described by Lambooy & Gits (1989) used since this is part is missing in Waeyenbergh's maintenance concept. The proposed approach helps to limit maintenance intervals, cluster maintenance operations and harmonize maintenance intervals.

3.3.1 Maintenance intervals

From the standpoint of availability, a distinction should be made between maintenance during operation and maintenance out of operation. Maintenance during operation can be carried out without shutting the machine down. Maintenance out of operation can only be carried out when the machine is not in operation. Furthermore, maintenance set-ups need to be distinguished. In this way can maintenance set-ups (optional) be clustered.

A limiting maintenance rule specifies a maintenance task and its minimum interval. To establish such rule must the failure behavior be known. This preferably should be based on component life (historical) data analysis. Where enough information about the failures is known. In reality is the situation much less clear. In absents should this be based on knowledge and experience from the employees (operators / technicians) or for instance the recommendations from the original equipment manufacturer. This rational approach of gaining knowledge on the failure behavior is to ask the right question to the right people. The question to ask is how much time elapse from the moment the potential failure becomes detectable until the moment it reaches the functionally failed state. This question should be asked to the people who have an intimate knowledge of the asset (most of the time the operator).

The maintenance interval will be determined for the preventive maintenance policies (DBM, UBM, CBM). In order to determine the optimal interval is the failure behavior of the component needed. The method for DBM is described in section 3.3.2 and for the others in section 3.3.3. The interval determination is mainly useful if the failure rate function is increasing over time and the cost of preventive maintenance are smaller than corrective maintenance.

3.3.2 Detective based interval

The tasks involves checks of (hidden) system functions to identify whether they have failed or not. In a detective based task (failure-finding), intervals are established using availability and reliability, which require knowledge of the failure behavior and useful life of the component. The reliability is indicated with the failure behavior represented by the MTBF (Mean Time Between Failures). The availability is determined during the analysis.

For example, the detective-based interval is set to 1 year. Where 10 components X have been in service for 4 years, the total service life equals 40 years. The failure on the X components has been checked once a year for 4 years, revealing 4 failures in this time. The MTBF is calculated as 40 years in service / 4 failures = 10 years. Assuming failures occur halfway through the year on average because of absence of any better information. The average failed state of a failed component is then half a year. The average unavailability is calculated by dividing the total failure state time through the total service life. $Average\ unavailability\ = \frac{4\ failures*0,5\ failed\ state}{40\ years\ of\ service} = \frac{2}{40} = 5\%$ corresponding to an average unavailability of 5%.

The formula suggests a linear correlation between the unavailability (5%), interval (1 year) and the reliability given by its MTBF (10 year), as follows:

$$Unavailability = \frac{0,5 * \ Interval}{MTBF} \rightarrow \ Interval \ = 2 * \ Unavailability * \ MTBF$$

The formula is translated in Table 4 which can be used as a first indication of the desired interval.

Table 4 Detective based maintenance interval (availability and reliability)

Availability required for the function [%]	99.99	99.9	99.5	99	98	95
Detective based interval (as a % of the MTBF) [%]	0.02	0.2	1	2	4	10

Accurate data on the failure behavior (MTBF) allows for a more precise calculation. Another method for calculating the MTBF is to make use of the time between the registered maintenance jobs on the specific component who represents the time between failures. The average of these times represents the MTBF. However, if this information is missing or unreliable, estimation becomes necessary within the specific context. Once the task interval is set, tracking whether the failure occurs each time the task is performed is crucial. Based on this information can the task interval revised.

3.3.3 Component Life Data Analysis

The analysis of failure data and modeling failure behavior using probability distribution function. Statistical methods are used to analyze failure(life) data. There are multiple failure distributions possible. The case study only briefly covers the analysis of the discrete empirical distribution and the Weibull distribution because of the data-driven approach using the available data in Ultimo and Weibull provides a good fit in many applications.

Discrete empirical distribution

This approach is data-driven, emphasizing a focus on observed data to gain a comprehensive understanding of the failure behavior. The method uses the available failure data from Intersnack. The current corrective maintenance policy leads to failed components, which helps to gain insight into the failure distribution. Examining failure behavior through the method aids in comprehending the variability of failures. Utilizing a histogram makes it easy to visualize the frequency of failure events, offering valuable insights into the distribution of these occurrences.

Example calculation with the discrete empirical distribution:
The model to determine the failure behavior uses the following variables:

- T: first time to failure given that a system (first time) is in operation at time 0
- Cumulative probability distribution: F(t)=P(T≤t)
- Probability density of first failure: f(t)=F'(t)
- Reliability (Survival) function: $R(t)=\bar{F}(t)=1-F(t)$
- Failure rate: $z(t)=f(t)/R(t)$

The observed failures are registered in the different intervals as shown in Table 5. Where the fraction of failed components per interval is indicated (f(n)).

Table 5 Example discrete empirical distribution using historic data

Interval	[0,300]	[301,400]	[401,500]	[501,600]	[601,700]	[701,800]	[801,900]	[901,1000]
f(n)	0	0.02	0.09	0.21	0.4	0.19	0.08	0.01
n	3	4	5	6	7	8	9	10
F(n)	0	0.02	0.11	0.32	0.72	0.91	0.99	1
R(n)	1	0.98	0.89	0.68	0.28	0.09	0.01	0
z(n)	0	0.02	0.09	0.24	0.59	0.68	0.89	1

Next, can the failure function of the component be plotted. An example of two failure behaviors is shown in Figure 16. The distribution of the component failure is determined by the registered failures and can now be used to determine the optimal maintenance interval.

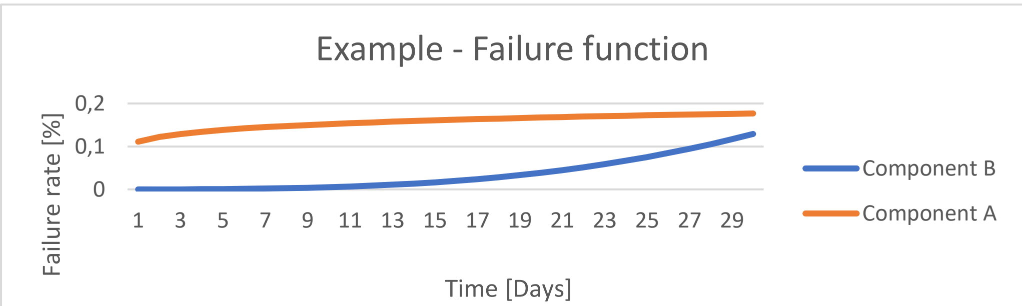


Figure 16 Example Failure function

Weibull
The method for an arbitrary monotone system with independent and non-renewable components, the system lifetime can be approximated by a Weibull distribution (Pittel, 1972). The Weibull distribution provides a good fit with data in many applications since it has a great variety of shapes which enable it to fit many kinds of data. An example of a failure behavior with different failure rate phases (decreasing failure rate (start-up), increasing failure rate (wear-out), and constant failure rate (stable)) is shown in Figure 17. With the Weibull distribution is it possible to formulate these patterns.

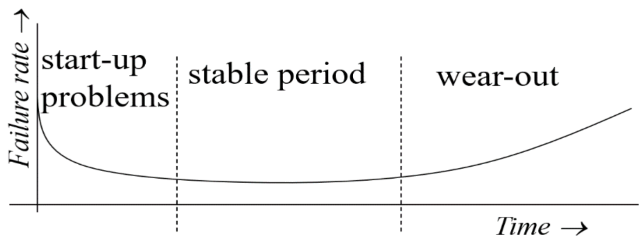


Figure 17 Example failure behavior "Bathtub curve"

The Weibull distribution has a specific shape character which can be determined. The different phases of the "Bathtub curve" can be indicated using this shape parameter. Figure 18 is the effect of the shape parameter (β) demonstrated. The calculation that has to be performed to determine the distribution is explained in Appendix C section Maintenance interval based on the failure behavior.

<u>Constant failure rate</u>: z (t)= λ (constant failure rate (CFR)) → β=1
<u>Wear out:</u> z (t) is an increasing function of the time t: Increasing Failure Rate (IFR) → β>1
<u>Running in:</u> z (t) is a decreasing function of the time t: Decreasing Failure rate (DFR) → β<1

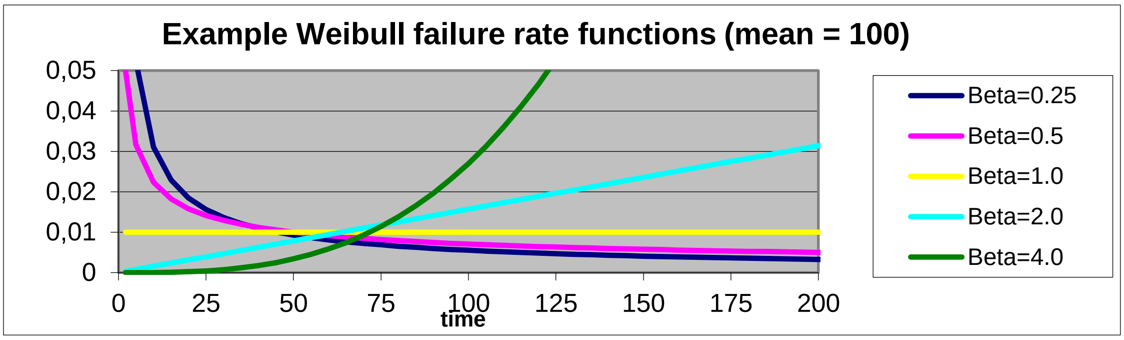


Figure 18 Example of Failure behavior Weibull distribution

Maintenance costs - Direct and indirect
Direct cost – PM, CM, Set-up costs
Costs (c0) if the system does not fail before T, costs of preventive maintenance.
Costs (c1) if the system fails before T, costs of corrective maintenance.
Set-up costs, before a maintenance task can be executed is it possible to have set-up costs.

Indirect costs - Downtime
For example, when corrective maintenance (CM) takes 3 days and preventive maintenance (PM) takes 2 days. If the costs of downtime are not considered, CM may be the more cost-effective option because it has a lower direct cost. For example, direct costs CM are €1000 and for PM €1200. However, if the cost of 1 day of downtime is € 500, then the indirect cost of CM is 3 x €500 = €1500, while the indirect cost of PM is 2 x €500 = €1000. Thus, downtime costs need to be taken into account, PM is the more cost-effective option, even though it has a higher direct cost.

Example calculation costs per time period:
An example calculation of the optimal maintenance interval is explained. The component life cycle (failure behavior) is known. An example is shown for a PM interval of 10:

- Costs c0 if the system does not fail before T, costs of preventive maintenance: 2000, -
- Costs c1 if the system fails before T, costs of corrective maintenance: 1250, -
- Cumulative probability distribution: F(t)=P(T≤t) → F(t)= 0.7
- Reliability (Survival) function: $R(t)=\bar{F}(t)=1-F(t)$ → $\bar{F}(t)=1-0.7=0.3$
- Example calculation of the costs per cycle T=10:
- $g(T) = \frac{Expected\ costs\ per\ cycle}{Expected\ cycle\ length} = \frac{c_0\bar{F}(T)+c_1F(T)}{T\bar{F}(T)+\int_0^T tf(t)dt} = \frac{c_0\bar{F}(T)+c_1F(T)}{\int_0^T \bar{F}(t)dt} = \frac{2000{*}0.3+1250{*}0.7}{5{*}0.3+10{*}0.7} = €173.5$

Next can the formula of the average cost per time unit be plotted as shown in Figure 19. The optimum interval can be determined from the graph by determining the minimal costs with corresponding time interval. In the case of the example is the optimal interval at 25 days.

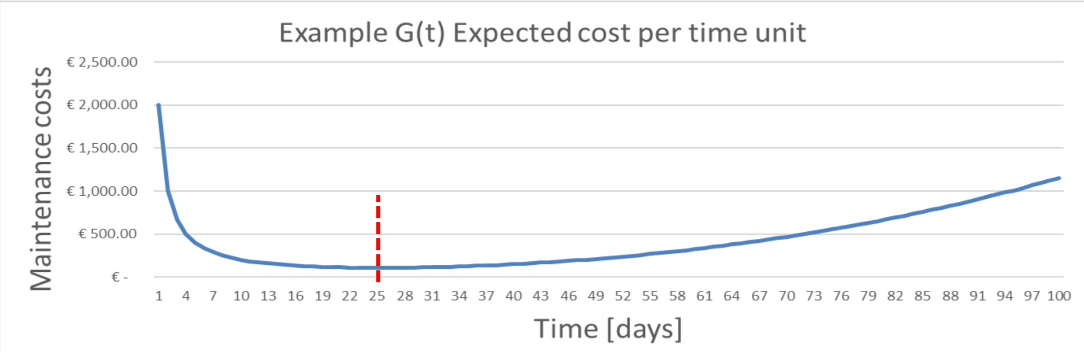


Figure 19 Example of the maintenance costs plotted in time

3.3.4 Cluster maintenance operations

Clustering maintenance jobs helps to create optimal maintenance work packages. Maintenance jobs often require one or more set-up activities. For this reason, clustering of maintenance jobs is a powerful instrument to reduce shut-down costs. "Maintenance jobs that must be carried out with a prescribed frequency are considered a clustering problem" Dijkhuizen (1997). The clustering of maintenance operations is the design step in which the limiting maintenance rules are combined into maintenance sets and clusters.

Maintenance jobs are divided into those that occur during operation and those that occur outside operation. Structuring maintenance during operation is considered inefficient. Therefore, this rule is directly included in the list of maintenance jobs. The maintenance jobs related to out-of-service maintenance form the basis for harmonizing maintenance intervals.

Optimal maintenance models are often too difficult to implement in real life. The maintenance job set-ups are distinguished (common and shared). In this research, only the method for frequency-constrained maintenance jobs with common set-ups is explained. This is a decomposition of the optimization problem. Practical examples of set-ups are cooldown time or dissembling jobs for the machine/components.

Clustering method

The clustering method is only needed for preventive maintenance policies. Maintenance jobs are combined in a maintenance set executed at a fixed interval. The following information is needed when clustering the maintenance jobs:

- Overview of the maintenance jobs i = 1, …, n
- Maintenance costs c_i per job
- Prescribed maintenance interval f_i
- Set-up costs s_1

The required steps when determining the maintenance job clusters are:

1. Cluster jobs with (identical) same interval
2. Sort the jobs according to decreasing interval, $f_1>f_2>..>f_n$
3. Compute upper bounds on intervals in optimal clustering

- Only integer intervals and determined with $\hat{f}_i = \left\lfloor f_i \frac{s_1+c_i}{c_i} \right\rfloor$

4. If interval of job i is between two jobs in the same cluster (in the optimal clustering), then job i should be in that cluster too
5. Define minimal cost (g(k)) for clustering (ordered) first k jobs
   - $g(k) = \min_{1 \le j \le k: f_j \le \hat{f}_k} \{g(j-1) + f_j(s_1 + c_j + .. + c_k)\}$

In the case study are the steps described with a practical example.

3.3.5 Harmonize maintenance intervals

Harmonizing maintenance intervals is the design phase in which a work package, a collection of maintenance tasks with the same interval, is prescribed. Then the maintenance work packages are grouped to fit into maintenance intervals that meet the interval conditions, where it is desirable to distribute the workload as evenly as possible. The harmonization is created in Ultimo as described in appendix D section Harmonizing maintenance jobs. The result is a maintenance plan where the maintenance clusters are planned in time.

3.4 Research gap

The research gap between the literature proposed maintenance method and the current maintenance method is that there is no maintenance concept at Intersnack. A maintenance concept is defined as a set of various maintenance interventions (corrective, preventive, condition based, etc.) and the general structure in which these interventions are foreseen (Waeyenbergh & Pintelon, 2000).

Within Intersnack are parts from the TPM method, the AM & PM pillar, used to execute maintenance. Where the AM pillar is mainly focused on the development of skilled production operators/technicians. The PM pillar is used to achieve optimal equipment and process conditions. A clear and structured method on how to create a maintenance plan is missing. This results in poor machine performance and conditions. There is no clear maintenance strategy at Intersnack's Nuts Packaging department. The maintenance policy for the components is currently corrective "run to failure" due to the missing maintenance plan.

The proposed steps from the framework of Waeyenbergh will help to guide Intersnack in the creation of a maintenance concept where a set of various maintenance interventions is described. The framework needs to be specified for the situation at Intersnack. The structure and action steps will help to determine and make supported decisions regarding the maintenance. The maintenance concept will help to determine and specify the day-to-day maintenance tasks.

Within the literature is the implementation and execution for the maintenance concept development, for instance the 7-step framework, limited described. For instance, information about optimizing the maintenance policy parameters, and maintenance clustering is missing. A clear structure in the form of a maintenance concept is therefore needed.

3.5 Transition gap

The research gap between the literature proposed maintenance concept and current maintenance method can be closed by performing a case study where the proposed maintenance concept development of Waeyebergh is executed for the situation at Intersnack Nuts Packaging department. The proposed steps from the 7-step framework will be executed on the machine with the highest unplanned downtime, the Transwrapper, of production line D028. This case study will be the foundation for further development of the maintenance concept. During the execution, the IWS tools will be integrated where possible to provide. The execution of the 7-step framework is described in the next chapter. Including the practical application of clustering and harmonization of maintenance tasks into maintenance work packages.

3.6 Conclusion

The existing maintenance framework at Intersnack is rooted in TPM, but its limitation lies in the absence of clear decision rules for developing a maintenance plan. Specifically, there is a lack of information regarding the selection and actual execution of the maintenance policy. Presently, failures are not proactively prevented but only analyzed post-occurrence. The absence of a (preventive) maintenance plan and a method for its construction is evident. Combining the RCM method with Waeyenbergh's 7-step framework provides the necessary structure to formulate a comprehensive maintenance plan. Utilizing the failure analysis (FMEA) and the maintenance policy decision tree from RCM facilitates the creation of specific maintenance tasks, while the overall framework ensures a systematic approach to developing the maintenance plan.

The proposed maintenance concept will combine the current TPM approach with enhancements from RCM. Additionally, developing a maintenance plan is crucial to guide Intersnack towards more preventive maintenance. Therefore, the maintenance concept is tested by conducting a case study on the Transwrapper. The next chapter will describe the development of the maintenance concept. The case study will illustrate how the maintenance concept is applied practically, including executing different maintenance policies and optimizing them.

4 Solution Design

The solution design describes the proposed maintenance model, discusses which problem it solves, how it works, and what information and data is needed. The maintenance model is the maintenance concept development where the 7-step framework is described and executed. The most suitable solution for creating a preventive maintenance plan at Intersnack is to create a maintenance concept which can be used to determine the needed maintenance actions. The solution design should be implemented in the IWS structure. The different steps from the framework will therefore be translated from literature to Intersnack's standard. The maintenance concept will provide a path on how to construct a maintenance plan.

Development maintenance concept – Case study

The maintenance concept development is created according to the proposed 7-step framework from Waeyenbergh (Waeyenbergh G. &., 2002). The developed maintenance concept is then tested and evaluated through this case study. The maintenance concept affects the organization through multiple layers, Figure 20. Therefore, is a controlled case study executed to implement the maintenance concept through the layers, and successful results can lead to its expansion throughout the organization. The maintenance concept development case study is created by analyzing production line D028.

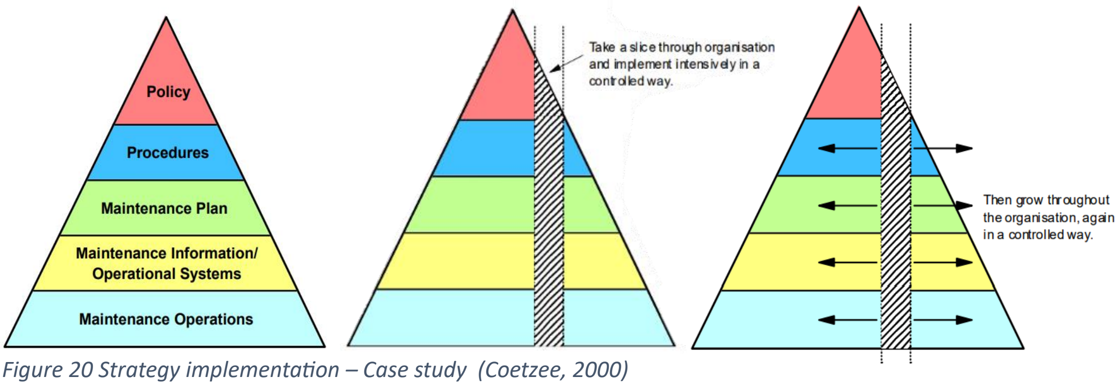


Figure 20 Strategy implementation – Case study (Coetzee, 2000)

4.1 Identification of the objective and resources

The first step of the 7-step framework is to identify the objective and resources. As indicated in section 2.1.1 is the objective to ensure equipment reliability/availability, minimize unplanned downtime, enhance safety, and reduce machine ownership costs. The objective should be realized in a cost-effective manner and accordance with the safety and environmental regulations. The requirement to meet the objective should also be identified for example material, people, know-how, information, tools, and last but not least money. The current maintenance goal is stated as follows:

"Maximum reliability and availability while gaining a thorough insight into the technical systems"

4.2 Selection Most Important Systems (MIS)

Step 2 is the MIS selected from the systems. The MIS of the production line D028 is determined with the analyses from chapter two and the Equipment Ranking. In the Equipment ranking are the machines rated based on multiple categories namely safety, quality, productivity, delivery, and cost as can be seen in Figure 43. The Equipment Ranking is a tool from IWS.

The machines are clustered in the ranking so that an equipment owner (operator responsible that equipment runs cost-effectively and safely at a target output rate) could create ownership of the cluster. The Equipment Ranking is a standard format used within Intersnack. The machines of a production line are graded based on the criteria of Figure 43 by the line team. The grading is based on the experience of the line team. The result is shown in Table 6.

As can be seen in the Equipment Ranking is the "Metal detection- Transwrapper - String belt" categorized as the highest A priority with a score of 34. The Equipment Ranking has a downfall in that it is a cluster of machines which makes it hard to rate the machine and to determine the focus. The priority is based on the high scores regarding safety, quality, productivity, and cost. Due to the impact on the end product quality, usage time of the machine, and high maintenance budget.

Table 6 Equipment Ranking D028

Nuts Packaging			S	Q	P		D		C		
Equipment	Manufacturer	Rank	Safety and environmental incidents in case of failure	How does the equipment affect the quality of the finished product?	How often is the equipment used?	Impact of the equipment on the operation MTBF	MTBF	Impact on the service level / customer	Expenditure Maintenance budget	Value related to monthly waste/ material loss	Total points
Filling Station- elevating conveyor		B	6	2	5	3	1	5	1	0.5	23.5
Vibrating shute - weigher	*Ishida*	A	6	8	5	3	3	5	1	1	32
Metal detection- Transwrapper-String belt	*Mettler + Bosch*	A	6	8	5	3	4	4	2.5	1.5	34
Box folding machine- White belt	*Knecht*	C	4	2	5	1	4	1	1	0.5	18.5
Casepacker- infeed belt	*Blueprint*	B	2	2	5	3	5	4	1	0.5	22.5
Box Shutter -Sticker press - Conveyor belt	*Knecht-Koning*	B	4	6	1	3	4	2	1	0.5	21.5
Stacking robots - Input conveyor	*Smart-Robotic*	B	2	8	5	1	3	1	0.5	0.5	21

To further specify the focus on a single machine are the results from the unplanned downtime analysis from paragraph 2.4.1 used. The Transwrapper is indicated as the machine that causes the highest unplanned downtime among the A-ranked machines. For this reason, is the Transwrapper selected as the Most Important System for the case study. After the maintenance plan is constructed for this machine can the focused be shifted on the next machine from the equipment ranking in combination with the unplanned downtime analysis.

4.3 Identification of the Most Critical Components

Step 3 is to identify the most critical components. As earlier mentioned in section 1.2 is the current machine structure only describes the components at the highest machine level. An improvement in the machine structure would be to divide the machine into sub-assemblies and include all components that correspond to the assembly.

When dividing the machine into components, the final level of detail to consider is what to register when disassembling and changing the machine. This is most of the time the line replaceable unit. The machine structure must be arranged in a way that makes it suitable for machine inspections. The current machine structure, as shown in Figure 38, limits the critical component analysis since only the machine is indicated in the registration of failures.

For this reason, is the identification of the Most Critical Components based on the analyses from paragraph 2.4.1. The most critical failure events of the Transwrapper, based on the unplanned downtime, are the “Seal Jaws” and “Film transport”. These failure events consist of multiple assemblies and components. The function of these events is briefly described below. These assemblies and components are the input for the criticality analysis. Since there is little information about the failure behavior of the components is the Failure Mode Effect Analysis (FMEA) method used as described in RCM.

In this research is chosen to only perform the criticality analysis on the event “Seal Jaws” since the analysis will ask for some time from the participating employees in the FMEA session and the case study size. The FMEA is conducted with the maintenance lead, process lead, and two operators to make informed and experienced decisions.

4.3.1 FMEA method

The FMEA method helps to structure the analysis. The goal of the analysis is to increase reliability, reduce risk, reduce cost, and improve safety which is in line with the maintenance goal. The following steps are performed during the FMEA analysis

- List the components and functions from the highest-ranking items to compare with functional requirements.
- List the potential failure modes for each component and function. Identify possible ways each component or function could fail.
- List the potential effects of each failure mode.
- Identify the potential causes/mechanisms of each failure mode.
- Determine the severity of the failure mode.
- Determine the occurrence – how likely is each failure mode to occur.
- Determine the detectability for the failure.
- Multiply the severity, occurrence, and detection rankings to determine the Risk Priority Number (RPN).
- Sort by RPN and identify the most critical failure modes.
- Go to step 4 of the maintenance concept to assign a maintenance policy with actions to the failure mode.
- After implementing the action plan, recalculate the RPN and take further action if necessary.

Quick risk analysis - Severity, Occurrence, Detectability

For the evaluation of the failure modes are the standard parameters of the FMEA used from the RCM methodology. Quantification and the choice of values are based on the historical data and the number of interruptions at Nuts packaging over a period of 2 years from Qlickview.

A practical and easy-to-use prioritization is desired by the organization. The prioritization of the failure modes is based on multiple criteria rated on a scale from 1 to 10. The format of the criteria is from the Lean Six Sigma Academy (2024). The criteria are specified the production line. For the case study, the criteria for the D028 are determined from the registered events from Qlickview, see Table 7. The severity is based on the normalized unplanned downtime where the downtime varies between 1 minute up to 450 minutes. The occurrence is based on the stops normalized from the registered events for the D028 variates the number of stops from multiple a week up to rarely. The criteria should be reflected on after the analysis is performed to determine the effectiveness.

The criteria are sufficient to calculate the RPN value using the table and to determine the greatest risks. The severity, occurrence, and detectability of each failure mode will be determined based on Table 7. The severity rating is based on the production interruption. The occurrence rating is based on the expected time interval of the failure mode. The detectability of a failure depends on how evident the failure is. A component can have for instance an evident function whose failure will on its own become evident to the operators under normal circumstances.

Table 7 Severity, Occurrence, Detectability Rating Scale FMEA

Severity (S)			Occurrence (O)			Detectability (D)		
Duration of interruption	**Criterion of severity**	**Value**	**Possible rate of occurrence**	**Criterion of occurrence**	**Value**	**Level of detectability**	**Criterion of detectability**	**Value**
< 30 min	Very small	1	Once every 12 years	Failure near zero or no	1	Detection at all times	Immediate corrective action	1
30 min	Small	2	Once every 10 years	Very low, failure isolation, rarely	2		Immediate	2
1 h	Very minor	3	Once every 8 years	Low, often fail	3	Reliable detection	Easy	3
2 h	Minor	4	Once every 6 years		4		Late	4
3 h	Significant	5	Once every 4 years	Average, occasional failure	5	Possible detection	Low	5
4 h	Medium	6	Once every 2 years		6		Occasional	6
5 h	Serious	7	Once every year		7	Detecting random (Unlikely)	Not sure	7
6 h	Very serious	8	Once every 6 months	High, frequent failure	8		Very late	8
7 h	Catastrophic	9	Once every month		9	Difficult to detect	Very difficult	9
> 8h	Very catastrophic	10	Once every week	Very high, very high failure	10	Not detectable	Impossible	10

Next is the risk priority number (RPN) calculated by multiplying the severity, occurrence, and detectability scores. The failure modes can be filtered from high to low based on the RPN. The failure modes with the highest RPN need to be addressed first.

4.3.2 FMEA executed - Seal jaws

During the execution of the FMEA is concluded that the performance of an FMEA on all parts of the installations is too much effort. For example, the Transwrapper consists of more than a thousand parts multiplied by a conservatively estimated time for analysis of 1 hour per part would yield approximately 1 year of analysis work. Therefore, the analysis is limited to the Seal Jaws.

The function of the Seal jaws

The seal jaws, number 10 on the left in Figure 21, are assemblies consisting of multiple parts. The seal jaw main function is to cut the packages and seal them airtight. The seal jaw, detailed overview right side of Figure 21, main components are the cutting knife (1), housing (2), and two seal beams (3 & 4), on the right in Figure 21. A more detailed explanation of the seal jaws components and function is described in appendix C FMEA analysis Case study - Criticality analysis Seal Jaws.

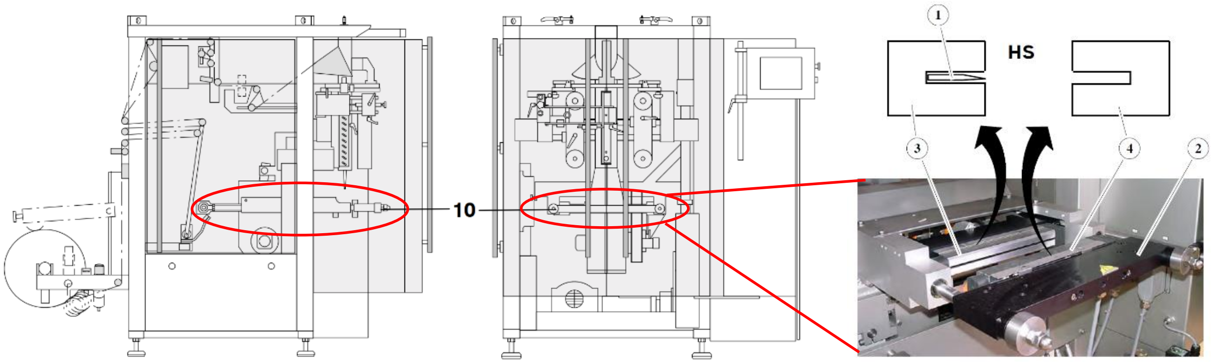


Figure 21 Assembly Seal jaws

For the case study is the FMEA method executed only on the seal jaw components where the failures are registered in the defect handling. The purpose of the case study, to develop a maintenance concept, is to provide a structure to determine the required maintenance. The maintenance concept structure is explained by analyzing the registered component failures.

The analysis should be extended in the same way for the components where no failure occurred (yet). Since there currently is no maintenance plan is decided with the Maintenance Lead to start creating the maintenance plan for these failures. These failures are recurring over time and create unplanned downtime events. Another reason is that limited information on failures is available. In the registered maintenance jobs (Ultimo) is the failure shortly described which helps the analysis. The input for further creating the maintenance plan should be based on:

- The failures that already occurred
    - Historic failure data from the registered maintenance jobs
    - Spare parts orders, to validate the historic failure data
- The failure modes which are included in (proactive) maintenance routines
    - Maintenance tasks that are described in the Clean Inspect Lubricate (CIL), tasks that are related to failure modes of components.
    - (Progressive) Maintenance jobs on a similar machine (and production environment) from other Intersnack locations (i.e. Hardinxveld and Lelystad)
    - Recommended maintenance tasks OEM
        - Bosch is the OEM of the Transwrapper and prescribes a maintenance plan
- Failure modes from the FMEA analysis
    - Starting with the RPN priority

4.3.3 FMEA – Seal Jaws

The FMEA structure is executed as described above. The input information for the analysis is provided by the intern. Next is during a meeting with the machine operators and the Line team the FMEA created. This resulted in an overview of the failure modes per item including the RPN (see Table 8). The full overview is shown in the appendix C Figure 51. The overview is needed for the next step of the maintenance concept where the maintenance policy is determined for the different failure modes.

An example of a filled-in FMEA row is now explained based on the top row. The function of the knife is to cut the foil to separate the bags. A failure mode from the knife is that it becomes dull which can be caused by usage wear of the knife and dirt on the blade due to scorched foil or product. The knife can easily be replaced with a new one, which will take around 30 minutes and is therefore a small interruption. The failure mode of a dull knife occurs monthly and is possible to detect visually. Most likely will it be detected late when the knife is already dull. For this reason, is decided with the Line Team and Operators that the severity, occurrence, and detectability of the failure mode is classified with a 2, 9, and 4 respectively.

In addition to the FMEA overview, the average Mean Time To Repair (MTTR) of the failed component is incorporated as can be seen on the right column of Table 8. This addition is motivated by the insights it provides into the impact of the failure mode on unplanned downtime. However, it's essential to acknowledge the limited scope of this information, as not all failures are consistently registered or documented. The quality of the data depends on the operator's registration accuracy. Currently, MTTR is recorded for some components, lacking specificity on the particular failure mode in the registration. Therefore, the average MTTR of a component is applied across the different failure modes. To enhance the analysis, there is a need for improved failure registration practices to ensure the information's quality and accuracy.

Table 8 FMEA Seal Jaws

Item	Function	Potential failure mode	Potential failure effects	Potential causes	SEV	OCC	DET	RPN	MTTR (UPDT)
Knife	Seperate the filled bag with the next bag	Dull knife	Unable to cut or only partially cut, tear open the bag	Usage wear of the knife	2	9	4	72	42,5
				Soiling on the blade. Scorched foil due to knife getting too hot causing foil to stick.	2	9	4	72	42,5
				Soiling on the blade. Product hits the knife due to wrong setting regarding closing	2	7	3	42	42,5
		Crokked / Chipped teeth knife	Unable to cut or only partially cut, tear open the bag	Knife incorrectly attached (e.g. crooked) causing it to touch the closing profile.	2	7	5	70	42,5
				Knife incorrectly attached (e.g. crooked) due to contamination in the attachment points	2	8	3	48	42,5
				Overloaded during cutting, lack of free passage of knife in closing profile gap, contamination	2	7	6	84	42,5
Knife clamb	Fixing the blade	Losse fitting knife	Unable to cut or only partially cut, tear open	Wrongly turned screw thread / bolt	3	9	3	81	120
				No / poor clamping due to contamination	4	7	6	168	120
Seal profile	Heat conducting heating elements to close the bags	Damage on the closure profile	Poor closure / leaking package	Knife touches closing profile	8	8	4	256	140
		Dirt accumulation profile	Poor closure / leaking package	Wrong setting (temperature, drop time, jaw sensitivity) allowing product to get between locking profile or wrong temperature causing film to scorch on profile	3	10	3	90	140
		Misalignment	Poor closure / leaking package	Contamination in the guide hole preventing the positioning pin from calibrating	5	5	7	175	140
				Too much space in the pilot hole preventing the positioning pin from calibrating properly	10	2	9	180	140
				Wear self-aligning linear ball bearing shafts	5	3	8	120	140
Heating element	Heating the sealing profile	Fluctuating temperature	Wrong temperature change poor closure	Limitation of heater type, the heater cannot keep the temperature constant (on/off power)	4	9	2	72	220
				Contact pin for temperature control does not make contact	5	8	7	280	220
		No connection power supply	Wrong temperature change poor closure	Wire breakage	7	8	4	224	220
				Lack of fastening, Prick bolt / paste does not hold heating element. Heating causes fastener degradation	7	7	4	196	220
				Amp cable shoes (power cable connection) is loose	7	6	4	168	220
				Defective start relai (In control box start relay U23 ultimo: 161369)	7	6	5	210	220
PT100 Sensor	Temperature detecting seal profile	Electronic damage	Wrong temperature	Missing connection resulting in no signal being received	5	9	4	180	220
		Cable break	Unable to detect/control temperature	Movement of cable creates friction & tension causing wear. Cable is shortened causing tension.	5	8	5	200	220
		Breakage	Wrong temperature	Wear vibration	7	7	5	245	220
		Aging	Unable to detect/control temperature	Drift in resistance values, material fatigue	8	3	8	192	220
		Overheating	Unable to detect/control temperature	Overload temperature from heating element	7	6	5	210	220
				Paste (conductive paste) missing, use wear	7	8	5	280	220

The FMEA analysis identified critical components that will be addressed in the next phase. This structured approach facilitated the documentation of specific failure modes and their causes. This documentation plays a critical role in increasing the technical knowledge of the participants and helping future employees understand the machine.

4.4 Selecting maintenance policy

In step 4 is a maintenance policy selected for the failure modes from the FMEA analysis. The maintenance policy is selected with the help of the decision tree from Figure 22. The decision tree is based on the RCM decision tree in combination with the proposed maintenance policies from Waeyenberg. The questions from the RCM decision tree are used because of the relation to the set priorities (criteria Equipment Ranking Figure 43) from Intersnack. The questions are structured in a logical way where "no" goes down and "yes" up in the decision tree.

The participants from the FMEA analysis can answer the question together. When combining the results of the failure analyses and the decision diagram will produce the final results in the form of maintenance actions following the component requirements. First is determined how evident the failure is. A hidden failure is one who not become evident to the operators under normal circumstances. Next is the impact on safety and environment indicated. At last, the impact on the operations is determined.

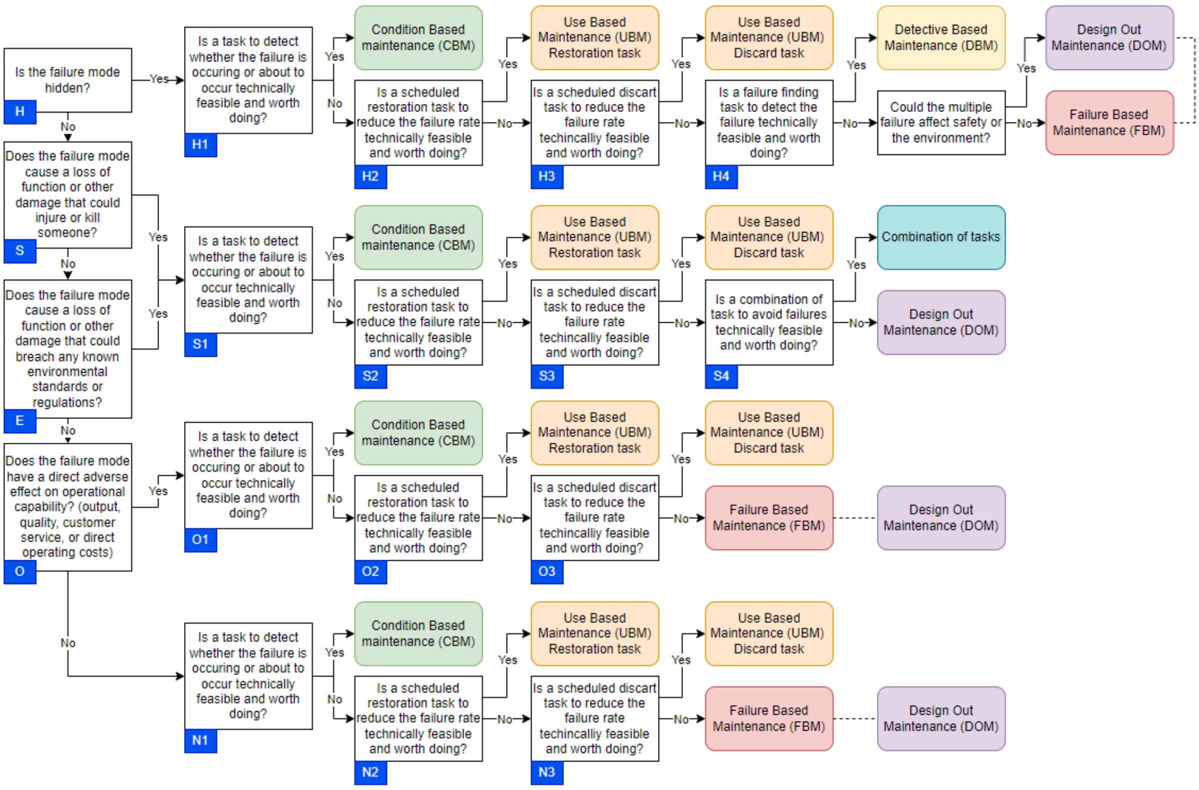


Figure 22 Maintenance policy decision tree

For each failure mode, a maintenance task is only suitable if it is worth doing and technically feasible. The criteria to determine this is summarized in Table 21 in appendix C. In general, a task is technically feasible when all questions from Table 21 are answered with 'worth doing'.

In the Excel model, where the FMEA is created, the answers (Yes or No) to the decision tree questions can be filled in the row of the corresponding failure mode. The execution is shown in Appendix Figure 52. After answering all needed questions is the advised maintenance policy automatically filled in at the end column where the columns correspond with the blue squares from the decision tree. The recommended maintenance task needs to be further specified in the next step of the maintenance concept.

An example of how to use the decision tree will be indicated in the top row (the failure mode of a dull knife) of Figure 23. The failure mode is not hidden since the degradation of the knife can be detected and the consequence will be seen. The failure effect will be detected in for instance leaking bags (not airtight) or combined bags. The failure mode does not have an impact on safety or the environment but on the operational capability (quality and output). The condition of the knife is technically infeasible to monitor. The degradation of the knife cannot be restored since the material of the knife is worn off and cannot be restored. The knife is economically feasible to discard. The price of a new knife is around 170 euros and it takes 30 minutes to replace. The maintenance task is worth doing since the consequence of a dull knife is that the production cannot continue since the produced bags are not of the right quality.

Item	Potential failure mode	Potential causes	MTTR (UPDT)	Hidden failure	Safety	Environmental	Operational	H1 S1 O1 N1	H2 S2 O2 N2	H3 S3 O3 N3	H4	H5	S4	Maintenance strategy
Knife	Dull knife	Usage wear of the knife	42.5	N	N	N	Y	N	N	Y				UBM discard
		Dirt on the blade. Scorched foil on knife	42.5	N	N	N	Y	N	Y					UBM restoration
		Dirt on the blade. Product hits the blade	42.5	N	N	N	Y	N	Y					UBM restoration
	Crooked / chipped teeth (knife)	Knife hitting the seal closing profile	42.5	N	N	N	Y	N	N	N				FBM
		Knife incorrectly attached due to dirt accumulation at fixing points	42.5	N	N	N	Y	N	Y					UBM restoration
		Overload during cutting, no free passage of knife in closing profile	42.5	N	N	N	Y	N	Y					UBM restoration

Figure 23 Maintenance policy selection

The percentages of the maintenance policy type for the components are shown in Figure 24. The percentages are from the analyzed components and may differ when other components are chosen. As can be seen in Figure 24, a major shift has taken place from corrective maintenance (current situation) to more proactive maintenance. The maintenance task "Failure Based Maintenance" (FBM) is reduced to only 22%. More than 50% of tasks now incorporate proactive measures such as Use Based Maintenance (UBM) and Condition Based Maintenance (CBM). Additionally, a list of suggested changes to eliminate or minimize maintenance requirements was compiled under Design Out Maintenance (DOM).

There are few CBM tasks because the required technology, knowledge, and information are currently limited within Intersnack. For most tasks, the expectation is that the failure behavior can be detected or that it follows a certain failure pattern. In many cases, there is still a significant possibility of restoring the component, which is often more economically advantageous.

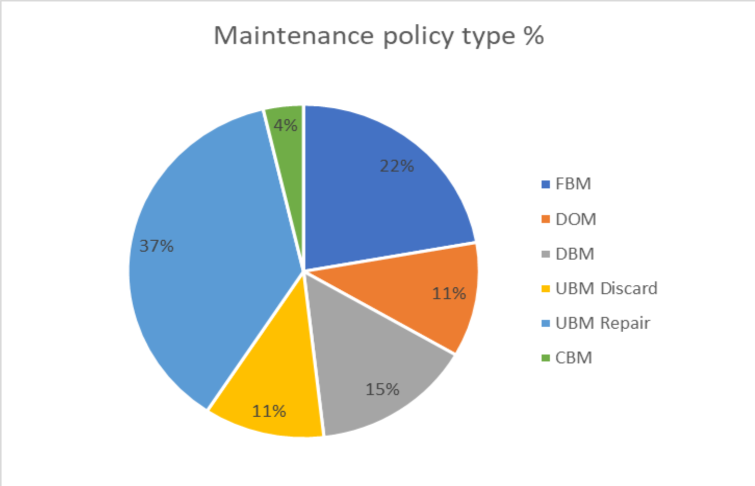


Figure 24 Maintenance policy type percentages case study

In the next step is the selected maintenance policy specified to a maintenance task that can be executed by a technician or operator. The policy selection helps to determine the direction of the specific maintenance task. This translation is made with the project team and explained in the next step of the framework.

4.5 Optimization of the maintenance policy

After the maintenance policy is selected for a specific failure mode, with the help of the decision diagram, can the maintenance task be specified. The maintenance task is determined with the project team and based on the information sources as indicated in section 3.2 step 5. For each maintenance policy type is a maintenance task highlighted based on the case study. Also, the task interval determination for the proactive and detective-based tasks is indicated in this section.

4.5.1 Interval maintenance tasks

The interval needs to be indicated for each maintenance task. The task interval could be based on any appropriate measure. This includes calendar time, running time, stop-start cycles, output or throughput, or any other measurable variable that bears a direct relationship to the failure mode. For practical reasons, it is most often measured in terms of elapsed time. Within Ultimo is this the only option to register. The interval depends on the selected maintenance policy. There is no interval for the policy FBM or DOM. For the other policies should the following fist rules be applied:

- *On-condition task (CBM),* the interval should be based on an identifiable condition which indicates that a functional failure is either about to occur or in the process of occurring. The failure function or pre-described failure limit can be used as indicated in 3.3.1.
- *Use Based Maintenance task (restoration or discard)*, the interval depends on the '*useful life*' of the component. The interval is governed by the age at which the component shows a rapid increase in the conditional probability of failure. The '*useful life*' can be split up into '*safe life*' & '*economic life*'. Safe applies only for safety or environmental consequences and are indicated with a risk limit. Economic life is determined by comparing the failure costs with the maintenance action as indicated in section .
- *Detective based (Failure-finding) task,* intervals are established using availability and reliability, which require knowledge of MTBF (Mean Time Between Failures) and desired availability. Table 4 from the literature review is used as a first indication of the desired interval.

Recommended interval (OEM)
Currently, an untapped source of information due to the absence of emphasis on preventive maintenance is the set of recommended maintenance tasks with specified service intervals provided by the Original Equipment Manufacturer (OEM). These pre-determined maintenance tasks can be incorporated into the maintenance plan, following an assessment of their relevance to the specific conditions at Intersnack. The downside is that the risk reduction of the failure is not indicated and therefore not be translated in reduction in unplanned downtime. The OEM's recommendations include service intervals determined based on the equipment's operational time. Integrating this information from the OEM will serve as a valuable foundation for developing the maintenance plan for various machines at Intersnack. A few of the recommended maintenance tasks with intervals is illustrated in Figure 59. The relevant task on the seal jaws is included in the maintenance plan of the case study.

Over time can the task frequency or whole task be changed it is therefore needed to specify the interval for each specific task. When the task is executed, a feedback loop is required on the task interval. This check helps to better optimize the task interval. The multiple tasks will be consolidated into a smaller number of work packages when compiling the maintenance schedules in the next step of the framework.

4.5.2 Maintenance Policy task

There are a lot of specific maintenance policies that can be applied to the failure modes. Within this research are the different optimizations for the maintenance policies from the literature study shortly explained. The default maintenance tasks require a different optimization compared to the proactive maintenance tasks. Next are the optimization examples described that are used in the case study.

Default maintenance task
Failure based maintenance (FBM)
Maintenance is carried out only after a breakdown. While a component may be crucial, it is possible for a failure to happen and then be repaired, depending on the presence of secondary damage, redundancy, and ease of repair. When using FBM it's important to determine these effects for instance also the economic effect regarding downtime and spare parts management. Where it is wise to know how to act when the failure occurs.

> *Example - Failure based maintenance applied*
> The maintenance policy FBM is used for the starting relay of the seal jaws. The economic feasibility and spare parts management of this policy is acceptable. The part costs are ±40 euro and is a common spare part for multiple switch boxes in the factory. Furthermore, the failure of the relay is easily detected (due to the LED light indication) and replaced within half an hour.

Design-out maintenance (DOM)
The maintenance policy includes two types, namely, design-out maintenance and design for the ease of maintenance. Design-out maintenance aims at removing the high-risk failure modes in combination with minimizing the required corrective and preventive maintenance actions.

On the other hand, designing for ease of maintenance focuses on simplifying the remaining maintenance actions. The design guidelines regarding Reliability, Availability, Maintainability, Safety, Supportability, Health, Environment, Economics, and Politics (RAMPSHEEP) as indicated by Martinetti

(2012) can be used. Design-out examples are, shown in Figure 25, moving parts to avoid unnecessary movements (left), snap fasteners allowing for quick opening and closing (middle), and standardization of the range of bolts to be used (right).

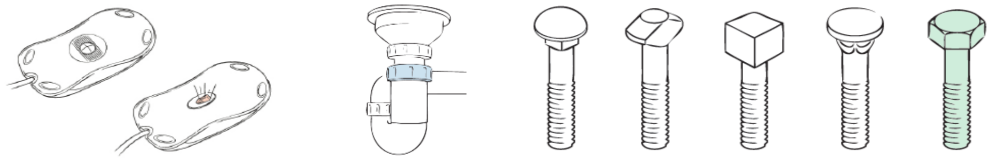


Figure 25 Design changes - Examples of Reliability (left), Maintainability (mid), Supportability (right)

Examples - Design-out maintenance applied

There are two DOM tasks proposed namely:

The maintenance policy DOM is selected to improve the maintainability of the clamping block (Figure 26) of the knives. The knives are clamped between the lower and upper part of the clamping block by screwing the bolts through the thread hole. The clamping block holes have both the upper- and lower-part thread. The holes need therefore to be aligned above each other to fix the knife. When not executed correctly can the bolt become stuck or even be damaged (see Figure 26 red circles). There are for this reason special bolts available where the tread is only on the bottom part (see Figure 26 orange circles).

- Redesigning the part by removing the thread from the upper part is therefore recommended. The tread has no function and creates failures. Redesigning the part can make maintainability easier and a standardized bolt type can be used.

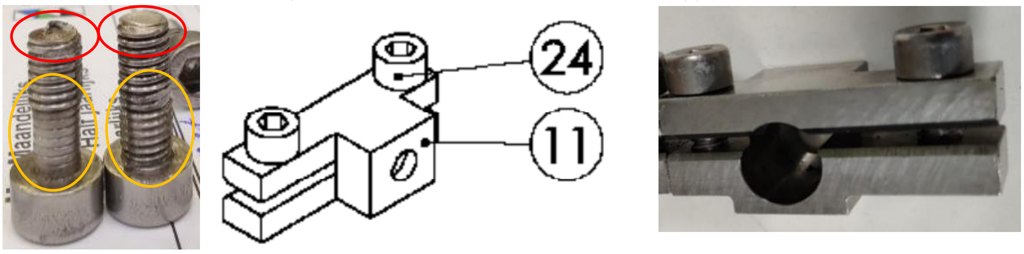


Figure 26 Clamping block Seal Jaw with bolts

The capability of the Heating element & resistance sensor (PT100) needs to be further analyzed. The PT100 sensor measures the temperature and corresponds with the heating element to adjust the power which results in the temperature of the seal jaws.

- The sensor is sending an “on or off” signal and is not measuring the temperature constantly. This results in temperature fluctuations around the correct temperature. An example of the fluctuation is shown in Figure 27 where the black line is the current situation and the purple line is what is desired.
- The inconsistent temperature can also be caused by the heating element. The heat distribution is currently shown in Figure 27 (Orange) the line indicates the temperature across the element. As can be seen in the middle a higher temperature. A different heat element can distribute the heat more evenly as indicated in Figure 27 (Green).

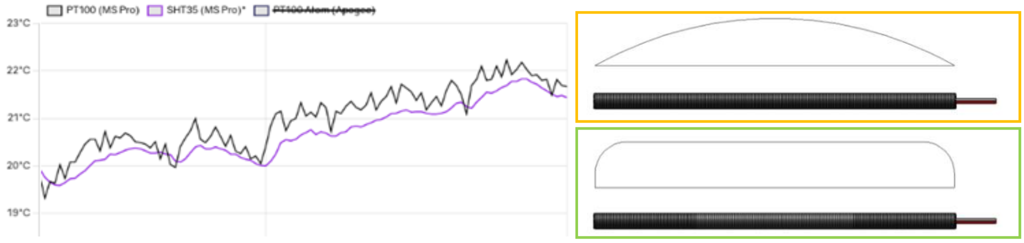


Figure 27 Temperature drift of the seal (left) – Heating element temperature distribution (right)

Detective based maintenance (DBM)
Inspection of (hidden) system functions to identify whether they have failed or not in other words a "functional check" or a "failure-finding task". When this can be detected by the operators is DBM possible. The interval is based on Table 4 as indicated in section 3.3.2. The desired availability and MTBF have te be known. If not, can the inspection interval initially be set higher or could it be beneficial to allow the failure to occur to reduce the uncertainty keeping the economic impact in mind.

Example - Detective based maintenance applied
The inspection and cleaning task, Figure 28, of dirt accumulation at the guidance hole for the determination pin of the seal jaws is created. The pin helps to ensure a correct seal angle. The failure mode can visually be detected by the operator/technician but the seal jaw needs to be detached from the machine. This situation occurs a multiple times a year when switching from product bag type. Next, the task can be performed. The interval depends on the desired availability which is indicated at 95%. The MTBF of the component is unknown, since the registration of the maintenance jobs is lacking specification in Ultimo. The MTBF is estimated at 1 year by the operators, who directly work with the machine. For this reason, the project team determined to initially set the interval to 1 month as indicated in Table 4 (95% availability → 10% of the MTBF of 1 year) assuming exponential survival distribution (random failure).

Figure 28 Example Detective based maintenance task (cleaning)

Proactive maintenance task optimization
Use Based maintenance (UBM)
The maintenance policy UBM is based on performing maintenance on actual use and operational conditions. These failure modes are not hidden and are technologically / economically feasible to perform UBM. The maintenance task is split up into restoring or discarding the component after a specified interval. Restoration entails restoring the initial capability of the component and discard entails discarding the component at specified interval. The focus is on age-related failures since the equipment comes into direct contact with the product. Therefore, having wear-out characteristics associated with fatigue, oxidation, and corrosion. When possible, should the interval be based on (historical) data as described in section 3.3.3.

Example - Use Based maintenance applied knife

The example UBM task, on the (bag cutting) knife, depends on the degradation of the knife (left side of Figure 29). Both types of maintenance tasks, restoration and discard, are used. The interval is based on the production time. The restoration is cleaning and sharpening the knife. The cleaning will be executed in the ultrasonic bath to loosen the attached foil/product (shown on the right side of Figure 29). Next, the knives are sharpened with a file set by the technician. The knife will be discarded when the knife cannot be restored for example due to too small or bent teeth. Furthermore, the discard task is also performed after the knife is restored more than 5 times which is based on the experience of the project team. The knife is less reliable after restoring it this many times and is harder to restore.

Figure 29 UBM – Dirt accumulation knife restoration task

<u>*Maintenance interval - Knife restoration task*</u>

The method as described in literature section 3.3.3 is used to determine the maintenance interval. The information about the failure behavior is limited. For this reason, the registered maintenance jobs from Ultimo are used to determine the time between failure. A total of 70 jobs related to the knife (n=70) are registered. The time between failures is calculated by determining the time between two consecutive jobs. The failure behavior of the knife based on the time between failure is plotted in Figure 30.

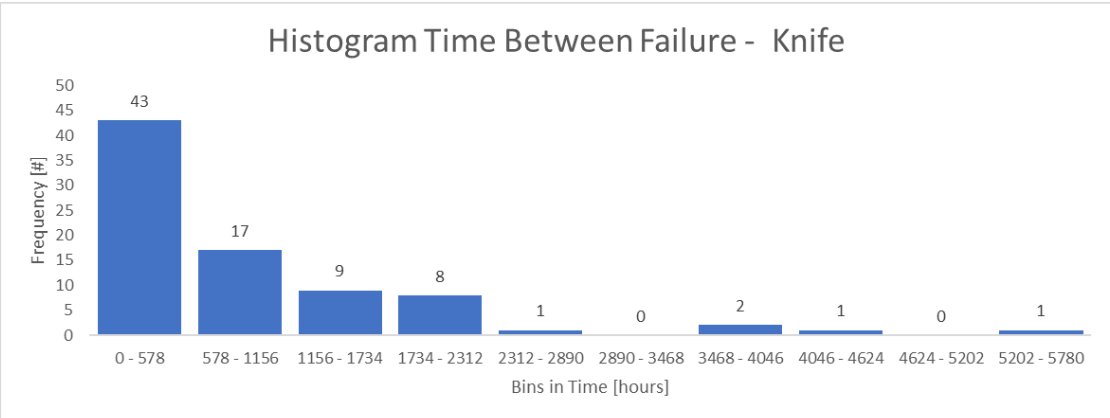


Figure 30 Time between failures - Knife

The knife failure distribution is approached with a Weibull distribution to make a better estimation of the failure behavior. The method from section 3.3.3 is used. With the regression statistic function from Excel is the shape (β=0.824) and scale parameter (η=845.653) determined. A statistical technique (Goodness-of-fit test from Winston) is used to check if the probability distribution provides a realistic description of the failure behavior. The data showed this is not a correct fit since the chi-square distribution is larger than the chi-square test (Figure 58). Which was expected since the failure pattern is decreasing (β < 1). The knife is a component that is in contact with the product (foil/product). The expected failure pattern of the knife is to increase over time due to wear-out characteristics. The executed steps for this conclusion are described in appendix C section Maintenance interval based on the failure behavior.

As can be seen in Figure 30 varies the time between failures heavily, from a minimum of 32 hours and a maximum of 5270 hours. This variation is created due to the different failure modes affecting the component. Example failures that occurred during the research are shown in appendix D for example when the knife is angled mounted or when accumulated dirt hits the knife. Moreover, human actions and handling of the knife have a significant impact on failure behavior. The expectation is that the operator treats the knife with care and removes it cautiously. In practice, it has been observed that humans do not always handle the knife with the necessary caution. This increases the risk of damaging the knife and therefore the failure behavior. Multiple human factors can be identified that influence the failure behavior. While the human impact on failure modes is not explored within the scope of this research, it is acknowledged as a key aspect contributing to various failures. In section 5.2 is the human impact further discussed.

The complexity (multiple failure modes) and diversity (failure intervals) make it hard to develop a complete analytical description of the reliability characteristics of the component. The failure behavior, based on the registered jobs, is not reliable enough to use the method as described in section 3.3.3. For this reason, is the interval set to 1 work week (5 work days 3 shifts of 8 hours) based on the experience of the project team. The interval is in line with the proposed time interval from Table 4 page 24**.** The average MTBF of the knife equals 40 days and the desired availability is 95%. Resulting in an interval of 4 days (10% of MTBF equals a 95% availability as indicated in Table 4 page 24) which is in line with the 1 work week. The maintenance task to restore the knife is indicated in the SOP shown in Figure 64. The UBM task interval is therefore set to 1 work week and needs to be monitored after implementation.

<u>Example UBM - PT100 Failure Behavior descriptive method</u>
The recorded maintenance jobs for the PT100 on the D028 are shown in Figure 31. As can be seen in the task description, inconsistent naming registration is used. For example, both D28 and D028 are used, different names for the machine Transwrapper (“Verpakkingsmachine”) and Bosch, inconsistent capitalization, and an unclear general description of the failure. As a result, it is not possible to perform a reliable failure behavior analysis. Although the data provide insight into the time between failures of the PT100, specific failure modes are not delineated. The data is extracted from Ultimo with the filters “28” combined with “PT100”. The downfall of the registration system is that the maintenance job description does not always include the specific component and machine. There are no clear rules or unity on how to register the failures and the technical knowledge regarding the names of specific components is not inhouse.

The inconsistency of the failure behavior is indicated with the time between failures in Figure 31. According to the manufacturer, the service life of a PT100 is equivalent to 2000 to 4000 service hours as shown in Figure 60. The recorded failure behavior of the PT100 at Intersnack varies from 120 to 23208 hours. From the failure behavior, can be concluded that the PT100 is impacted by other factors besides natural wear.

The other factors besides natural wear such as human aspect is shown in red shaded of Figure 31. On October 3, 2019, the failure was repaired and the following was indicated in the job by the technician: *"PT100 defective, broken off at PT100 connection. New one placed. Reason was due to wear"*. Then already on Tuesday, October 8, 2019 another failure occurred stated: *"PT100 cables broken off at the point where they come out of the PT100."*. This failure behavior is probably related to the way of connecting the PT100 which caused the failure to occur so quickly. In fact, a work instruction for connecting the PT100 sensor is also missing. Besides this example, there are several factors that strongly influence the failure behavior. Before determining a standard interval, it is important to eliminate these factors.

Maintenance Job Description	Date	Time between failure [Hours.]	Time between failure [day]
D28 verpakkingsmachine: luchtuitdrijvers vervangen en mantel van kabels PT100 repareren	9/24/2022	5664:00:00	236:00:00
d28; tegenbek rechts pt100 kapot	1/31/2022	20304:00:00	846:00:00
D28- Geen pt100 zone 4 van de euroloch bekken.	10/8/2019	120:00:00	5:00:00
d28 bosch geen pt100 op temperatuur zone 4 melding, blijkt een kabel breuk te zijn	10/3/2019	1704:00:00	71:00:00
d28 bosch melding: 050 geen pt100 op temperatuur zone 8 en temperatuur zone 1 om de paar sec.	7/24/2019	2376:00:00	99:00:00
D28 mesbek links pt100 is overleden of kabelbreuk temp: 454	4/16/2019	3168:00:00	132:00:00
D28 PT100 mesbek links stuk	12/5/2018	23208:00:00	967:00:00
d028 geen pt100 op temperatuur zone 4	4/12/2016	2856:00:00	119:00:00
D28 Geen PT100 op zone 7	12/15/2015	4512:00:00	188:00:00
D028 PT100 voorbekken defect	6/10/2015		

Figure 31 Registered Maintenance jobs PT100 on the D028

Another downfall is that not all failures are registered by the operator or technician when addressed. This is reflected in the difference between the number of parts written off compared to the number of registered maintenance jobs. In Ultimo are only 9 maintenance jobs of the PT100 registered. Looking at the number of PT100 booked on the D028 from the warehouse, this is a total of 24 jobs as shown in Figure 32. This is not an exception for this specific component.

Also, the time between failures would then vary between 120 hours and 11808 hours. Where the MTBF of the PT100 equals 2704 hours and is calculated by taking the average of the registered time between failures. When using only the registered maintenance jobs the MTBF would equal 7104 hours. The data from Figure 32 is more in line with the recommended lifespan of the manufacturer. The booked components give a more realistic distribution of the failure behavior. When using the time between failures should be considered that the machine is not operating all the time.

Partcode	Job code	Machine	Date	Time between failure [day]	Time between failure [hours]
9521	167114	D028	2023-09-28	57	1368
9521	164439	D028	2023-08-02	37	888
9521	162767	D028	2023-06-26	18	432
9521	161971	D028	2023-06-08	492	11808
9521	138108	D028	2022-02-01	48	1152
9521	135867	D028	2021-12-15	296	7104
9521	121101	D028	2021-02-22	354	8496
9521	103693	D028	2020-03-05	86	2064
9521	99579	D028	2019-12-10	20	480
9521	98722	D028	2019-11-20	43	1032
9521	96629	D028	2019-10-08	5	120
9521	96453	D028	2019-10-03	120	2880
9521	90942	D028	2019-06-05	50	1200
9521	88707	D028	2019-04-16	11	264
9521	88175	D028	2019-04-05	60	1440
9521	85023	D028	2019-02-04	61	1464
9521	82372	D028	2018-12-05	117	2808
9521	76554	D028	2018-08-10	64	1536
9521	73821	D028	2018-06-07	122	2928
9521	68399	D028	2018-02-05	119	2856
9521	63417	D028	2017-10-09	13	312
9521	62755	D028	2017-09-26	287	6888
9521	51287	D028	2016-12-13	111	2664
9521	46366	D028	2016-08-24	-	-

Figure 32 Registered PT100's for the D028 with the booked date

Nevertheless, the MTBF of the PT100 helps to determine the interval of the component. The descriptive method as described in section 3.3.3 is used to determine the failure behavior of the PT100 based on the data from Table 9. The number of bins is determined at 5 by taking the square root of the amount of data points and the bin length by taking the maximum minus the minimum divided by the number of bins equaling 2440. Next are the cumulative failure probability distribution F(t) and reliability (survival) function R(t) determined in Table 9. The failure rate is not increasing overtime which was expected. Based on the desired reliability can the interval be selected. For this part is the advised interval of 2000 service hours used as the maintenance interval.

Table 9 Failure behavior PT100 - Descriptive method

Interval [hours]	0	2440	4880	7320	9760	12200
f(t)	0.000	0.609	0.217	0.087	0.043	0.043
F(t)	0.000	0.609	0.826	0.913	0.957	1.000
R(t)	1,000	0,391	0,174	0,087	0,043	0,000
z(t)	0,000	0,609	0,556	0,500	0,500	1,000

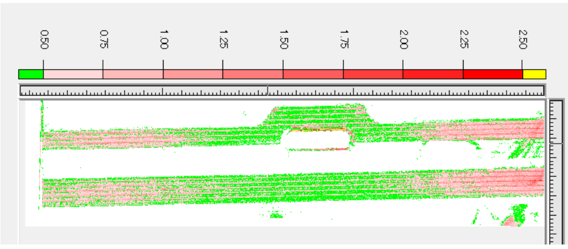
Condition based maintenance (CBM)

CBM recommends maintenance actions based on real data describing the component condition. This condition information is used to assess the remaining useful life of the components. Maintenance actions are executed only when needed, i.e., when there is evidence of abnormal health conditions. When the degradation (condition) information is known can be determined how the degradation will evolve in the future and be predicted what the remaining useful lifetime is. A component fails when its signal reaches a specified critical failure limit. A failure limit is a predefined threshold or condition beyond which a component is considered to have failed or reached an unacceptable level of performance. Some specific critical failure limits are known at Intersnack, as illustrated in the example below with the pressure test. Most failure limits are not yet known within Intersnack, and the information needs to be obtained, for instance, from the manufacturer in order to make use of this policy.

CBM is currently underutilized at Intersnack. In an effort to enhance its implementation, a decision has been made in collaboration with the Maintenance Coordinator and Line team to initially prioritize the use of human condition inspection techniques (such as visual observation, listening, tactile assessment, and odor detection). The technical feasibility of these methods is low-threshold, allowing for immediate application following proper work instructions. Additionally, these inspections contribute to the accumulation of technical knowledge. As proficiency grows and critical limits become better understood, more advanced machine condition monitoring techniques, outlined in appendix D section Condition based maintenance analysis, can be introduced. Presently, these advanced techniques are predominantly employed for corrective maintenance, exemplified by their use in identifying failed relays through thermography analysis.

Example - Condition based maintenance applied
CBM provides the opportunity to proactively monitor the condition of the Seal Jaw. This enables the early identification of potential issues, such as leaking bags due to damaged sealing profiles, thereby reducing the need for more frequent preventive maintenance. Simultaneously, the early detection of condition changes results in a decrease in corrective maintenance, as potential defects, like dirt accumulation, are addressed (restored or cleaned) before they escalate into critical failures (leaking bags).

The seal jaw condition can be measured with a (pre-scale) pressure test. The test consists of clamping pressure foil between the seal jaws. The paper registers the pressure as can be seen in Figure 33. If the measured prescale effective rate is below 50%, it means that the failure limit has been reached. This indicates that the majority of the print is outside the range of the film. The maintenance task should then be carried out. The test provides insight into the functionality and possible failure modes of the seal jaw. For instance, defects in the pattern of the seal beam are detected.



	No.	Whole
Prescale Effective Rate(%)	1	67.3
Pressed Area(mm2)	2	5847
Ave Pressure(MPa)	3	0.79
Max Pressure(MPa)	4	3.06
Load(N)	5	4631
Measured Area(mm2)	6	17550

Figure 33 Condition based task - Pre-scale test

Monitoring the condition incurs costs, typically involving the acquisition of monitoring equipment and the deployment of personnel for maintenance tasks. In this example, the monitoring equipment is available, and the costs associated with the pre-scale foil (approximately €10 per measurement) are negligible. The primary cost factors include employees and machine downtime, equating to one hour (for measurement and analysis) of labor costs and 20 minutes of production downtime. Which represents a total of €300.

The assumption for unplanned downtime is based on one registration by the Maintenance Lead, where a total time of 120 minutes was recorded. However, most failure behavior data is not available within Intersnack. The impact of unplanned downtime includes the emergency technician, operators, and production stoppage. Depending on how quickly the operator contacts the technician and resolves the issue, there is an impact on production time loss, equivalent to a total cost of €1250 in this example. Additionally, it may be the case that restoration of the component is no longer feasible, necessitating the purchase of a new part at approximately €2000. This cost could have been avoided through condition monitoring, extending the component's lifespan, and allowing for potential restoration.

In conclusion, the investment in condition monitoring proves economically beneficial by minimizing downtime-related costs and supporting more effective maintenance practices.

Advanced condition monitoring - Thermography
Thermography can be used for monitoring temperature deviations of the machines. The operation conditions specifications of the machine have to be known. Mainly mechanical heat will be inspected that is generated from friction caused by faulty bearings, inadequate lubrication, misalignment, misuse, and normal wear. An example of condition based task is demonstrated in Figure 34.

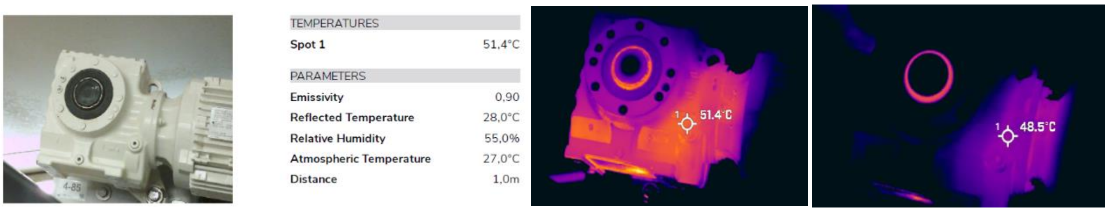


Figure 34 Condition based maintenance - Thermography analysis

Determined Maintenance Tasks
In addition to the provided examples, maintenance tasks have also been developed for the various other failure modes in collaboration with the project team. The complete list of established maintenance tasks can be seen in Figure 53. In the next step of the framework, outlined in section 4.6, the formulated tasks can be implemented and evaluated.

4.5.3 Maintenance tasks impact unplanned downtime
The unplanned downtime of a component (failure mode) is not registered by Intersnack only the downtime of the machine event as shown in Table 19 page 66. For some components is a BDE performed and therefore more information is available. The information is manually registered by the operator. The time to repair (TTR) is registered for the component failure. Since the current policy is corrective, the manually recorded TTR best reflects the impact of the failure on the unplanned downtime. The TTR is not specified for a failure mode and is therefore used for all failure modes of the components as indicated in Table 11 current MTTR. More information is currently not available to indicate the impact of a failed component on the unplanned downtime.

To better quantify the impact of maintenance tasks on the unplanned downtime is a percentage assigned indicating the impact. The impact overview is shown in Figure 53 page , which includes the various failure modes with selected maintenance policies. The maintenance tasks are determined as demonstrated in the examples from the previous section.

For proactive maintenance policies, there is a preference to determine the impact of unplanned downtime by utilizing the failure behavior. In this way, the expected impact of new maintenance tasks can be determined before actual implementation. In practice, as shown below, this proves challenging at Intersnack due to the quality or absence of reliable failure data.

From the failure behavior combined with the interval can the impact on unplanned downtime be determined. The failure behavior can be determined as described in section 3.3.3. Currently, the registered TTR data is assumed equal to the unplanned downtime, as only corrective maintenance takes place. The failure behavior (cumulative failure F(n)) of the knife is presented in Table 10. The risk of corrective failure at interval T=578 equals 53%. This indicates that when maintenance is performed at interval T=578, unplanned downtime will reduce by approximately half 47%. In this way is it possible to indicate the impact of a maintenance task on the unplanned downtime.

Table 10 Failure behavior knife based on registered failures

Interval	0	578	1156	1734	2312	2890	3468	4046	4624	5202	5780
F(n)	0	0.530	0.735	0.843	0.940	0.952	0.952	0.976	0.988	0.988	1.000

Due to the lack of available data on the failure behavior of the different components, this factor is determined based on input from the project team, which comprises knowledge and experience. Therefore, it is currently crucial to consult operators and technicians who are directly involved in the execution for validation of the impact. Their feedback is currently essential for accurately assessing the impact on the unplanned downtime. The impact is translated into an assigned percentage of reduction per maintenance task as shown in Figure 53.

Table 11 Impact maintenance task on unplanned downtime

Components	**Average unplanned downtime [min]**		**Reduction**
	Current	**New**	
Knife	42.5	9	-80%
Knife attachment	120	18	-85%
Closing profile	140	37	-73%
Heating element	220	59	-73%
Resistance sensor (PT100)	220	117	-47%

The average impact of the maintenance tasks is used to determine the new unplanned downtime in Table 11 of the analyzed components. As shown in Table 11, the created maintenance tasks have different impacts on the unplanned downtime, ranging from a reduction of almost 50% to over 80%. In conclusion, the impact on the unplanned downtime depends on the established maintenance task, but in all cases, there is a significant reduction. Furthermore, in order to get better insight in the impact on the unplanned downtime should the data quality be improved with the registration of the failure mode at a component level and monitoring of the maintenance task execution.

4.6 Implementation and evaluation

The next step of the framework is the implementation and evaluation of the maintenance tasks. The previous section gives an example of the different maintenance policies. In this section are the actions regarding the practical implementation described. Also, it indicated how to create a maintenance plan from the determined maintenance tasks. Including the optimization regarding clustering and harmonizing the workload. The evaluation is not included since the maintenance tasks are not implemented and executed. The next chapter is the evaluation of the maintenance concept described.

4.6.1 Implementation

To maximize the long-term benefits of the maintenance concept, it is necessary to implement the recommendations formally. The maintenance tasks, from previous sections, need to be translated into practical jobs for the operators and technicians at Intersnack. They have to be registered within the systems (Ultimo, CIL) and explained with a job instruction.

Implementing in the systems

The maintenance jobs are created and registered within Ultimo. The names of the maintenance policies do not correspond with the maintenance job categories from Ultimo (section 2.2.1) and are adapted to the options in Ultimo (categories 3 and 4). When creating the maintenance job is it important to fill out all the available information. The specific actions in Ultimo that need to be executed and/or included are described in appendix D Ultimo Maintenance job. The detective-based and UBM tasks with a small-time frequency (less or equal to a month), and can be executed by the operator need to be implemented in the CIL. The CIL is described in section 2.1.1.1.

Maintenance job instructions

To perform the maintenance job correctly are instructions needed. As a rule, tasks should only be incorporated into operating procedures if they need to be done at intervals of one week or less. Otherwise, need all the aspects of the SIMPTWW be included in the job instruction as shown in section 4.1.1. The maintenance instruction format options are Standard Operating Procedures (SOP), One Point Lesson (OPL), and Job Aids (JA). In many cases are SOPs the simplest and cheapest way to manage high-frequency tasks that need to be done by operators. The instructions must be clear and concise so that enough detail is given to leave no doubt at all as to what is to be done. The created maintenance job instructions for the case study are attached in Appendix D. These include the maintenance instructions for the knife, pre-scale, resistance sensor, and heating element.

Maintenance plan (Clustering and harmonization)

The determined maintenance tasks by the project team (Student, Operator, Technician, Line Team) for the Seal Jaws to reduce unplanned downtime, as shown in Figure 54, still need to be combined and harmonized into a maintenance plan with acceptable work packages. The recommended maintenance tasks by the OEM are also included to create a more comprehensive maintenance plan for the Seal Jaw. The maintenance tasks from the OEM are indicated in the manual and part overview as indicated in section 3.3.7. Currently, these recommendations are not used or executed at Intersnack Nuts Packaging department.

A maintenance cluster is a group of maintenance tasks with commonalities. A past of the formed maintenance clusters are shown on the right side of Figure 35. The total overview consists of 44 maintenance points and is shown in Figure 54. The described steps in section 3.3 resulted in these initial clusters. In the overview is indicated whether a task can be executed during or out of operation, the maintenance type, setup type, workload, interval, and required personnel. More details about Figure 35 and the information are described in appendix C Maintenance task overview including the clusters.

Maintenance point	Job Description	Workload (minutes)	During or Outside Operation	Setup type	Interval Production Hours	Personel type	Cluster
PT-100	Replace	120	BB	C	5000	2	C14
Sealing profile	Replace	960	BB	D	5000	2	C15
Lubrication points vertical seal seal jaw drive	Lubricate	10	BB	A	500	2	C10
Drive seal jaws	Check belt tension	10	BB	A	500	2	C10
Bearing ring seal jaws	Check bearing ring seal jaws for play	10	BB	A	500	2	C10
Seal jaws clossing	Check seal jaws for function	10	TB	A	500	2	C10
Slide bearings seal jaws	Lubricate the sliding bearings of the seal jaws	10	BB	A	500	2	C10
Knife	Check knife for contamination	5	TB	A	500	2	C11
Cylinder knife	Check knife cylinder for function and leakage	10	TB	A	500	2	C11

Figure 35 Section of the maintenance job overview of Figure 54

Clustering maintenance jobs – Common set-up

The required steps that are indicated in the literature to determine the maintenance job clusters are followed. An example of creating a job cluster with the executed steps is explained below. The jobs from Figure 54 are used in the example.

The maintenance jobs with setup C from the overview in Figure 54 are used in this example. The set-up costs are equal to s_1 = 30 euro and a total of 260 workdays a year are used in the calculation.

Step 1: Cluster jobs with the same criteria

(During or out of operation, setup type, interval, and required personnel)

The maintenance jobs with the same criteria are clustered. The workload of the different tasks is added to the total. Resulting in the initial job clusters as shown Table 12.

Step 2: Sort the jobs according to decreasing minimal interval (Table 12)

Table 12 Clusters after step 1 from the maintenance job overview in decreasing order

Job	Component	Workload (minutes)	Variable cost per job ci	Setup type	Interval Production Hours	Minimal Interval (# jobs per year)	Upper bound frequency
1	Knife	240	240	C	160	39	44
2	Seal Beam	25	25	C	500	13	29
3	Heating element	20	20	C	500	13	33
4	PT-100	25	25	C	500	13	29
5	Knife clamping block	20	20	C	500	13	33
6	Resistance sensor	120	120	C	5000	2	3

Step 3: Compute upper bounds on frequencies in optimal clustering:

Jobs 2, 3, 4, 5, 6 shouldn't form a cluster with 1 since the minimal interval of job cluster 1 is higher than the upper bound of the other jobs. This makes job 1 the first cluster. For the other jobs still needs to be determined what the most optimal cluster is.

Step 4: If the interval of job i is between two jobs in the same cluster (in the optimal clustering), then job i should be in that cluster too

Job 2 & 4 and job 3 & 5 have the same upper bound and are clustered. Resulting in Table 13.

Table 13 New formed clusters based on upper bound frequency

Job	Component	Workload (minutes)	Variable cost per job ci	Setup type	Interval Production Hours	Minimal Interval (# jobs per year)	Upper bound frequency
1	Knife	240	240	C	160	39	44
2	Seal Beam + PT-100	25	25	C	500	13	29
3	Heating element + Knife clamping block	20	40	C	500	13	23
4	Resistance sensor	120	120	C	5000	2	3

Step 5: Define minimal cost (g(k)) for clustering (ordered) first k jobs

The minimal costs for clustering the jobs is determined with dynamic clustering. The result is shown in Table 14. The jobs from step 4 are used for determining the optimal cluster. As can be seen in Table 14 is the minimal cost determined when job 2 and 3 are clustered and job 4 is performed alone.

Table 14 Minimal costs calculation job clusters – On the left are the costs indicated and right the corresponding clusters

G( )			
0	€ -		
1	€ 1,595.00		
2	€ 2,755.00	€ 3,205.00	
3	€ 6,235.00	€ 5,965.00	€ 3,205.00

G( )	Job combination respectively		
0	0		
1	{2}		
2	{2 & 3}	{2},{3}	
3	{2 & 3 & 4}	{3 & 4},{2}	{2 & 3},{4}

In conclusion, the optimal (most cost-efficient way) job clusters (from the initial jobs of Table 12) are: first Job 1, because of step 3, second Job 2, 3, 4, and 5, and three Job 6.

The next step is to harmonize maintenance, by assessing the workload of the created maintenance clusters over time. Here an equal workload distribution is desired, where maintaining the established maintenance interval for each task is important. Assessing and monitoring the workload is done using the "graphical overview" function in Ultimo, as explained in appendix D Harmonizing maintenance jobs. In this overview mode is the workload indicated for each task and can the task be planned in time. Further development of maintenance planning is outside the scope of this research.

4.7 Feedback

The last step of the framework is to evaluate the tasks if they meet the requirements and objectives. The proposed 7-step framework is an iterative process where continually reviewing and improving the initial maintenance plan is required. The data that is collected from the inspection reports, component failures, maintenance costs, operator findings, etc. gives an overview of the maintenance performance.

The final step of the framework is currently pending execution. Maintenance tasks are in the process of being implemented while this research is being written. A substantial amount of time must elapse before a thorough conclusion can be drawn when reflecting on the impact of these maintenance tasks.

4.8 Conclusion

Framework result

In this chapter, the seven proposed steps by Weayenbergh have been executed for the development of a maintenance concept. In practice, it has been demonstrated that the framework's structure ensured a comprehensive consideration of all aspects involved in creating a detailed maintenance plan. The main outcome of the framework is the development of the maintenance plan for the analyzed components of the Seal Jaw. In total, 44 maintenance tasks have been identified as shown in Figure 54. These maintenance tasks are ready to be implemented in practice, ranging from minor inspections and cleanings to the replacement or repair of parts.

FMEA method
The FMEA method, while useful in identifying critical components, proved less suitable for Intersnack's current situation due to numerous factors beyond standard wear affecting component failure. Human factors emerged as significant contributors to failure behavior during the analysis. Additionally, the need for a machine system-level maintenance plan made component-level analysis premature. However, the FMEA method did enhance documentation of machine and parts knowledge, significantly improving the project team's understanding during implementation.

Interval optimization
The absence of reliable data on component failure behavior makes determining the optimal maintenance interval challenging. In such instances, intervals are typically determined based on the experience and knowledge of the project team. However, a method for establishing the optimal interval based on failure behavior has been outlined for future implementation once reliable data becomes available.

Corrective to pro-active maintenance
The maintenance concept execution led to a shift from mainly corrective to more preventive maintenance, reducing corrective actions to only 22% of maintenance tasks. Over 50% of maintenance tasks now involve proactive measures. This shift reflects a deliberate strategy rather than an incidental outcome.

Moreover, the implementation significantly reduced unplanned downtime, with reductions ranging from nearly 50% to over 80% for analyzed components, as indicated in Table 11. Additionally, a list of components requiring modification or redesign to minimize maintenance has been compiled, with valuable input from operators enhancing engagement and motivation.

Practical consideration and next steps
Intersnack prefers a maintenance approach that prioritizes knowledge extraction from experienced personnel, minimizing reliance on extensive documentation. Adopting the 7-step framework for all machines would prove intricate and costly, requiring time and support for progression through the steps. Challenges arise from the project team's lack of experience and the complexity of analysis. The next chapter evaluates the case study and cost benefit analysis. Furthermore, it outlines the implementation plan, including the recommended approach.

5 Evaluation and implementation

The outcomes of the case study are analyzed and evaluated in this chapter. The evaluation of the case study is structured according to the 7-step framework. Furthermore, is a cost-benefit analysis constructed about the implementation of the maintenance concept within Intersnack. At last is the implementation plan described.

5.1 Case Study Evaluation

The case study is performed to demonstrate the different proposed steps of the framework. The conclusions and key learning points are mentioned in this section.

Never too late to incorporate the maintenance concept

The maintenance concept should be applied as early in the acquisition cycle as practical, but the steps may be applied with good benefits, even after some of the initial system design work has been completed. The structure is ideally suited to analyze existing systems and equipment, it is equally powerful in analyzing concepts and designs. The specification of maintenance with the structure will help ensure that an effective and economical maintenance strategy is selected through its life cycle.

Maintenance goal

Intersnack's maintenance goal is currently only broadly described and needs further specification for the FMEA. Due to the broad formulation is it hard to specify required maintenance tasks. The goal, to achieve maximum availability and reliability, leads to maintenance tasks for all possible failure modes. The maintenance concept execution will be more effective when there is clarity about the specific required machine performances. Including a specified maintenance budget.

Prioritization (MIS)

Intersnack has a method to determine the priority, the Equipment Ranking, of a machine. The Equipment Ranking within Intersnack is suitable at a machine level but less so for a component. As indicated in the case study, it is beneficial to conduct a brief analysis of unplanned downtime performances. This analysis aids in prioritizing a group of components. For these components, the Risk Priority Number can be determined with the RPN criteria tables.

The foundation of the maintenance plan

Analyzing the failure modes during the FMEA analysis at a component level may be too detailed for the current situation at Intersnack. It is wiser to shift the focus to the machine level first to get the basics right and then proceed with further development. Currently, the foundation is not advanced enough to have the maintenance plan in order. Therefore, it is advisable to analyze the critical assemblies first and then determine their critical points. Subsequently, a more in-depth analysis can take place, rather than diving directly into component-level analysis.

Currently is Intersnack Nuts Packaging department determining the required inspections and maintenance for each machine on a high level based on the external advice and inhouse experience. This mainly includes the maintenance that needs to be executed by the external parties. Based on the maintenance tasks is an annual maintenance plan created on a machine level. Once Intersnack has created the maintenance overview (and improved maintenance, a deeper analysis, as done during the case study, can also be performed. On a higher level in the machine structure, it is also possible to analyze data from downtimes in QlikView, as described in Chapter 2.

Maintenance implementation

Job clustering is in the case study done at a component level. This clustering method is better suited for grouping 'large' maintenance tasks for machines. Currently, additional maintenance tasks alongside major maintenance have come to the fore. These points can be better placed at the machine or assembly level.

Performing the analysis
The execution of the analysis in the 7-step framework is currently carried out by the intern, operators, and the Line Team. In this, the intern has assumed the facilitating role, despite not being fully familiar with the process and role. Consequently, there is room for improvement in the execution. Going forward, it is advisable to form the analysis team with a Facilitator, Operator, Line Team, Technician, Engineering Supervisor, and optionally, an external specialist. This approach ensures more comprehensive information for the analysis. Additionally, the facilitator can guarantee the quality.

External maintenance
The inspection and large maintenance tasks are currently performed by externals. These schedules should be included in the maintenance plan. When implementing the maintenance concept should the external maintenance continue but after understanding the performed inspections and maintenance tasks can be determined if they could be executed by the technical department of Intersnack. In this way is a better technical knowledge inhouse.

The information from the externals can be very useful. They see multiple environments where the machines are used and know therefore a lot of critical failure modes. This is valuable information for the failure analysis. Their knowledge should be used to better understand the failure modes at Intersnack.

5.2 Human impact failure behavior

During the analysis and investigation of failure behavior, it has been revealed that failures are often caused by human factors, particularly in how individuals make use of the component and their level of knowledge and experience.

After a technician repairs a component, it has often occurred that the fault reoccurs shortly afterward, despite the issue seemingly being resolved. An example of is shown in Figure 31, where the PT100 sensor was replaced and failed again in the same week, despite having an average lifespan of over 2000 service hours. The incorrect connection made by the technician ultimately led to the component's failure. This incorrect connection can be caused by various factors, such as the absence of work instructions, time pressure to resume machine operation, incorrect materials, or improper execution.

In the case of the knife, the operator's handling has an impact on the knife faster failing. The failure pattern of the blade in Figure 56 shows a wide variation in failure behavior. Blades within the interval of 0 to 570 hours often experience human impacts and do not fail due to standard wear. Several causes can be identified, including lack of information, time constraints, or behavior. Further examination of the human aspect is necessary to reduce its impact on failure behavior.

The human aspect is currently not considered in the failure behavior of the components, as also stated in the scope of the research. In the FMEA method are the failure modes due to human impact not included. However, it is advisable to address or include this when developing the maintenance plan, as it has repeatedly proven to be a significant factor in component failures as shown in the failure behavior of the knife in Figure 56 and PT100 failure in Figure 31.

While preventive maintenance is beneficial for most cases, it is more crucial to focus on mitigating the human impact to prolong the time between failures and reduce the frequency of failures. This approach will enhance the reliability of failure behavior data, allowing for better implementation of preventive maintenance.

5.3 Cost-benefit analysis

To evaluate whether the proposed maintenance concept will result in a cost reduction are the expected implementation costs compared to the expected benefits. As earlier mentioned in section 2.4.3 maintenance is related to a lot of different aspects of the business as shown in the key figure overview for maintenance in Figure 44 created by Komonen (2002). Therefore, the impact of the maintenance concept is limited to the direct impact regarding equipment reliability, maintenance costs, and downtime. The maintenance tasks from the case study are used as an example.

5.3.1 Benefit

Reliability impact on the unplanned downtime

The primary goal of the maintenance concept is to improve the reliability of the machines or systems. The FMEA analysis, in the maintenance concept, provides proactive risk mitigation of downtime by identifying potential failures before they occur. This results in a reduction of the unplanned downtime as shown in Table 11. An example of reducing the downtime is described below with one of the monthly maintenance tasks of the Seal Jaws as described in appendix D SOP - Knife replacement.

> *The component failures have an impact on the downtime. For 17 incidents (related to the created monthly inspection task), both the mean downtime and technician waiting time were recorded. The unplanned downtime for these 17 incidents amounts to a total of 3403 minutes (Appendix Table 18). The components are corrective maintained, which also results in a waiting time for technicians, totaling 573 minutes. This is roughly equivalent to an average downtime of 4 hours per defect. Calculating a loss of production of €8 per minute (€0.2 per bag, 80 bags per minute, and an OEE of 50%), along with two operator labor costs of €60 per hour, this represents approximately €2000 per defect.*
>
> *The planned maintenance task is estimated to reduce the number of failures with approximate 70% as shown in Figure 53 by combining the tasks impact resulting in a saving of €1400 per defect. The task can be performed offline by the technician without affecting the production. The execution takes the technician half an hour when everything is in order (costing only €45). If defects are identified, the maintenance will take longer, but this is equivalent to the time for corrective maintenance.*

Improved technical knowledge, communication & documentation

The reliability improvement also comes through a constant reevaluation of the created maintenance plan and the improved communication between the project members as indicated in the RACI chart (i.e., Maintenance Lead, Operators, Technicians, Maintenance Coordinator, and Engineers). One of the key benefits of the analysis is understanding and documentation of operations and maintenance key features, failure modes, basis of PM tasks, related drawings and manuals, etc. This documentation is perfect training material for new Operators or Technicians. This helps achieve the maintenance goal.

Achieving the Intersnack mission
Safety, characterized by 100% risk management, is a top priority at Intersnack, as highlighted in the Intersnack mission statement. The maintenance concept underscores this commitment, but also provides a structured framework for achieving the goal. This includes identifying various risks and prescribing corresponding actions. The flexibility inherent in this approach ensures that the right type of maintenance is performed exactly when needed. The notable benefit is maximizing the use of parts with optimal replacements, contributing to overall efficiency.

Cost
Adopting a new maintenance concept initially involves a significant investment in acquiring technological tools, providing training, and establishing machine condition baselines. However, in the case of Intersnack, access to necessary technical tools is already available, and the machine condition baseline can be established by leveraging external (OEM) technicians for required maintenance tasks. The key resources are training and obtaining machine baseline conditions.

The upfront costs are associated with creating the necessary infrastructure for the new maintenance approach. It's important to note that the expense is primarily short-term. Over time, the cost of corrective maintenance tends to decrease as failures are prevented and preventive maintenance tasks are replaced by condition monitoring. In the case study is the shift from to po-active maintenance and only 22% of the analyzed parts are still corrective maintained. Consequently, there is a net positive effect with a reduction in corrective maintenance and, ultimately, a decrease in total maintenance costs.

5.4 Implementation plan

The implementation plan describes how the maintenance concept can be implemented at Intersnack Doetinchem. Furthermore, the key steps are described for a successful implementation. An overview of the key implementation steps for the maintenance tasks is shown in Figure 36.

5.4.1 Implementation approach of the maintenance concept

Given that the maintenance plan is in its initial phase, and various factors still impact machine performance, it is advisable to employ a selective approach to implement the maintenance concept. The selective approach is to apply the maintenance concept steps for about 30% of the assets representing the A classification of the equipment ranking.

Another reason is that resources and time have to be committed to the execution and are limited with the current resources. The investment in the analysis will generally yield quick and measurable returns since the analysis is only applied to the most crucial assets. The unplanned downtime of the analyzed components in the case study reduced with more than 50%. This makes the project manageable and controllable. The downside is that the emphasis is mainly on the technical aspect, with less focus on developing the capacities of the people involved.

5.4.2 Implementation key steps

The constructed 7-step framework that is provided in the previous chapter helps to specify the required maintenance. The people who participate in the process learn a great deal about how the asset works and how it fails. Most of the time leads the execution to changes in the participant's behavior in ways that lead to improvements in the asset performance.

To successful implement the determined maintenance tasks are the following key steps required:

- Audit the maintenance tasks. The proposed recommendations are approved formally by the Line Team and Production Manager with overall responsibility for the assets.
- The (routine) tasks are described clearly and concisely.
- The proposed Design Out Maintenance tasks are identified and implemented correctly.
- Operating procedures are included (see Appendix D) and incorporated into appropriate work packages (section 3.3).
- Implement the maintenance tasks in the system Ultimo and within the structures from IWS.

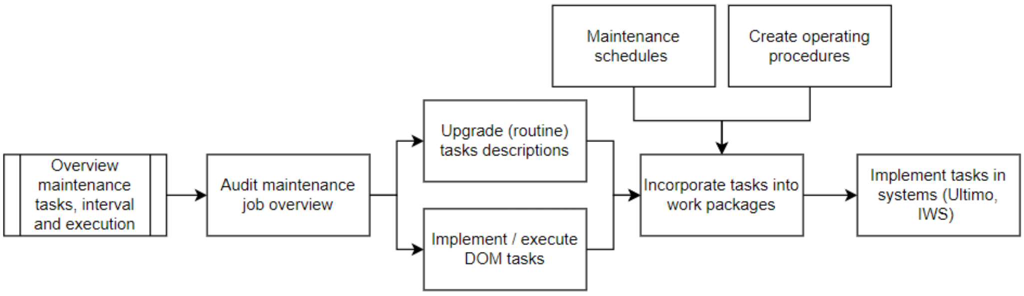


Figure 36 Implementation steps

Execution maintenance concept RASCI chart

A visual representation that delineates the roles of the team members regarding the execution of the maintenance concept is created to better manage the project. The RASCI chart is used since it gives a clear overview of the different roles and tasks. The structure is based on the execution of the case study. The steps from the framework with the various project roles based on the organizational structure are indicated in Figure 37.

			ROLES	Facilitator	Maintenance Lead	Process lead	Line Lead	Maintenance Coordinator	Operators	Technicians	Engineering	External expert
	Deliverable or Task	Status		Project team								
	Exectution Maintenance concept											
1	Define System Boundaries			R	A	S	S	C				
2	Identify Critical Functions			R	A	S						C
3	Determine Failure Modes			R	A				S	S	C	C
4	Assess Consequences			R	A	S	S	C	S	S	C	
5	Prioritize Failure Modes			R	A	S	S	C	S	S	C	
6	Develop Maintenance Strategies			R	A			S				
7	Document Analysis			R	A							
8	Review and Approve Analysis				R	I	I	A	I	I	C	
9	Implement Maintenance Strategies				R	S	S	A	S	S	S	
10	Monitor Effectiveness				R	S		A				

R	Responsible	Assigned to complete the task or deliverable.
A	Accountable	Has final decision-making authority and accountability for completion. Only 1 per task.
S	Support	Provides support during implementation.
C	Consulted	An adviser, stakeholder, or subject matter expert who is consulted before a decision or action.
I	Informed	Must be informed after a decision or action.

a*Figure 37 RASCI Chart – Execution project based on the case study*

5.5 Conclusion

In conclusion, the evaluation of the case study indicates that the 7-step framework provides a structured approach to determining maintenance tasks, subsequently defining a concrete maintenance plan. The maintenance tasks primarily have a proactive nature, enabling the execution of scheduled and planned maintenance. The maintenance concept facilitates the transition from corrective to preventive maintenance. It is worth noting that while introducing the maintenance concept early is advantageous, significant benefits can still be realized later, even with existing machines.

To establish a robust foundation for the maintenance plan, it is recommended to initially shift focus to the machine level before conducting a detailed analysis at the component level. The maintenance plan should be outlined at a high machine level first, utilizing the effective prioritization method, Equipment Ranking, but expanding it with the performance analysis of unplanned downtime. While external maintenance continues, understanding tasks performed by external parties allows for a potential transition to internal execution, leveraging better technical knowledge.

The execution of the framework would benefit from a more diverse team composition, including a technician and facilitator for the framework. The recommended composition of the RACI chart should be adhered to for each step. The significant impact of human factors on failure behavior highlights the importance of addressing this through training, work instructions, and information dissemination to enhance reliability. Part of the maintenance concept involves revising work methods and procedures.

The implementation plan outlines key steps for integrating the maintenance concept, emphasizing task allocation and integration into Intersnack's systems. The cost-benefit analysis demonstrates that the initial investment in the maintenance concept yields long-term benefits, with a reduction in corrective maintenance costs and overall maintenance expenses over time.

6 Conclusion and recommendation

6.1 Conclusion

Research objective

The proposed method of Waeyenbergh in combination with RCM perfectly fits the objective of how to achieve the transition from corrective to preventive maintenance. As indicated “RCM is defined as a series of activities generated on the base of a systematic evaluation to develop or optimize a program of maintenance”. For that reason, the framework and in particular the methods FMEA and Maintenance policy decision diagram will be chosen to create a preventive maintenance plan for the machines.

Maintenance plan

To create a successful (preventive) maintenance plan, critical machines and systems need to be analyzed using the constructed 7-step framework. The will unplanned downtime will decrease after executing the analysis. As indicated in the implementation plan, it is wise to make use of a selective implementation approach for the maintenance concept. Making use of the FMEA and the maintenance policy decision tree as indicated in the case study. The result of the analysis is a comprehensive (preventive) maintenance plan. In the maintenance model is indicated which machine/parts require what type of maintenance and when. It should be noted that FMEA documents are 'living documents' and should be updated if practical experience reveals inaccuracies. For this reason, it is recommended to review the documents annually to assess whether changes in the production environment impact the maintenance policy.

The result of the maintenance concept is an overview of the maintenance steps and tasks to be performed. Regarding the planning of various maintenance tasks, a structure is provided on how maintenance tasks can be clustered and harmonized in practice. Where is specified which maintenance can be carried out by whom (first- and second-line maintenance). Also, it is indicated how the optimal maintenance interval for preventive maintenance should be determined.

Current Maintenance approach Nuts Packaging

The current maintenance strategy is primarily corrective, with external inspections and large maintenance performed in combination. The maintenance plan is only registered at a high-level machine perspective, lacking specificity for individual machines or components. Also, the maintenance jobs for failures and defects are registered at this level without specification of sub-assemblies or components. The planning of maintenance is based on the 8-week cycle between inspection and large maintenance by the different external technicians. In between is mainly corrective maintenance performed when needed. The maintenance objective aims to enhance reliability, improve safety, and reduce machine ownership costs of the machines.

The current maintenance performance is indicated by the reliability KPI's, safety triggers, and maintenance costs. For the production line D028, there is an unplanned downtime of 32%. The Transwrapper emerges as the most critical machine, experiencing a total of 1600 minutes unplanned downtime with 1847 stops in one year. The failure event of the "Seal jaws" is mainly attributed to.

Maintenance model

The maintenance model for Intersnack is the 7-step framework. It involves identifying objectives, selecting critical systems, indicating critical components, choosing a maintenance policy, optimizing policy parameters, implementing and evaluating, and feedback loop. To bridge the gap between theoretical concepts and operational realities, a case study was conducted, applying the developed maintenance concept to the Transwrapper machine in production line D028. This practical application served as a crucial step in aligning theoretical principles with the actual maintenance needs and challenges within the operational context.

The critical system is indicated by extending the existing Equipment Ranking with the unplanned downtime analysis. Next are the components analyzed with the FMEA method. The information, in the case study, is derived from historic failure data and FMEA analysis. The information should be extended with the information on spare parts orders to understand past failures. Additionally, information can be gathered from maintenance routines, both in Clean Inspect Lubricate (CIL) and (progressive) maintenance jobs on similar machines at different Intersnack locations. The OEM-provided maintenance plan also contributes to a comprehensive understanding.

Results
The quality of the 7-steps framework is tested in practice. The execution of the framework helped to create a supported maintenance plan for the selected components of the Tranwrapper. The structure helped to determine specific maintenance tasks and how to translate them into day-to-day work packages for the operators and technicians. This method was not provided within the current situation. The maintenance transition from mainly corrective to predictive is now possible. Furthermore, the framework indicates how to optimize the task intervals and how to cluster. The framework not only guides in optimizing task intervals and clustering but also stands out for its detailed and comprehensive analysis, promising enhanced machine reliability and deeper technical insight.

The main outcome of the framework is the development of the maintenance plan for the analyzed components of the Seal Jaw. In total, 44 maintenance tasks have been determined as shown in Figure 54. The maintenance concept execution led to a shift from mainly corrective to proactive maintenance, reducing corrective actions to only 22% of maintenance tasks. Over 50% of the determined maintenance tasks now involve proactive measures.

The impact of the tasks on the unplanned downtime is hard to indicate since there is no available data about the unplanned downtime of specific failure modes. The maintenance tasks are determined for these specific failure modes. The only available data is the time to repair the components. To indicate the impact is the manual registered time to repair data used for the components. The impact of the maintenance task on these times is determined based on the failure behavior and by estimations from the project team. Implementing the maintenance task for the analyzed components is estimated to significantly reduce unplanned downtime, with reductions ranging from nearly 50% to over 80% for analyzed components, as indicated in Table 11.

Implementation Maintenance Concept
The implementation of the maintenance concept at Intersnack proves to be beneficial, offering benefits even after adapting it at a later stadium. The specified framework, combining RCM and the 7-step approach of Waeyenbergh, ensures an effective and economical maintenance strategy. The implementation plan suggests a selective approach, focusing on crucial components determined by the Equipment Ranking method. The cost-benefit analysis shows reduced downtime and improved reliability, aligning with Intersnack's Global Business Need. In conclusion, the maintenance concept, when implemented selectively and with a diverse team, provides a structured and proactive approach, offering a transition from corrective to preventive maintenance with significant benefits.

6.1.1 Discussion

Historic data failure behavior

Obtaining details about the failure behavior of components from information systems such as Ultimo proves to be challenging. In Ultimo, either no detailed information is collected, or the quality of the information is low due to a lack of knowledge and perceived utility of data collection by those entering the data as shown in the example of the PT100 in Figure 31. If data about the failure behavior or failure frequencies cannot be extracted from information systems, interviews with experts (operators, technicians) often provide much of the required information to determine the mean time between failures. It is also highly beneficial to involve the external technician or OEM manufacturer (Original Equipment Manufacturer) of the system during the analysis.

During the execution of the case study, only the components that had registered faults or breakdowns were used as input for developing the maintenance concept. The reason for this is that otherwise, no information is available regarding the failure behavior and causes. In the future, it is recommended to include all components during the analysis and then prioritize them as indicated in FMEA. As a result, the developed maintenance tasks are only detailed for these components.

The maintenance concept development has been carried out for the Transwrapper. The results can be utilized for other production lines and facilities. However, knowledge regarding the differences in machines and production environments must be known. This way, maintenance tasks can be adjusted where necessary before implementing them across the board.

6.2 Recommendations for further research

Human impact failures

What has been revealed during the research is that a significant portion of failures is caused by human impact as explained in 5.2. Therefore, before considering adjustments to the machines, substantial improvements in machine availability (reducing UPDT) can be achieved by enhancing operator instructions and training. Creating awareness that certain ways of operating the machines can lead to failures is crucial, but this requires a detailed analysis of frequent failures to first identify the root causes and prioritize them.

Documenting knowledge

The leave rate within Intersnack Doetinchem is relatively high. It is, therefore, crucial that information is documented during the execution of the maintenance concept. This way, certain choices made during the analysis can be made transparent and assessed. Including the knowledge of the operators should be documented.

Knowledge Sharing

Within the Intersnack Group, there is a lot of knowledge. However, the knowledge is currently not actively shared. A similar situation regarding missing maintenance approach as in Intersnack Doetinchem arises at the other facilities in the Netherlands. This leads to reinventing the wheel or repeating the same mistakes at multiple locations. Therefore, the application of the maintenance concept development is recommended at the other locations.

An example related to the research is the development of a maintenance plan for the Transwrapper. The Transwrapper is a standard machine within the Intersnack Group. The application of the maintenance concept results in an optimal maintenance plan for the machine. This plan is largely directly applicable to other production locations. Knowledge sharing needs to be encouraged. An option is to establish a joint communication group (Teams group) with similar roles and schedule regular meetings.

Within Intersnack Doetinchem, there are four Maintenance Leads. Collaborating should be stimulated more. This means discussing different cases with each other to better substantiate certain decisions and establish a standard approach. A monthly meeting would be a suitable starting point for this.

Focus on reducing Unplanned Downtime

During the analysis of unplanned downtime, it has been revealed that the events "Break" and "unknown" are responsible for almost 30% of the total unplanned downtime for D028. The "unknown" event occurs when no event is entered by the operator. When determining the focus and resources of the line team is it crucial to indicate the event correctly. This way, the data becomes more reliable, and better measures can be taken against it. The "Break" event is selected by the operator when they take a break and cannot let the machine continue running. There is still much to be gained here to reduce the overall unplanned downtime. A follow-up investigation regarding this event is, therefore, recommended. For instance, investigating if a “runner” can operate the machines when others are having a break or a special machine setting during a break. For the “unkown” events should the Line Team and Team Lead monitor these events and specify them to the right event when they occur.

The most important system - Equipment ranking

During the execution of the equipment ranking, various machines are clustered to subsequently score them based on different criteria. However, it is not always possible to determine a correct score since the criteria scores differ among the clustered machines. This is achievable by individually evaluating the machines.

Maintenance Recommendations from OEM

Regarding the maintenance of machine components, prescribed standards, and advice are available from the OEM. However, this is not handled (correctly) within Intersnack. An example of this is that the cleaning work instructions clearly state that compressed air should not be used in the Transwrapper. Operator awareness and knowledge are crucial factors that the Line Team needs to create.

The supplier also recommends a set of periodic maintenance tasks for certain components. These service intervals are currently not being adhered to. The external parties are only invited during the timeslots as indicated in Figure 6. During the development of the maintenance concept, these recommendations have been considered. Additionally, consultation with the external technician has been sought regarding critical maintenance points and their corresponding intervals.

Information job instruction - Defects and Solutions

The information provided by the operator and technician is limited in the registration system. A defect is often incomplete or wrong reported in a maintenance job. Frequently, only the machine is indicated without providing further details about the malfunction/defect or the involved component. This requires the technician to gather a lot of information from the operator before they can start executing the needed maintenance. Also, the registration of defects with maintenance actions or solutions by the technician is lacking in the maintenance job. This often leads to recurring defects, and the solution must be sought anew. The registration from both sides needs to be improved. This can be achieved by training and controlling the input to make the information useful.

Information registration
The research analysis had to rely on the assumptions of the employees due to a lack of data. The challenge also arises from the widely scattered information in existing databases Ultimo. To make well-founded decisions based on existing data, it is advisable to conduct a study on methods to structure and unify the information from the failure registration. Establishing a systematic approach to enhance data quality and availability will contribute to more informed decision-making.

Machine Reset & Quick Fixes
During the resolution of faults, many quick fixes are applied to keep the machine running. However, the systematic resolution of problems is often neglected. Technicians frequently reset the machine without conducting further investigation. This leads to the recurrence of faults and defects. Systematic solutions such as redesigning components can prevent a lot of low-hanging fruit concerning repetitive failures.

Opportunity maintenance
As earlier mentioned in this research are multiple maintenance time slots. The maintenance time slots can be planned but also opportunities due to unplanned downtime. To lower the downtime is it recommended to utilize these unplanned downtime time slots. The maintenance tasks can be executed at these timeslots.

Outsourcing
The maintenance policy that isn't included in the decision diagram is outsourcing. Nevertheless, this might be a solution for some maintenance tasks. As indicated in section 2.1.2 are the inspections and (large) maintenance tasks executed by externals. The main reason for outsourcing is that Intersnack can focus better on its core activity (production), combined with outsourcing non-core activities such as maintenance. The advantages (i.e. high knowledge level) and disadvantages (i.e. less technical in-house knowledge) of outsourcing are listed in Appendix C Maintenance policy - Outsourcing.

7 Bibliography

Academy, L. S. (2024, 01 08). *Resources Lean Six Sigma Whitepapers.* Retrieved from LSSA: https://www.lssa.eu/resources/lean-six-sigma-whitepapers/

Barlow, R. (1960). Optimum Preventive Maintenance Policies. Operations Research. *Institute for Operations Research and the Management Sciences*, 90-100.

Braaksma, J. &. (2012). A Quantitative Method for Failure Mode and Effect Analysis. . *International Journal of Production Research. 50*, 1-12.

Coetzee, J. (2000). The Maintenance Strategy Gap. *World Trends in Maintenance*, 7.

D. Vasseur, M. L. (1999). International survey on PSA figures of merit. *Reliability Engineering & System Safety*, 261-274.

Faghihinia, E., & Mollaverdi, N. (2012). Building a maintenance policy through a multi-criterion decision-making model. *Industrial engineering international*, 15.

Gerhard van Dijkhuizen, A. v. (1997). Optimal clustering of frequency-constrained maintenance jobs with shared set-ups. *European Journal of Operational Research*, 552-564.

Group, I. (2023, 09 08). *About-us*. Retrieved from Intersnackgroup: https://www.intersnackgroup.com/about-us/overview

Gurumeta, E. M. (2007). Reliability Centered Maintenance. *9th International Conference Electrical*.

Komonen, K. (2002). A cost model of industrial maintenance for profitability analysis and benchmarking. *Production Economics*, 17.

Lambooy, M. H., & Gits, C. W. (1989). *Het ontwerpen van het onderhoudsconcept: een toepassing bij DMV Campina.* Eindhoven: Onderhoudsmanagement.

Moubray, J. (1999). *Reliability-Centered Maintenance.* Oxford: The Aladon Network.

Moubray, J. (2008). *Reliability-centred Maintenance.* Oxford: Elsevier.

Pinciroli, L., Baraldi, P., & Zio, E. (2023). *Maintenance optimization in industry 4.0.* Milan: Elsevier Ltd.

Pittel, B. &. (1972). Extreme Value Theory and Applications. *National Institue of Standards and Technology*, 248.

Stevering, H. (2019). *IWS Booklet.* Doetinchem: Intersnack .

W., M., J., B., S., H., & F.G.M., K. (2012). *Design for maintenance. Guidelines to enhance maintainability, reliability and supportability of industrial products.* Twente: University of Twente.

Waeyenbergh, G. &. (2002). A framework for maintenance concept development. *International Journal of Production Economics*, 299-313.

Waeyenbergh, G., & Pintelon, L. (2000). A framework for maintenance concept development. *Centre for Industrial Management*, 15.

Wang, H. (2002). A survey of maintenance policies of deteriorating systems. *European Journal of Operational Research*, 469-489.

1 Appendix – A - Production process

1.1 Packaging line D028

The packaging line D028 is the focus of this research since it has the highest unplanned downtime. The packaging line consists of several machines. Different kinds of products are packed on the packaging line. The different machines with their functions are shortly described:

1. Filling station, Big bag of nuts is lifted and emptied into the infeed conveyor.
2. Elevating conveyor, Transports the nuts to the weigher.
3. Weigher, Distributes the nuts, in equal quantities, into the pockets. Drops the nuts into the film for packaging.
4. Metal detection, checks for metal in the product.
5. Packaging machine, released nuts from the weigher are packed in foil, code stamping, sealing and cutting the bags.
6. Transport belt + pressing belt, Transporting and straightening the product towards the Case Packer.
7. Case Packer, Transporting the product with an arm (with suction cups) from the transport belt into boxes.
    a. Box Folding Machine, cartons are placed in the machine which folds it into boxes, seals the bottom, and transports them towards the Case Packer to be filled with bags.
8. Box Shutter, the filled boxes get a top lid sealed on the box.
9. Sticker Press, Places a sticker on the box with the required data.
10. Stacking robot, Stacks the boxes on a pallet according to the required pattern.
11. Wrapper, Wraps the pallet of boxes with foil for safe transport.

Machine structure D028 in the registration system Ultimo

The current machine structure in Ultimo of the D028 is visualized in Figure 38. As can be seen in the figure, only the highest level of the machines of the production line are indicated. The specific failures and defects cannot be registered at a subassembly or even component level.

D028, Verpakkingslijn D028
- BOK022, Stortbok D028
- TVT002, Toevoer trilgoot D028
- OVB002, Opvoerband D028
- MHD004, Weger D028
- MED004, Metaaldetectie D028
- TWR004, Transwrap vuller D028
- CAP002, Case packer D028
- DOM002, Dozen opzetter Knecht D028
- DOS004, Dozensluiter D028
- DSU005, Dozenstikkerapparaat D028
- PAL2801, Palletiser (Robot) Links D028
- PAL2802, Palletiser (Robot) Rechts D028
- CET011, Centrale besturing D028

Figure 38 Machine structure D028

1.2 Maintenance performance KPI's D028

The maintenance performance is measured with the KPI's reliability, safety, and maintenance costs. The KPI's are selected since these are impacting the maintenance goal. An overview is shown in the table below.

Table 15 Maintenance performance D028

KPI	Reliability				Safety	Maintenance costs	
Asset Name	Stops [#]	MTBF [min/#]	MTTR [min/#]	Downtime [min]	Triggers [#]	External [€]	Internal [€]
Bosch Transwrapper D028 2022	1847	95,2	8,6	15.933	0	36.210	30.000

1.2.1 Reliability

The KPI reliability is measured with the number of stops [#], MTBF [min/#], MTTR [min/#], and Downtime [min]. The KPI's regarding the reliability are explained in section 2.4.1.

1.2.2 Safety triggers

The safety triggers (unsafe situation) that are registered in 2022 on the production line D028 are in total 6 safety triggers as shown in the table below. None of these are caused by the Transwrapper. The registered safety triggers are not related to the machine or the condition of the machine.

Table 16 Safety triggers D028 in 2022

Standplaats	Datum ongeval	Lijnnummer / Locatie	Equipment	Aard van de verwonding	Letsel
Doetinchem	2/15/2022	D28	Pallet opstapelplek	stoten	schaafwond
Doetinchem	3/14/2022	D28	Tussen D27 en D28	uitglijden in/over	Kneuzing aan de rug
Doetinchem	3/15/2022	D28	hal 3	vallen, struikelen	schaafwond aan de knie
Doetinchem	5/10/2022	D28	Dozensluiter	verbranden	Zere vinger
Doetinchem	9/8/2022	D28	Boschverpakker	vallen, struikelen	zwelling
Doetinchem	12/1/2022	D28	Boven bij de weger/trilgoot	stoten	oogletsel

1.2.3 Purchase Orders Maintenance - Transwrapper

The external maintenance costs for the Transwrapper are recorded in the purchase orders. An example of the purchase orders of the Transwrapper in 2022 are shown in table below. The orders consist mostly of parts that are purchased after inspection and some spare parts.

Table 17 Purchase orders Transwrapper D028 in 2022

OrderDate	Description	Comments
08/03/2022	Preventive maintenance kit (PM-kit) voor vacuumsysteem typeVT4.40	Onderdelen na inspectie D028
08/03/2022	OMLEGROL	Onderdelen na inspectie D028
08/03/2022	Tandriem 30T10/840 left yellow	Onderdelen na inspectie D028
08/03/2022	Tandriem 30T10/840 right yellow	Onderdelen na inspectie D028
08/03/2022	GELEIDEROL	Onderdelen na inspectie D028
08/03/2022	ZELFINSTELBAAR KOGELLAGER	Onderdelen na inspectie D028
08/03/2022	Vrachtkosten	Onderdelen na inspectie D028
06/04/2022	CPU 332-V6 Compleet	Reserve besturingsonderdelen Bosch D028
06/04/2022	Backplane powerplane (x10a)	Reserve besturingsonderdelen Bosch D028
06/04/2022	Backplane VME-bus-VMNL (X10)	Reserve besturingsonderdelen Bosch D028
06/04/2022	Bosch inputcard FW37A	Reserve besturingsonderdelen Bosch D028
06/04/2022	Bosch plc kaart 32 output FW38A	Reserve besturingsonderdelen Bosch D028
06/04/2022	Bosch printplaat 8101307087	Reserve besturingsonderdelen Bosch D028
06/04/2022	CONTRA-STEKKER (FEMALE)	Reserve besturingsonderdelen Bosch D028
06/04/2022	Power supply; HPU100-T050II (G1)	Reserve besturingsonderdelen Bosch D028
06/04/2022	Power supply HSU45-31 (G2)	Reserve besturingsonderdelen Bosch D028
06/04/2022	Memory card, 1MB sram, Glyn	Reserve besturingsonderdelen Bosch D028
06/04/2022	External card reader for PC with USB connection	Reserve besturingsonderdelen Bosch D028
06/04/2022	Vrachtkosten.	Reserve besturingsonderdelen Bosch D028
06/04/2022	Power supply ABL-8RPS24050 24V/5A (G3;G4)	Reserve besturingsonderdelen Bosch D028
06/04/2022	VME-backplane 12 slots. (X10)	Reserve besturingsonderdelen Bosch D028
06/04/2022	Houder/behuizing (v. bouwgroep)	Reserve besturingsonderdelen Bosch D028
06/04/2022	Software VME (copy) send digitally	Reserve besturingsonderdelen Bosch D028
09/05/2022	Schouder 160, kunststof E2520AR400	D28 2x 160 schouders
09/05/2022	vrachtkosten	D28 2x 160 schouders
05/07/2022	Geleiderol met kogellager L=978	Onderdelen na inspectie D028
05/07/2022	Geleiderol met kogellager L=828	Onderdelen na inspectie D028
05/07/2022	LOOPROL	Onderdelen na inspectie D028
05/07/2022	Preventive maintenance kit (PM-kit) voor vacuumsysteem typeVT4.40	Onderdelen na inspectie D028
05/07/2022	Tandriem linkerzijde (kleur rood)	Onderdelen na inspectie D028
05/07/2022	Tandriem rechterzijde (kleur rood)	Onderdelen na inspectie D028
05/07/2022	Vrachtkosten	Onderdelen na inspectie D028

1.2.4 Internal maintenance tasks

The internal maintenance costs are registered in Ultimo. Each maintenance job records working hours and material costs. There are a total of 100 working hours and € 26,544 material costs on the D028 Transwrapper registered in 2022. This represents a total cost of ± €30,000.

1.2.5 Failure registration Tracking sheet

The failure data that is registered by the operator related to the monthly maintenance task on the seal jaw from section 4 is shown in Table 18. The data is used to demonstrate the impact of corrective maintenance.

Table 18 Failure registration related to the new monthly inspection task

Items inspected during task	Amount of registered failures	Sum waiting time technician (min.)	Sum mean downtime (min.)
Cabling attachment	1	5	240
Heating cable	3	117	540
Seal beam pattern	3	20	420
Temperature	10	431	2203
Total	**17**	**573**	**3403**

1.3 Downtime Events

Unplanned Downtime (UPD)

The unplanned downtime consists of breakdowns of the different machines, quality and general events. The different events that cause unplanned downtime are shown in Table 19. The operator of the production line will select the main event and underlying event in the registration tool.

Planned Downtime (PDT)

The planned downtime consists of checks, change over and similar activities. Similar to the unplanned downtime are different events that cause planned downtime listed in Table 19. The operator selects the main event and underlying event in the registration tool.

Table 19 Downtime Events (Events are in Dutch)

UPD / PDT	Asset – Main Event	Asset - Event
UPD	Algemeen	Algemeen-Calamiteit
		Algemeen-Onderbezetting
		Algemeen-Pauze
		Algemeen-Schoonmaak ongepland
		Algemeen-Storing FMES
		Algemeen-Wachten Expeditie
		Algemeen-Wachten monteur
UPD	Casepacker	Casepacker-Dozenkieper
		Casepacker-Dozentransport
		Casepacker-Oppakkop
		Casepacker-Smartrackbanden
		Casepacker-Stilstand onverklaarbaar (maak comment)
		Casepacker-Zakjestransport
UPD	D28 (IWS verpakken)	D28 (IWS verpakken)-unknown
UPD	Dozensluiter	Dozensluiter-Dekseltransport
		Dozensluiter-Dozentransport
		Dozensluiter-Lijmkop
		Dozensluiter-Oppakkop
		Dozensluiter-Stilstand onverklaarbaar (maak comment)
UPD	Dozenvouwer	Dozenvouwer-Dozentransport
		Dozenvouwer-Lijmkop
		Dozenvouwer-Oppakkop
		Dozenvouwer-Stilstand onverklaarbaar (maak comment)
UPD	Kwaliteit	Kwaliteit-Blokkade
		Kwaliteit-Deksels
		Kwaliteit-Dozen
		Kwaliteit-Folie
		Kwaliteit-Pallets
		Kwaliteit-Product
		Kwaliteit-Stickers
UPD	Labelaar	Labelaar-Aandrukrol
		Labelaar-Communicatie PC
		Labelaar-Dozentransport
		Labelaar-Stickertransport
		Labelaar-Stilstand onverklaarbaar (maak comment)

UPD	Metaaldetectie	Metaaldetectie-Metaal gedetecteerd
		Metaaldetectie-Storing metaaldetectie
UPD	Product / emballage	Product / emballage-Geen dozen
		Product / emballage-Geen folie
		Product / emballage-Geen product
UPD	Product aanvoer	Product aanvoer-Schudgoot
		Product aanvoer-Stilstand onverklaarbaar (maak comment)
		Product aanvoer-Takel
		Product aanvoer-Trilgoot
UPD	Snelheidsremmer	Snelheidsremmer-Handstapelen
		Snelheidsremmer-Kwaliteit emballage
		Snelheidsremmer-Onderbezetting
		Snelheidsremmer-Opstartproblemen
		Snelheidsremmer-Product aanvoer
		Snelheidsremmer-Vervuiling
		Snelheidsremmer-Weger
UPD	Stapelaar	Stapelaar-Dozentransport
		Stapelaar-Oppakkop
		Stapelaar-Stilstand onverklaarbaar (maak comment)
UPD	Transportbanden	Transportbanden-Invoerband casepacker
		Transportbanden-Invoerband dozensluiter
		Transportbanden-Invoerband stapelaar
		Transportbanden-Opvoerband
		Transportbanden-Rollenbaan bocht
		Transportbanden-Zakjestransportband
UPD	Verpakkingsmachine	Verpakkingsmachine-Bekken
		Verpakkingsmachine-Folietransport
		Verpakkingsmachine-Glijgoot
		Verpakkingsmachine-Langseal
		Verpakkingsmachine-Mes
		Verpakkingsmachine-Snarenband
		Verpakkingsmachine-Stilstand onverklaarbaar (maak comment)
		Verpakkingsmachine-Zakjescodering
UPD	Weger	Weger-Display
		Weger-Stilstand onverklaarbaar (maak comment)
		Weger-Toevoertriller
		Weger-Wegeronderdeel
UPD	Wissel	Wissel-Bigbag
PDT	Algemeen	Algemeen-AM_activiteiten
		Algemeen-Onderhoud gepland
		Algemeen-Opleiding
		Algemeen-Pitstop
		Algemeen-Weger / Timinghopper schoonmaken na trigger.
		Algemeen-Werkoverleg
PDT	Metaaldetectie	Metaaldetectie-Controle metaaldetectie
PDT	Ombouw	Ombouw-Folie
		Ombouw-Folie/doos.
		Ombouw-Folie/doos/formaat

		Ombouw-Folie/doos/product
		Ombouw-Folie/doos/product/formaat.
		Ombouw-Folie/doos/product/formaat/schoonmaak
		Ombouw-Folie/doos/product/sealbekken
		Ombouw-Folie/product
		Ombouw-leegdraaien
		Ombouw-Opstart week
		Ombouw-schoonmaak
PDT	Snelheidsremmer	Snelheidsremmer-Handstapelen
PDT	Wissel	Wissel-Folie
		Wissel-Printlint
		Wissel-Rekwikkelfolie
		Wissel-Stickers

2 Appendix – B – Intersnack Tools

2.1 Intersnack Work Systems - IWS

In this research, will Intersnack's standard operating procedures take into account, which are abbreviated as IWS (Intersnack Work Systems). IWS is a program designed to enhance capabilities through the use of standardized tools and systems aimed at eliminating losses, with the active involvement of all employees.

The Intersnack Work System is derived from the Integrated Work System. Its primary objective is to build organizational capability by continuously improving business performance, with a strong emphasis on employee engagement and the concept of zero losses. At Intersnack BV, IWS has proven to be a more effective approach for performance improvements compared to traditional Lean or TPM programs (Stevering, 2019).

A key structural component within the IWS "Program" is the support provided by pillars in the implementation of IWS. These pillars play a crucial role in supporting, guiding, and strengthening the process of change and improvement, ultimately striving for zero defects, zero losses, and achieving 100% employee engagement. The 12 pillars can be seen in Figure 39. The project is related to the pillars PM and AM. These pillars and tools are shortly explained in section 2.1.1 & 2.1.2.

Figure 39 Intersnack Work Systems - 12 Pillars

The different pillars and their tasks are shortly listed below:

- LDR, ensuring that Compelling Business Need CBN goal is realized, conductor of the IWS program
- FI, supports systematic elimination of losses
- **PM**, optimize machine park availability with reduction of maintenance costs
- ET, reduce losses caused by lack of knowledge and skills through effective training courses
- SN, optimize the supply process
- WPI, eliminate losses and prevent them in the future
- IM, implement all changes without losses
- Q, risk inventory and prevention. Problem solving
- HSE, lead to a culture of safety
- ENT, give direction to. Draw up Master Plan
- **AM**, bring machine park into basic condition
- ORG, support the organization

2.1.1 AM Pillar

The goal of Autonomous Maintenance is to develop well-trained production technicians and create reliable machines that are in basic condition. The combination of people and machines creates a workplace that is effective (zero losses/defects) and efficient (with the least amount of effort). The AM pillar has three tools (CIL, DH and CL) that are of high importance regarding the Basic conditions of the machines.

2.1.1.1 CIL

The goal of the CIL is Cleaning → Inspecting → finding and resolving defects → preventing Breakdowns. The goal is achieved by implementing "Clean-Inspect-Lubricate" standards for operations. Specific actions and frequencies for cleaning, inspection, and lubrication which operators use to keep the line in basic condition, thus extending machine uptime. An example of a CIL list for the Transwrapper is shown in Figure 40. On the top part of the picture is the input for the CIL shown. For each component are the inspection method, tools, actions, time, and frequency described. The input results in the CIL planning at the bottom of Figure 40.

D/S	Insp Punt	Component	Inspectie Standaard	Methode	Tool	Actie bij afwijking	Tijd (min)	Freq
S	0	zeef van schudgoot	vrij van vervuiling			Schoonmaken	2	D
S	1	Sealbekken	Schoon			Schoonmaken	2	D
S	2	Mes	Schoon en vrij van beschadigingen		8	Vervangen door schoon mes	5	D
S	3	Controle luchtuitdrijvers	Vrij van defecten			Vervangen van delen of ultimo maken	1	D
S	4	Kabels bekken	Schoon en vrij van beschadigingen			Schoonmaken, indien beschadigingen ultimobon maken	2	W
S	5	Langsnaad	Schoon en vrij van beschadigingen			Schoonmaken met vochtige doek	2	D
S	6	Vacuumbanden	Vrij van beschadigingen			Ultimobon maken	2	M
S	7	Bosch	Smeren EO + ML			Schoonmaken, inspecteren en smeren	10	M
S	8	Smartdate	Rollen vrij van inkt			Schoonmaken met Markem, printhead cleaning wipe.	5	D
S	9	Snarenband	Snaren aanwezig, vrij van vervuiling en geen speling			Schoonmaken met vochtige doek, indien speling of vermissing ultimobon maken	4	W
S	10	Spreiders	Vrij van scherpe randen en punt			Ultimobon maken en direct laten vervangen	2	W
S	11	Weegbandjes	Schoon en vrij van beschadigingen			Schoonmaken met vochtige doek	4	D

Insp Punt	Component	Tijd Geschat.	Freq	D/S	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0	Zeef van schudgoot	2	D	S	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢
1	Sealbekken	2	D	S	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢
2	Mes	5	D	S	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢
3	Controle luchtuitdrijvers	1	D	S	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢
4	Kabels bekken	2	W	S						◢							◢							◢							◢				
5	Langsnaad	2	D	S	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢
6	Vacuumbanden	2	M	S																													◢		
7	Bosch	10	M	S																													◢		
8	Smartdate	5	D	S	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢
9	Snarenband	4	W	S						◢							◢							◢							◢				
10	Spreiders	2	W	S						◢							◢							◢							◢				
11	Weegbandjes	4	D	S	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢	◢

Figure 40 Clean Inspect Lubricate list - Transwrapper

2.1.1.2 DH

The goal of Defect handling is to ensure that defects are found and fixed in a timely manner and that the production line is maintained in basic condition. A defect (or deviation) is any situation of a specific machine that is not as it was designed or intended. There are 7 types of defects classified:

1. Minor Defects
2. Lack of Basic Conditions
3. Hard To Reach Areas
4. Sources of Contamination
5. Quality Defect Sources
6. Unnecessary and Non – Urgent Items
7. Safety Defects

The different defects are registered in the defect handling list as shown in Figure 41. The operator will indicate the defect in the first columns.

DH Lijst D28

Volgnr.	Machine Onderdeel	Equipment Owner	Type defect	Omschrijving van het defect en / of probleem.	Verbonden aan CIL-taak	Naam operator	Reden	Datum gevonden	Prioriteit	Verantwoordelijk	Datum ingepland	Datum opgelost	Opgelost door Operator/ ML	Status	Ultimo Job nummer	Opmerkingen	Safety defect binnen 24 veiliggesteld	Bij stilstand
346	Verpakker		Mechanisch	de rollenbuizen waar de folie door heen gaat en begeleid wordt gaan ook regelmatig los zitten	Nee	andre k	Afwijking van de basis toestand	30.06.2023						Open				
358	Verpakker		Overig	de twee deuren gaan open met het starten die twee cil van de bekken komen tegen de deur	Nee	andre k	afwijking van de basis toestand	11.09.2023						Open	166134	eventueel gelijk nakijken		
363	Verpakker		Overig	de kabels van de bekken en langseal beginnen te slijten	Nee	andre k	afwijking van de basis toestand	14.09.2023						Open	166355	spoed		
365	Verpakker		Overig	Luchtuitdrijvers gescheurd van de pillow bekken voor	Nee	Valeriy	afwijking van de basis toestand	28.09.2023						Open	167111			
368	Verpakker		Overig	Kabelbehuizing kapot pillowbekken	Nee	Seda	Klein defect	25.10.2023						Open	168340			

Figure 41 Defect Handling list D28

2.1.1.3 CL

The goal of the CL is to reduce variation in daily results. Centerline is a system to manage optimal settings of all process parameters to deliver product at target (e.g. MTBF, MTTR, PR) with high quality. Process parameters can be divided into: fixed centerlines, centerlines with "range" and Control variables. An example of a CL sheet is shown in Figure 42. The operator will use the CL sheet to adjust the settings of the machine.

Bosch verpakmachine — Equipment Map (optional)

		Adjustment List								Centerline Setting				
		Nr.	Wanneer draaiend (D) / stilstaand (S)	Machine deel/plaats	foto's	afstelling aanduiding	OPL #	afleespunt (wijzer, display, lineaal enz.)	Meeteenheid (mm / cm / m etc)	501008 ICA Sour cream & — Target		Omgebouwd?	Binnen Centerling — Ja	Nee
										Min	Max			
2	1	2.1	D	Programma nummer		programma nummer		Display	Nummer	00002 ICA 150gr borrelnoten				
2	2	2.2	D	Formaatdelen		Kleur		Kleur	Vulbuis, aanslag en trechter.	Bruin				
2	3	2.3	D	Type bekken		Pillow bag / Euroloch		Job Instructie	Visueel	Euroloch				
2	4	2.4	D	Foliebaanrol t.h.v. Smartdate		Lineaal		Wijzer	Millimeter (mm)	190				
2	5	2.5	D	Positie Smartdate Links1		Waarde		Teller	Waarde	22				
										21.5	22.5			

Figure 42 Centerline Sheet Changeover Bosch

2.1.1.4 Equipment ranking

The equipment ranking is a tool within IWS that helps to grade the different machines on multiple categories to prioritize the machines. After grading the machines is a priority given to the machine. The grading card for the equipment ranking is shown in Figure 43.

EQUIPMENT RANKING CARD

Category	Te evalueren factoren	Evaluation score Reductie factor	Evaluation Criteria		max. score	Toelichting (vrije invulbaar)
SAFETY	Safety en milieu incidenten in geval van storing	1.00	10	Het brengt mensenlevens in gevaar	10	
			8	Impact op de menselijke gezondheid en de omgeving buiten de fabriek		
			6	Impact voor de veiligheid en de menselijke gezondheid in de fabriek		
			4	Waarschijnlijkheid van Impact is zeer laag		
			2	Geen impact		
QUALITY	Wat is de invloed van de equipment op de kwaliteit van het eindproduct?	1.00	10	Significante kwaliteitsincidenten (buiten de fabriek)	10	
			8	Kwaliteitsincidenten (binnen de fabriek)		
			6	Kwaliteitsfouten (binnen de afdeling)		
			4	Waarschijnlijkheid van kwaliteitsfalen is zeer laag		
			2	Geen impact		
PRODUCTIVITY	Hoe vaak wordt de equipment gebruikt?	1.00	5	23-24 hrs/dag	10	
			4	21-22 hrs/dag		
			3	19-20 hrs/dag		
			2	14-18 hrs/dag		
			1	10-14 hrs/dag		
	Invloed van de equipment op de operatie		5	Falen zou leiden tot algehele stillegging van de site		
			4	Het beïnvloedt het volgende proces		
			3	Het beïnvloedt de lijn (stop of snelheidsafname)		
			2	Het heeft alleen betrekking op die equipment		
			1	Een back-up equipment is beschikbaar, of het is zuiniger om te repareren na een storing		
DELIVERY	MTBF	1.00	5	MTBF < 60 min	10	
			4	MTBF 60 - 240 min		
			3	MTBF 240 - 480 min		
			2	MTBF 480 - 1000 min		
			1	MTBF > 1000 min		
	Gevolgen voor het serviceniveau / de klant		5	Producten kunnen niet worden geleverd aan onze klant		
			4	Grote verscheidenheid aan producten kan niet worden geleverd aan onze klant		
			3	Kleine verscheidenheid aan producten kan niet worden geleverd aan onze klant		
			2	Doorlooptijd naar de klant neemt toe, maar geen stop van de levering		
			1	Geen impact op de klant, een back-up machine beschikbaar		
COST	Uitgave Maintenance budget	0.50	2.5	> 1000 €/month	5	
			2	< 1000 €/month		
			1.5	< 400 €/month		
			1	< 200 €/month		
			0.5	Geen		
	Waarde gerelateerd aan het maandelijkse afval/materiaal verlies		2.5	> 1000 €/month		
			2	< 1000 €/month		
			1.5	< 400 €/month		
			1	< 200 €/month		
			0.5	Geen		

Figure 43 Equipment ranking card

2.1.2 PM Pillar

Progressive maintenance is the methodical and deliberate activity of building and continuously improving maintenance systems in order to:

- Maximize equipment availability
- Extend equipment technical life
- Eliminate breakdowns
- Reduce maintenance costs (Parts + Contract labor + Contract materials + Internal labor)

2.1.2.1 Combination AM and PM
Autonomous Maintenance and Progressive Maintenance will share responsibility for periodic checks of the equipment, preventing recurrence of failures, corrective maintenance -reliability items, and the development of conditioning monitoring.

Autonomous Maintenance will focus on Normal Operation of equipment, Daily Maintenance, and quick discovery of undesirable conditions. Progressive Maintenance will be responsible for Periodic Maintenance (Time Based maintenance), Predictive Maintenance (Condition Based Maintenance), and all the remaining Corrective Maintenance activities.

2.2 Information sources
There are different information sources used within this report. The different information sources are described below.

Information sources Intersnack
- Intersnack employees
  - Employees from whom the information will be obtained during the research are: Operators, Maintenance Lead, Process Lead, Technical Department, Production Manager, and Engineers.
- Ross (ERP system)
  - Production data, inventory management, financial data, supply chain information, quality control, and more to support manufacturing and business operations
- Ultimo (enterprise asset management system)
  - Information related to the management of assets and facilities, including data on asset maintenance schedules, work orders, inventory, asset history, and performance analytics.
- QlikView
  - QlikView stores a wide range of data, including information on production processes, inventory management, quality control, safety alerts, and key performance indicators related to safety, quality, and delivery.

External information sources
In addition to internal sources of information, external information will also be obtained. This is because not all information about the machines and their components is available or known at Intersnack. External service technicians and suppliers/manufacturers of the machines will be consulted to obtain this information. The machines in the production line and their associated companies will be further documented in the production line overview.

3 Appendix – C – Case study

3.1 Overview Maintenance key figures

A hierarchical system of maintenance performance indicators is presented in Figure 44. The overview reveals clear causalities between certain variables and key figures related to maintenance. These are used to indicate the impact of the case study at the end.

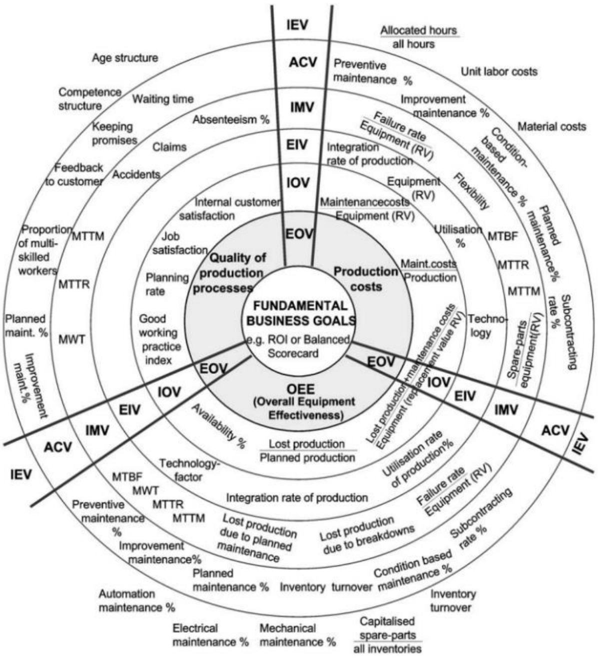


Figure 44 The sytem of key figures for industrial maintenance

3.2 Failure Mode Effects Analysis

"FMEA is a method of reliability analysis intended to identify failures, which have consequences affecting the functioning of a system within the limits of a given application, thus enabling priorities for action to be set" (Braaksma, 2012). To ensure the reliability of a machine, a systematic approach is necessary to identify the critical processes. The Failure Mode and Effects Analysis (FMEA) procedure provides this structured assessment. Three factors are taken into account when evaluating the failure: the severity; the probability of occurrence; and the likelihood of detecting the failure.

During an FMEA, participants assess the potential ways that a machine may fail to perform its intended function. The process starts by identifying the scope of the machine. Then, the analysis begins by identifying the different failure modes for each process step. A failure mode is anything that can go wrong or fail during the process. During the identification of failure modes, process experts brainstorm about anything that can fail within the identified scope.

For each failure mode, the experts identify the risk effect of the failure mode, which describes the impact on the product or process if the failure occurs. Then, the experts identify potential causes of the failure for each failure mode, and list any existing preventive controls that reduce the probability of the causes of the risks. Finally, experts evaluate the impact on the end user for every failure mode by estimating the probability and severity of a failure mode.

3.2.1.1 Failure Mode Effect Analyses – In detail

The input for the FMEA are the components functions. From the functions are the failure modes identified. The categories of failure modes are categorized into three main groups:

1. When capability falls below desired performance, in example due to:
    - Deterioration, all forms of “wear and tear” (fatigue, corrosion, abrasion, erosion, evaporation, degradation of insulation, etc.)
    - Lubrication failures, lack of lubrication or lubrication itself
    - Dirt, interference of function caused by blockage, stick or jam
    - Disassembly, components fall apart or come adrift
    - “Capability reducing” human errors
2. Increase in desired performance
    - Increase in stress causes deterioration
        - Sustained, deliberate overloading
        - Sustained, unintentional overloading
        - Sudden, unintentional overloading
        - Incorrect process material
3. Initial incapability
    - When the asset is not capable of doing what is wanted from the initial capability

The failure modes must be defined in enough detail for it to be possible to select a suitable failure management policy. The required detail level of the failure modes is to drill down until the right balance is found regarding the detail information and time required. The failure modes will then be rated on its occurrence, severity, and detectability.

Based on the criticality indexes from Table 20 can the failures be prioritized and identify those that exceed the predetermined criticality level.

Table 20 Risk Priority Number (RPN) - Criticality scale - Nuts Packaging

RPN - Criticality (C)		
Degree of criticality	**Value**	**Risk of Hazard**
Minor	0 - 30	Acceptable
Medium	31 - 60	Tolerable
High	61 - 180	
Very high	181- 252	Unacceptable
Critical	253 - 324	
Very critical	> 324	

3.2.2 Decision table maintenance policy

A decision table is a useful tool in reliability engineering and contributes to the systematic evaluation of technical feasibility in maintenance decisions. The decision table provides a systematic approach to guide maintenance strategies based on technical feasibility, ensuring a structured and informed decision-making process. The table is based on the RCM method (Moubray, Reliability-centred Maintenance, 2008).

Table 21 Decision table maintenance policy selection

…1	…2	…3	Technical feasibility criteria questions
Y			Is there a clear potential failure condition? What is it?

			What is the P-F interval? Is the interval long enough for action to be taken to avoid, eliminate or minimize the consequences of the failure? Is the P-F interval reasonably consistent? Is it practical to monitor the item at intervals less than the P-F interval?
N	Y		Is there an age at which there is a rapid increase in the conditional probability of failure? What is this age? Do most of the items survive to this age? Is it possible to restore the original resistance to failure of the item?
N	N	Y	Is there an age at which there is a rapid increase in the conditional probability of failure? What is this age? Do most of the items survive tot his age?
H4	**H5**	**S4**	**Default questions, <u>only when questions before where No</u>**
Y			Is it possible to do the task? Is it practical to do the task at the required frequency? Is it reducing the risk of the multiple failure to an acceptable level?
N N	Y N		Can the failure affect the safety or the environment? *If yes, **Design out maintenance is compulsory*** *If no, **Failure based maintenance (DOM may be desired)***
- -	- -	Y N	Is a combination of tasks technical feasible and worth doing? *Yes when a combination of two or more tasks will reduce the risk of the failure to an acceptable level, **apply the tasks*** *No, **Design out maintenance is compulsory***
- -	- -		The consequences of the failure are purely economic and no suitable preventive task has been found. Default decision is ***Failure based maintenance (DOM may be desired)***

3.2.3 Maintenance policy - Outsourcing

The maintenance policy that isn't included in the decision tree is outsourcing. Nevertheless, this might be a solution for some maintenance tasks. In this way can Intersnack better focus on their core activities, combined with outsourcing non-core activities. The advantages and disadvantages of outsourcing are:

Advantages:

- Personnel: Outsourcing transfers personnel training and management to service providers who are experts in the outsourced function. Service providers can leverage their experience with many clients to achieve world-class performance.
- Technology: Outsourcing grants access to state-of-the-art technology, reducing the risks associated with technology updating.
- Financial: Outsourcing can lead to a reduction in operating costs as defined costs are known in advance.

Disadvantages:

- Outsourcing is often not as beneficial as expected because of hidden costs, such as negotiation and contracting costs with the supplier.
- Outsourcing a business function can impact the workforce and may lead to social unrest.
- Loss of control and responsibility for adapting to new technologies now partly lies with the supplier, which can carry a risk and harm your business.

3.3 FMEA analysis Case study - Criticality analysis Seal Jaws

Detailed function description - Seal jaws

The seal jaws (1 and 6) close and clamp the tube film. Within the seal jaws, the welding jaw (2) is moved with a knife (9) to a fixed contra weld jaw (5) with silicone strips (8). The knife cuts through the tube film and successively welds the joints. After welding, the knife jaw (2) moves back and the joints are cooled with air (4). When the seal jaws open, the transverse seam should be able to support the product. The welding temperatures, the welding and cooling times, split pressure and cooling intensity are interdependent and must be adjusted by testing and error. The numbers correspond with the figure below.

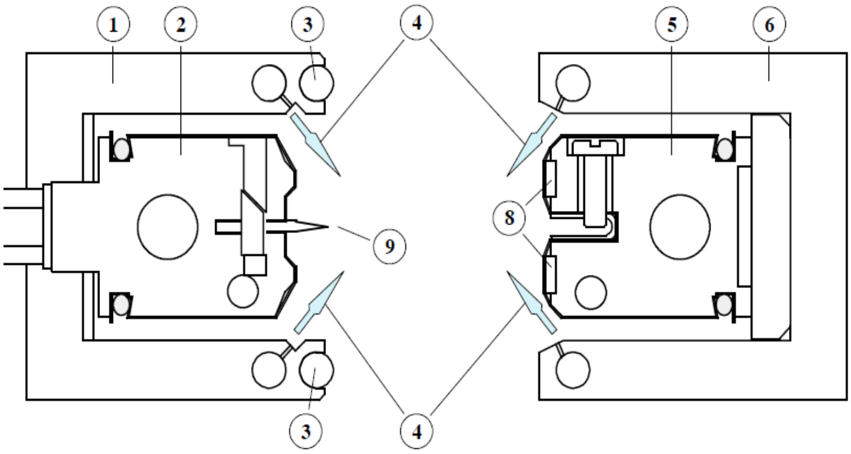


Figure 45 Detail view Seal Jaws

The seal jaw consists of more than 250 components. Therefore, the registered components that have failed are used for the analysis. The overview of these components is shown below.

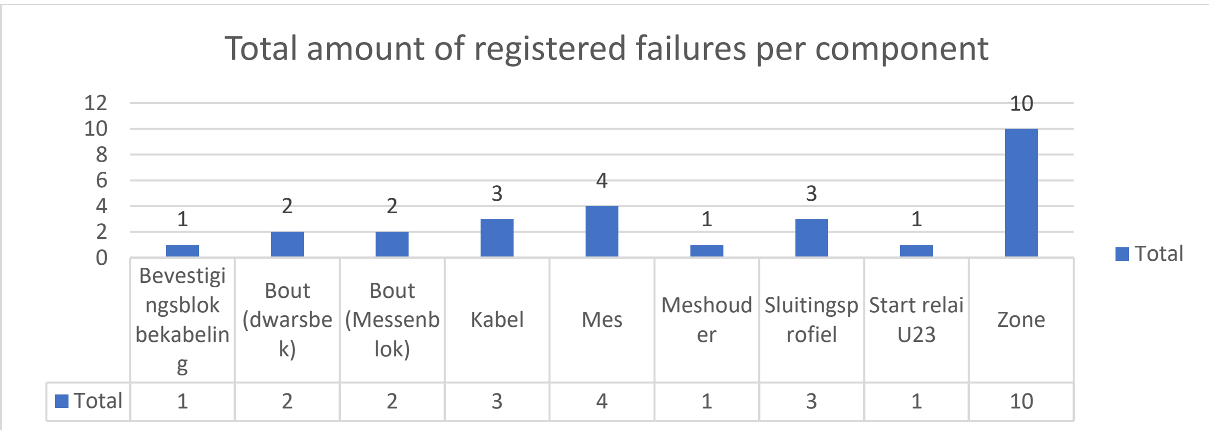


Figure 46 Registered failures manually

3.3.1 Film transport - information

The film transport is indicated as the second most critical machine assembly. The analysis of the FMEA is limited to the Seal Jaw due to the time limit of this research. The Film Transport can be analyzed after the Seal Jaws.

Critical assembly - Film transport

The film transport consisting of multiple assemblies. The main function of the film transport is to provide film for packing the products. The vacuum pull belts (7) transport the film at a (nearly) constant speed through a movable film web roll system (tension arm) (5), which temporarily compensates for speed differences between the pull belts (7) and the film wheel (6). The tension arm (6) maintains a constant film web tension and unwinds the film roll (6) to replenish stock film in the tension arm.

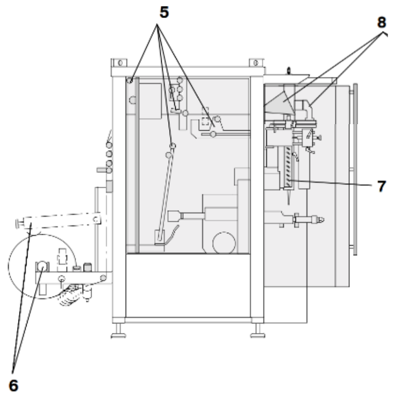


Figure 47 Film transport

Film transport – Film roll unwinder *6

The first assembly is the film roll unwinder. The film roll shaft with the film wheel on it is motor driven for unwinding the film wheel. The tension arm provides the film web tension and maintains a film supply capable of compensating for any speed differences between the pull belts and the film wheel.

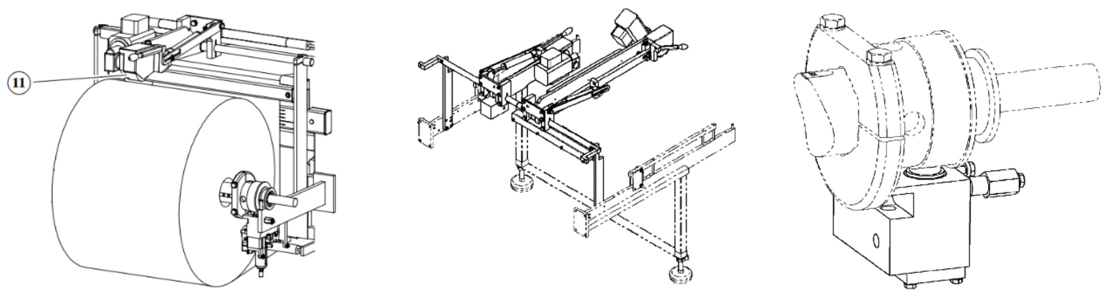


Figure 48 Film transport – Film wheel + Tension arm + Film roll brake (6)

Film transport - Movable film web roll system *5

The next assembly is the frame with multiple guiding rollers. The film is guided from the film wheel through the machine towards the filling pipe. The guiding roller function is to transport the film at a (nearly) constant speed through its movable film web roll system. This system compensates temporarily for speed differences.

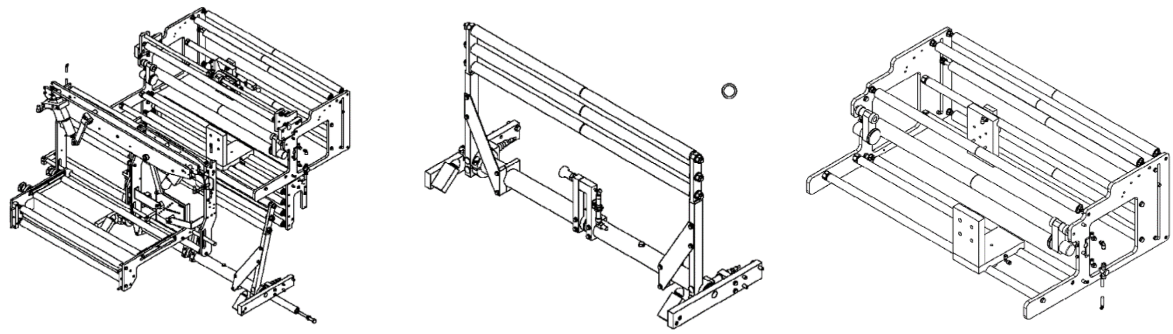


Figure 49 Movable film web roll system (5)

Film transport - Formset 8*

The following parts are part of the formset: Shoulder (1), Shoulder plate (2), Forming tube (3), and Mouth spreader (4). The shoulder forms a tube shape from the arriving film from the guiding rolls. Through the forming tube falls the product falls into the film and is then sealed with the seal jaws.

Film transport - Vacum pull bands 7*

A vacuum is created which sucks the film through the grooves of the pull belts in such a way that the film is pulled at an even speed from the pull belts. The pulling belts (4) pull the film along over a shoulder (2), thereby forming a vertical tubular film (3). A longitudinal seam jaw (3) closes this tubular film (5) vertically during film transport.

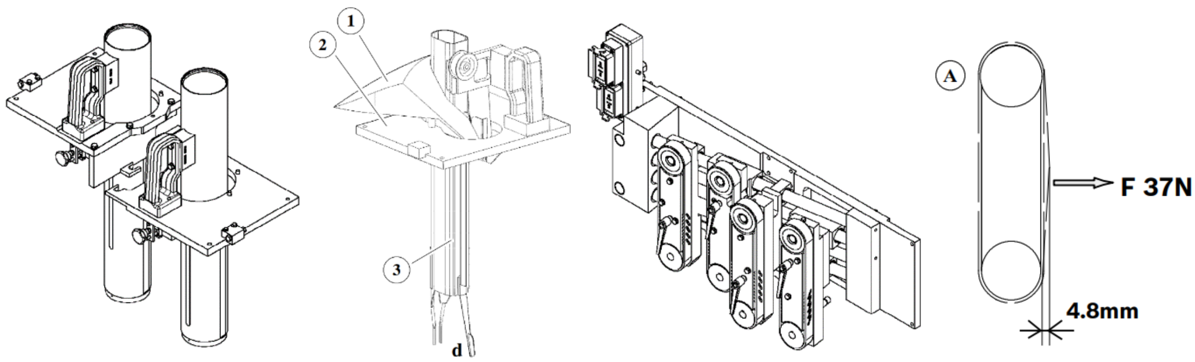


Figure 50 Formset (8) & Vacum pull bands (7)

3.3.2 Performed FMEA Seal Jaw

The performed FMEA analysis with the project team is shown below in the table. Where the registered failed parts are used as input for the analysis. The analysis is registered in Dutch.

Item	Function	Potential failure mode	Potential failure effects	Potential causes	SEV	OCC	DET	RPN
Mes	Scheid de gevulde zak met de volgende lege zak door deze door midden te snijden.	Bot mes	Niet of maar gedeeltelijk kunnen snijden, open scheuren van de zak	Gebruiksslijtage van het mes	2	9	4	72
				Vervuiling op het mes. Verschroeide folie doordat het mes te warm wordt waardoor folie blijft zitten.	2	9	4	72
				Vervuiling op het mes. Product raakt het mes door een verkeerde instelling betreft het sluiten	2	7	3	42
		Scheve / afgebroken tanden (mes)	Niet of maar gedeeltelijk kunnen snijden, open scheuren van de zak	Mes verkeerd bevestigd (bijvoorbeeld scheef) waardoor deze het sluitingsprofiel raakt.	2	7	5	70
				Mes verkeerd bevestigd (bijvoorbeeld scheef) doordat vervuiling in de bevestigingspunten zit	2	8	3	48
				Overbelast tijdens het snijden, ontbreken vrij doorgang mes in sluitingsprofielspleet, vervuiling	2	7	6	84
Meshouder/ blok	Het bevestigen/vastzetten van het mes	Los zittend mes	Niet of maar gedeeltelijk kunnen snijden, open scheuren van de zak	Dol gedraaid schroefdraad / bout	3	9	3	81
				Geen / slechte klemming door vervuiling	4	7	6	168
Sluitingsprofiel (Sealbek)	Warmte geleiden van de verwarmingselementen Het sluitingsprofiel wordt verhit om de zakken te dichten volgens het sluitingsprofiel	Beschadigingen op het sluitingingsprofiel (bramen)	Slechte sluiting / lekke zakken	Mes raakt het sluitingsprofiel	8	8	4	256
		Vervuiling (product / folie) op het sluitingsprofiel	Slechte sluiting / lekke zakken	Foutieve instelling (temperatuur, valtijd, bekkengevoeligheid), waardoor product tussen sluitingsprofiel kan komen of verkeerde temperatuur waardoor folie op het profiel schroeit	3	10	3	90
		Verkeerde uitlijning (scheef)	Slechte sluiting verhoogd de kans op lekke zakken	Vervuiling in het geleidingsgat waardoor de posititie bepalingspin niet kan kalibreren	5	5	7	175
				Te veel ruimte in het geleidingsgat waardoor de positie bepalingspin niet goed kan kalibreren	10	2	9	180
				Slijtage zelfinstellende lineair kogellager assen	5	3	8	120
Verwarmings element (Zone)	Het verwarmen van het sluitingsprofiel	Geen contstante temperatuur	Verkeerde temperatuur sluitingsprofiel. Slechte sluiting waardoor verhoogde kans op lekke zakken	Beperking van type verwarmingselement, het verwarmingselement kan de temperatuur niet constant houden (aan / uitzetten van vermogen)	4	9	2	72
				Contactpin voor temperatuur controle maakt geen contact	5	8	7	280
		Geen aansluiting / stroomtoevoer van het verwarmingselement	Verkeerde temperatuur sluitingsprofiel. Slechte sluiting waardoor verhoogde kans op lekke zakken	Draadbreuk	7	8	4	224
				Ontbreken bevestiging, Prikbout / pasta houdt het verwarmingselement niet vast. Verhitting zorgt voor degradatie bevestigingsmateriaal	7	7	4	196
				Amp kabel schoenen (aansluiting stroomkabel) zit los	7	6	4	168
				Defect start relai (In besturingskast start relais U23 ultimo: 161369)	7	6	5	210
PT100 Sensor	Temperatuur detecteren in het sluitingsprofiel	Electronische schade	Het niet correct kunnen bepalen van de temperatuur	Ontbreken aansluiting waardoor er geen signaal wordt ontvangen	5	9	4	180
		Kabelbreuk	Temperatuur niet kunnen detecteren / regelen (kortsluiting)	Beweging van de kabel zorgt voor frictie & spanning waardoor slijtage optreedt. De kabel wordt ingekort waardoor spanning ontstaat.	5	8	5	200
		Afbreken van de PT100	Verkeerde temperatuur	Slijtage trillingen --> Verkeerd gemonteerd, ontbreken instructie	7	7	5	245
		Veroudering	Temperatuur niet kunnen detecteren / regelen (kortsluiting)	Drift in weerstandswaarden, materiaalmoeheid	8	3	8	192
		Oververhit	Temperatuur niet kunnen detecteren / regelen (kortsluiting)	Overbelasting temperatuur vanuit verwarmingselement	7	6	5	210
				Pasta (geleidingspasta) ontbreekt / gebruiksslijtage	7	8	5	280

Figure 51 Case Study - FMEA execution Seal Jaw

3.3.3 Maintenance policy selection

The decision table above is used for the maintenance policy selection in the case study. The different answers that have been made with the project group are shown in the figure below.

Failure modes and effects analysis (FMEA)

Hoofd onderdeel	Item	Potential failure mode	Consequence evaluation: Hidden failure	Safety	Environmental	Operational	H1 S1 O1 N1	H2 S2 O2 N2	H3 S3 O3 N3	Default action: H4	H5	S4	Maintenance strategy
(Dwarsnaad) Bekkenhuis	Mes	Bot mes	N	N	N	Y	N	N	Y				Use based maintenance (UBM)
			N	N	N	Y	N	Y					Use based maintenance (UBM)
			N	N	N	Y	N	Y					Use based maintenance (UBM)
		Scheve / afgebroken tanden (mes)	N	N	N	Y	N	N	N				Design-out maintenance DOM, Poka Yoke + Werkinstructie
			N	N	N	Y	N	Y					Use based maintenance (UBM)
			N	N	N	Y	N	Y					Use based maintenance (UBM)
	Meshouder/ blok	Los zittend mes	Y				N	N	N	N	Y		Design-out maintenance (DOM)
			N	N	N	Y	N	Y					Use based maintenance (UBM)
	Sluitingsprofiel (Sealbek)	Beschadigingen op het sluitingsprofiel (bramen)	N	N	N	Y	N	N	Y				Use based maintenance (UBM)
		Vervuiling (product / folie) op het sluitingsprofiel	N	N	N	Y	N	N	N				FBM -> Design-out maintenance (DOM)
			N	N	N	Y	N	Y					Use based maintenance (UBM)
		Verkeerde uitlijning (scheef)	Y				N	N	N	Y			Detective based maintenance (DBM)
			Y				N	N	Y				Use based maintenance (UBM)
			Y				N	N	Y				Use based maintenance (UBM)
	Verwarmings element (Zone)	Geen contstante temperatuur	Y				N	N	N	N	N		FBM -> Design-out maintenance (DOM)
			N	N	N	Y	N	N	N				FBM -> Design-out maintenance (DOM)
			N	N	N	Y	N	Y					Use based maintenance (UBM)
		Geen aansluiting / stroomtoevoer van het verwarmingselement	N	N	N	Y	N	N	N				Use based maintenance (UBM) / Redesign
			N	N	N	Y	N	N	N				Use based maintenance (UBM) / Redesign
			N	N	N	Y	N	N	N				Use based maintenance (UBM) / Redesign
			Y				N	N	N	N			Failure Based Maintenance (FBM) / (UBM)
	PT100 Sensor	Electronische schade	N	N	N	Y	N	Y					Use based maintenance (UBM) / Redesign
		Kabelbreuk	N				N	N	N	Y			Detective Based Maintenance (DBM)
		Afbreken van de PT100	Y	N	N	Y	N	N	N	N			Desing-out maintenance (DOM)
		Veroudering	Y	N	N	Y	N	N	Y				Use Based Maintenance (UBM)
		Oververhit	Y	N	N	Y	N	N	N	N			Failure Based Maintenance (FBM) /
			N				N	N	N	Y			Detective Based Maintenance (DBM)

Figure 52 Case study - Maintenance policy selection

3.3.4 Maintenance task specification and impact unplanned downtime

The maintenance task is specified based on the maintenance policy. Furthermore, the impact of the task is indicated based on the registered mean time to repair of the component. The registered time required to repair the components, based on limited data, is indicated in the MTTR in the table below. Subsequently, the impact of the specific maintenance task has been determined. This impact is established based on the failure behavior in combination with the interval and assumptions made by the project team. The new registration method should help to better estimate the impact and monitor the effect. The main assumptions are:

- FBM has (very little to) no impact
- DOM largely mitigates the failure
- UBM impact is based on the interval with the corresponding failure percentage
- CBM impact is based on the corresponding failure percentage

Item	Potential failure mode	Potential causes	MTTR (UPDT)	Proposed task	Proposed task	% impact (estimation)	New MTTR
Mes	Bot mes	Gebruiksslijtage van het mes	42.5	UBM discard	UBM-taak vervangen messen. Controle conditie, verwijderen of reinigen. Instructie controle en reiniging	60	17
		Vervuiling op het mes. Verschroeide folie doordat het mes te warm wordt waardoor folie blijft zitten.	42.5	UBM restoration	Dagenlijks reiniging met staalborstel	80	8.5
		Vervuiling op het mes. Product raakt het mes door een verkeerde instelling betreft het sluiten	42.5	UBM restoration	Dagenlijks reiniging met staalborstel	80	8.5
	Scheve / afgebroken tanden (mes)	Mes verkeerd bevestigd en raakt sluitingsprofiel door vuilophoping aanslag achterkant	42.5	FBM	Reserve mes op voorraad / Redesign Poka Yoke principe + Werkinstructie	0	42.5
		Mes verkeerd bevestigd en raakt sluitingsprofiel door vuilophoping bevestigingspunten	42.5	UBM restoration	Inspectie bevestigingspunten mes op vervuiling en reiniging vervuiling	80	8.5
		Overbelast tijdens het snijden, ontbreken vrij doorgang mes in sluitingsprofielspleet, vervuiling	42.5	UBM restoration	Reiniging sluitingsprofiel spleet vervuiling hulpmiddel Hardinxveld mes + Half jaarlijkse reiniging volgens OEM instructie	80	8.5
Meshouder	Los zittend mes	Dol gedraaid schroefdraad / bout	120	FBM	Reserve bout op voorraad / Bevestiging met momentsleutel + werkinstructie	0	120
		Geen / slechte klemming door vervuiling in de houder	120	UBM restoration	Reinigen raakvlak mes	70	36
Sluitingsprofiel	Beschadigingen op het sluitingsprofiel (bramen)	Mes / Product raakt het sluitingsprofiel	140	UBM restoration	Pre-scale conditie sluitingsprofiel bepalen + Repareren	70	42
	Vervuiling (product / folie) op het sluitingsprofiel	Foutieve instelling (temperatuur, valtijd, bekkengevoeligheid), waardoor product tussen sluitingsprofiel kan komen of verkeerde temperatuur waardoor folie op het profiel schroeit	140	FBM	Werkinstructie + Instellingsbereik beperken (Min - Max)	80	28
			140	UBM restoration	Reiniging sluitingsprofiel met staalborstel	70	42
	Verkeerde uitlijning profielen	Vervuiling in het geleidingsgat waardoor de posititie bepalingspin niet kan kalibreren	140	DBM	Controle vervuiling en reiniging bepalingspin schuurspons	80	28
		Te veel ruimte in het geleidingsgat waardoor de positie bepalingspin niet goed kan kalibreren	140	DBM	Controle vervuiling en geleidingsgat tappen	80	28
		Slijtage zelfinstellende lineair kogellager assen	140	UBM discard	Vervangen van de lagers na 1 jaar	60	56
Verwarmings element (Zone)	Ontbreken contstante temperatuur	Beperking van type verwarmingselement, het verwarmingselement kan de temperatuur niet constant houden (aan / uitzetten van vermogen)	220	DOM	Nieuw verwarmingselement	100	0
		Temperatuurscontactpin maakt geen contact door het los raken hechting	220	DOM	Herontwerpen bevestiging verwarmingselement	100	0
	Ontbreken aansluiting / stroomtoevoert	Draadbreuk	220	DOM	Herontwerpen kabel	100	0
		Ontbreken bevestiging, prikbout / pasta houdt het verwarmingselement niet vast. Verhitting zorgt voor degradatie bevestigingsmateriaal	220	UBM restoration	Restoration pasta en prikbout bevestiging	70	66
		Amp kabel schoenen (aansluiting stroomkabel) zit los	220	UBM restoration	Restoration amp kabel schoen	70	66
		Defect start relai (In besturingskast start relais U23 ultimo: 161369)	220	FBM	Relais op voorraad	0	220
PT100 Sensor	Electronische schade	Ontbreken aansluiting waardoor er geen signaal wordt ontvangen	220	UBM restoration	Repareren van de bevestiging / Herontwerpen kabels en aansluitpunten	80	44
	Kabelbreuk	Beweging van de kabel zorgt voor frictie & spanning waardoor slijtage optreedt. De kabel wordt ingekort waardoor spanning ontstaat.	220	DBM	Inspecteren (en repareren) van de bevestiging	60	88
	Afbreken van de PT100	Slijtage PT100 trillingen	220	FBM	Herontwerpen aansluiting (Poka Yoke) + Montage instructie	0	220
	Veroudering	Drift in weerstandswaarden, materiaalmoeheid	220	UBM discard	Vervangen	80	44
	Oververhit	Overbelasting temperatuur vanuit verwarmingselement	220	FBM	Werkinstructie operator	0	220
		Pasta (geleidingspasta) ontbreekt gebruiksslijtage	220	DBM	Repareren geleidingspasta	60	88

Figure 53 Maintenance task Impact unplanned downtime

3.3.5 Maintenance task overview including the clusters

The different maintenance tasks that are constructed by the project team are shown in the figure below. The constructed tasks, recommended tasks from the OEM, CIL points, and Inspection tasks are used to create the maintenance plan for the Seal Jaw. For each task is indicated whether a task can be executed during or out of operation, the maintenance type, setup type, workload, interval, and required personal. The overview information is determined with the Maintenance Lead. The information is needed to correctly cluster the maintenance tasks. In the overview are the following criteria used regarding set-up and personnel:

Set-up type:
A = Machine off, no disassembly (5 minutes)
B = Machine off, expose electrical components (30 minutes)
C = Maintenance performed outside the machine but has first to be disassembled (30 minutes)
D = Major maintenance overhaul, address multiple components (60 minutes)

Personnel type:
1 = Operator
2 = Technician + Line Team
3 = Extern
4 = Technician + Operator

Clustering method

The clustering method is only needed for the preventive maintenance policies. Maintenance jobs are combined in a maintenance set executed at a fixed interval. Cluster jobs with (identical) same criteria (Interval, task execution during or out of operation, maintenance type, setup type, and required personal). The overview of the created maintenance clusters is shown in Figure 54.

Harmonizing maintenance intervals is the design phase in which a work package, a collection of maintenance tasks with the same interval, is prescribed. Then the maintenance work packages are grouped to fit into maintenance intervals that meet the interval conditions, where it is desirable to distribute the workload as evenly as possible. The result is a maintenance plan where the maintenance clusters are planned in time.

Onderhoudspunt	Taakomschrijving	Beschrijving	Workload (minutes)	Tijdens of Buiten Bedrijf	Setup type	Operation	Interval Production Hours	Personel type	Cluster
Mes	Vervangen / Reinigen	PM-taak wekenlijks vervangen messen. Laten reinigen en controle huidige staat, instructie om de messen te reinigen en controleren	240	TB	C	Repareren	160	2	C9
Mes	Inspectie + reiniging	Wekenlijks inspectie bevestigingspunten mes op vervuiling, reiniging vervuiling	10	BB	C	Reiniging	160	1	C8
Mes	Inspectie + reiniging	Wekenlijkse inspectie sluitingsprofiel spleet op vervuiling + eventuele reiniging vervuiling + Reiniging hulpmiddel tool Hardinxveld mes	10	BB	A / C	Reiniging	160	1	C7
Geleidingsassen dwarsnaad bekken	Smeren	Aanbrengen met borstel: Klübersynth UH 1 14-222 (standaard) Bell Ray HO-tox HD grease no. 2	10	BB	A	Smeren	160	2	C6
Smeerpunten dwarsnaad bekkenaandrijving	Smeren	Aanbrengen met spuitpistool: Bell Ray HO-tox HD grease no. 2	10	BB	A	Smeren	160	2	C6
Bosch	Smeren EO + ML	Schoonmaken, inspecteren en smeren	10	BB	A	Smeren	160	2	C6
Dwarsnaad bekken	Reinigen	Reinig de lagers en geleideassen met een droge doek.	5	BB	A	Reinigen	40	2	C5
Dwarsnaadmes	Controleer de snijfunctie	Vervang deze indien nodig	5	BB	A	Inspectie	40	2	C5
Kabels bekken	Schoon en vrij van beschadigingen	Schoonmaken, indien beschadigingen ultimobon maken	2	TB	A	Inspectie	40	1	C4
Het schroefdraad van de bekken, mes en mesruimte	Reinigen	Kleverige producten: Dwarsnaad schroefdraad, reinig de mesruimte en het mes met heet water en een niet-schurend reinigingsmiddel 2) 3). Indien nodig verwijdert u het mes (zie hoofdstuk 7) en reinigt u deze met heet water.	20	BB	C	Reinigen	8	2	C3
Dwarsnaad bekken	Reinigen	De bek kan heet zijn. Risico op letsel! Stofzuig de directe nabijheid van de bekken. Reinig het bereik van de bekken met een borstel/vochtige doek.	2	BB	A	Reinigen	8	2	C2
Het schroefdraad van de bekken, mes en mesruimte	Reinigen	Afborstelen met een koperdraadborstel die bij de levering is inbegrepen. Verschuif het mes naar de gesloten deuren met behulp van de knop Mes reinigen in het menuscherm "Productie" [1].	15	BB	A	Reinigen	8	2	C2
Sluitingsprofiel	Vervangen	Vervangen van de lagers na 1 jaar	960	BB	D	Repareren	5000	2	C15
PT-100	Vervangen	Drift in weerstandswaarden, materiaalmoeheid , Jaarlijks vervangen	120	BB	C	Repareren	5000	2	C14
PT-100	Inspectie + Vervangen	Kable spanning beweging, Repareren / Herontwerpen + Montage instructie	30	BB	C	Inspectie	500	1	C13
Elektrische componenten en kabel	Controleren op schade	*Schakel uit en vergrendel de hoofdschakelaar!	5	BB	B	Inspectie	500	2	C12
Hartingstekkers dwarsnaad incl. beschermslang	Controle hartingstekkers dwarsnaad incl. beschermslang	Inspectielijst	5	BB	B	Inspectie	500	2	C12
Mesblok	Inspectie + reiniging	Maandelijks reinigen bevestigingspunten mesblok	20	BB	C	Reiniging	500	2	C12
Sluitingsprofiel	Inspectie + reiniging	Vervuiling in het geleidingsgat, Inspectie + Reiniging, TAU	10	BB	C	Reiniging	500	2	C12
Sluitingsprofiel	Inspectie	Te veel ruimte in het geleidingsgat, Inspectie en eventueel blok vervangen	15	BB	C	Inspectie	500	2	C12
Verwarmingselement	Inspectie + Vervangen	Inspectie aansluiting contactpin	5	BB	C	Inspectie	500	2	C12
Verwarmingselement	Inspectie + Vervangen	Inspectie draadbreuk	5	BB	C	Inspectie	500	2	C12
Verwarmingselement	Inspectie + Vervangen	Inspectie bevestiging / Bevestiging verbeteren	5	BB	C	Inspectie	500	2	C12
Verwarmingselement	Inspectie + Vervangen	Inspectie amp kabel schoen / Bevestiging verbeteren	5	BB	C	Inspectie	500	2	C12
PT-100	Inspectie + Vervangen	Maandelijkse inspectie / Herontwerpen kabels en aansluitpunten met werkinstructie	10	BB	C	Inspectie	500	2	C12
PT-100	Inspectie + Repareren	Aansluiting geleidingspasta repareren / Herontwerpen aansluiting Poka Yoke + Montage instructie	15	BB	C	Inspectie	500	2	C12
Dwarsbekken	Controle dwarsbekken op werking	Inspectielijst	10	TB	A	Inspectie	500	2	C11
Mes	Controle mes op vervuiling	Inspectielijst	5	TB	A	Inspectie	500	2	C11
Cilinder mes	Controle cilinder van het mes op werking en lekkage	Inspectielijst	10	TB	A	Inspectie	500	2	C11
Smeerpunten verticaal dwarsnaad bekkenaandrijving	Smeren	Spuitpistool: Klübersynth UH 1 14-222 (standaard) HO-tox HD grease no.2	10	BB	A	Smeren	500	2	C10
Aandrijving dwarsnaad bekken	Controleer de bandspanning	Pas deze indien nodig aan	10	BB	A	Inspectie	500	2	C10
Lagerring dwarsbekken	Controle lagerring dwarsbekken op speling	Inspectielijst	10	BB	A	Inspectie	500	2	C10
Glijlagers dwarsbekken	Smeren van de glijlagers van de dwarsbekken	Inspectielijst	10	BB	A	Inspectie	500	2	C10
Sluitingsprofiel	Inspectie + reiniging	Inspectie (Pre-scale sluitingsprofiel) vervangen	60	BB	A	Inspectie	500	2	C10
Werkomgeving, machineonderdelen die in contact komen met het product, zoals de bovenzijde van de machine of de vormset	Reinigen	Stofzuig, verwijder het stof en afval van het product. Kleverige producten: Veeg, indien nodig, schoon met een vochtige doek en een niet schurend reinigingsmiddel (3). Drogen.	15	BB	A	Reinigen	8	1	C1
Sealbekken	Schoon	Schoonmaken	2	BB	A	Reinigen	8	1	C1
Mes	Schoon en vrij van beschadigingen	Vervangen door schoon mes	5	BB	A	Reinigen	8	1	C1
Controle luchtuitdrijvers	Vrij van defecten	Vervangen van delen of ultimo maken	1	BB	A	Inspectie	8	1	C1
Mes	Reiniging	CIL dagenlijks inspectie mes vervuiling, reiniging met staalborstel	5	BB	A	Reiniging	8	1	C1
Mes	Reiniging	CIL dagenlijks inspectie mes vervuiling, reiniging met staalborstel	5	BB	A	Reiniging	8	1	C1
Sluitingsprofiel	Inspectie + reiniging	CIL Inspectie + Reiniging, sluitingsprofiel met staalborstel schoonmaken	5	BB	A	Reiniging	8	1	C1

Figure 54 Case study - Maintenance task overview including created clusters

3.3.6 Maintenance interval based on the failure behavior

The failure behavior of the components is determined with a statistical method. The method that is used is descriptive and predicted with Weibull distribution. The interval in the examples is based on time but as earlier indicated can this be also another variable. The failure behavior is based on the different time between failures. In the analysis is the aspect (un-)censored data not included since the available data consists of the occurred failures due to the corrective maintenance.

Descriptive failure rate

First of all, the failure behavior can visually be inspected plotting the failures in time. A histogram helps to indicate the frequencies of a failure in time. Next, can the failure pattern, as shown in the figure below, be analyzed. The pattern helps to understand the failure behavior of the asset. The optimal interval can be determined. The interval can then be based on a predetermined (failure percentage) limit or when the average costs per time unit is optimal. An example of the failure behavior is shown below.

Table 22 Descriptive failure method case study

Interval	*Bin*	*Frequency*	**Fraction**
0	0	0	0
627.00	627	35	0.500
1254.00	1254	15	0.214
1881.00	1881	7	0.100
2508.00	2508	7	0.100
3135.00	3135	1	0.014
3762.00	3762	2	0.029
4389.00	4389	2	0.029
5016.00	5016	0	0.000
5643.00	5643	1	0.014
	More	0	

	Hours
Q1	296
Median	672
Q3	1406
Mean	1043
Min	32
Max	5270

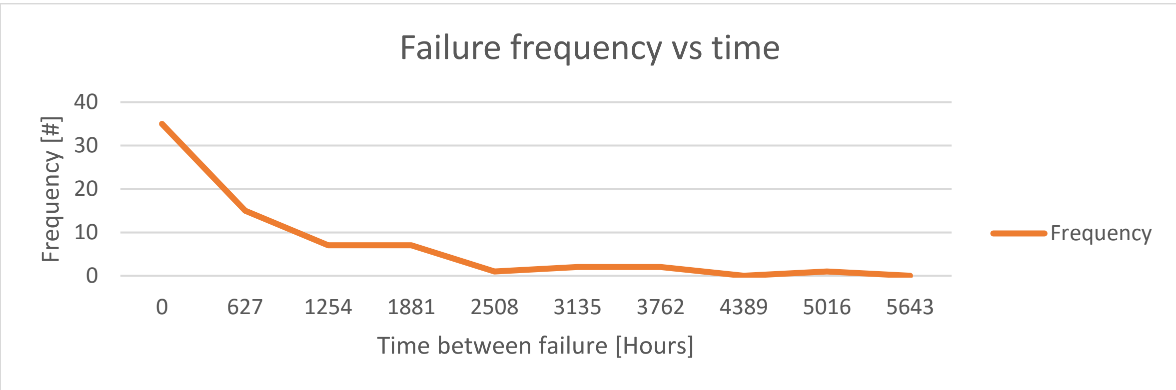


Figure 55 Failure frequency plotted in time

Weibull approach

The parameters of a Weibull probability distribution function that approximates the data is determined with the registered Time Between Failure (TBF) of a specific component. The TBF is extracted from the maintenance jobs in Ultimo. The jobs are sorted on reporting date. Next is the time between each reporting date determined by extracting the last reported with the newest as shown in Table 23.

Table 23 Example Time between failures Knife

Date	Time between failure [hours]
4-2-2024 23:29	1475:45:52
5-12-2023 11:43	490:16:35
15-11-2023 1:27	20:08:16
14-11-2023 5:18	151:46:40
7-11-2023 21:32	376:06:48
23-10-2023 5:25	81:11:03
19-10-2023 20:14	1189:09:44

The distribution of the TBF is shown in Figure 56. Which indicates that most failures occur in the interval of less than 578 hours.

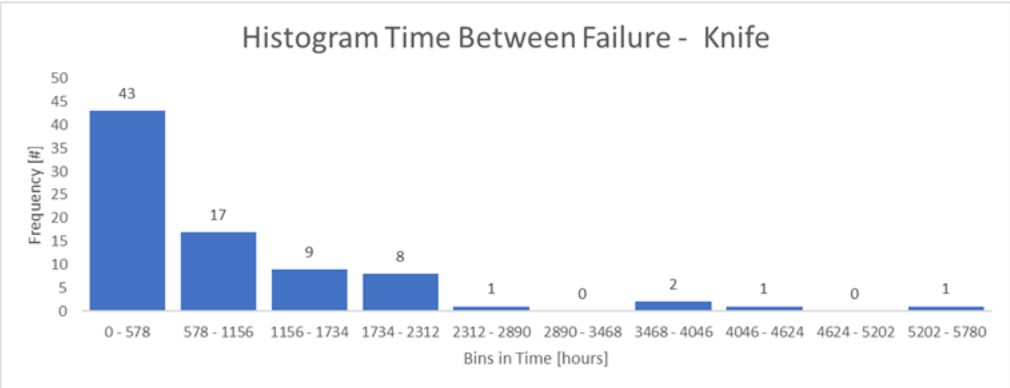


Figure 56 Distribution TBF Knife

The next step is to analyze the data to determine the distribution in order to optimize the maintenance interval. With making use of linear regression can the shape parameters ß and scale parameter η be determined. The Excel regression statistics function form the data analysis tool is used for this case. When the Betha is equal to 1 should the exponential distribution be used.

The Weibull distribution has the property: $\ln\left(\ln\frac{1}{\bar{F}(t)}\right) = \beta(\ln(t) - \ln(\eta))$. In order to check if the data shows a Weibull distribution (with no failure -free period) can the Weibull property formula be plotted and checked for linearity.

This can be checked by plotting the $\ln\left(\ln\frac{1}{\bar{F}(t)}\right)$ against the $\ln(t)$ equation in Excel. When the plotted data points are showing a linear pattern can be concluded that it is Weibull distributed. The function can be calculated as indicated in Table 24.

Table 24 Failure behavior Knife calculation

Rank	TTF [hours]	t	ln(t)	F(t)	R(t)=1-F(t)	Failure rate z(t)=f(t)/R(t)	ln(ln(1/(1-F(t)))
1	31.79	31.795	3.459309	0.006024	0.993975904	31.99	-5.108968152
2	62.26	62.26405	4.131384	0.018072	0.981927711	63.41	-4.004270565
3	66.48	66.48454	4.196969	0.03012	0.969879518	68.55	-3.487297137
4	81.18	81.18429	4.396722	0.042169	0.957831325	84.76	-3.144613187
5	83.05	83.0513	4.419458	0.054217	0.945783133	87.81	-2.887021682

As indicated should the plotted parameters show a linear distribution to conclude that the distribution is Weibull. On the right side of the figure is the distribution from the knife shown and can be concluded that the failure pattern is not according a Weibull distribution.

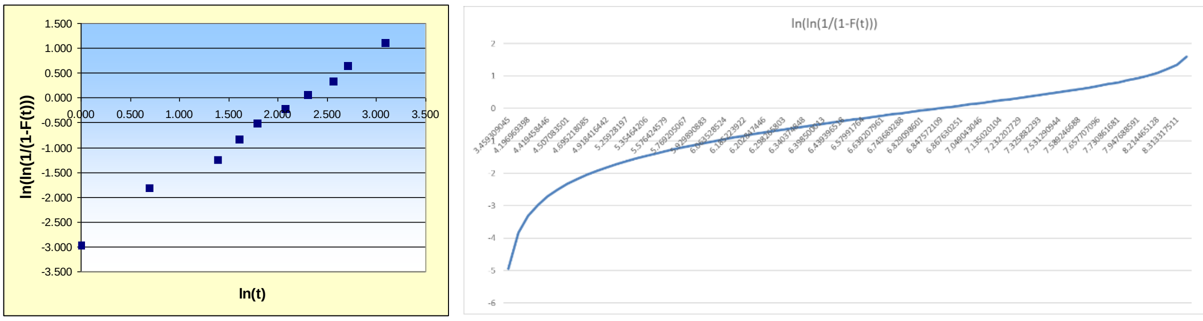


Figure 57 Distribution plotted- Example Weibull Failure pattern (left) - Failure pattern Knife (right)

When the data shows a linear function can be concluded that the distribution can be indicated with a Weibull distribution. The Weibull shape and scale parameters for the specific component can be determined with the regression data analysis. The shape parameter is equal to the X variable coefficient. The scale parameter is calculated with the function: $\eta = e^{-C/\beta}$ the C is the intercept from the regression analysis.

A statistical technique (Goodness-of-fit test from Winston) is used to check if the weibull probability distribution provides a realistic description of the failure behavior. The data showed this is not a correct fit since the chi-square distribution is larger than the chi-square test.

The used model is the Goodness-of-fit test (Winston) as described below:

- Define *k* number of bins: $k = \sqrt{n}$, n= number of observations
- Count O_i = the number of observations in interval I_i
- P_i = expected number of observations in interval I_i if each interval has equal probability mass: $n*[F(s_{i+1})-F(s_i)]$
- Test statistic: $Q_{k-1} = \sum_{i=1}^{k} \frac{(O_i - P_i)^2}{P_i}$
- H_0: "observations correspond to the distribution *F(t)*",
  - Q_{k-1} ~ Chi-square distribution with <u>*k-p-1* degrees of freedom</u> if $n \to \infty$,
  - *p* = number of parameters of *F(t)* estimated using the same observations

The result of the test is to reject the hypothesis "that observations correspond to the weibull distribution". The calculation is shown in Figure 58.

Bins	Interval		Oi =freq.	Pi	(Oi-Pi)^2	(Oi-Pi)^2/Pi
1	0.000	0.124	0	10.262	105.306	10.262
2	0.124	0.247	8	10.262	5.116	0.499
3	0.247	0.371	11	10.262	0.545	0.053
4	0.371	0.495	11	10.262	0.545	0.053
5	0.495	0.618	10	10.262	0.069	0.007
6	0.618	0.742	13	10.262	7.497	0.731
7	0.742	0.865	9	10.262	1.592	0.155
8	0.865	0.989	11	10.262	0.545	0.053
9	0.989	1.000	9	0.905	65.532	72.423
	1				0	
ChiSquareTest		Qk-1		Conclusion		
12.59158724		84.235		Reject hypothesis		*Since Qk-1>ChiINV

Figure 58 Goodness of fit test Knife

From the analysis of the failure data is the failure behavior with probability distribution function determined. In the case of the knife is the data not suitable for the method. Next can this information be used to determine the optimal maintenance interval. Using the probability distribution function estimating the parameters of the probability distribution function. The interval of the knife is therefore based on the experience of the project team combined with the data.

3.3.7 Recommended Maintenance Service interval OEM

The service interval for specific maintenance task is prescribed by the OEM. There is indicated which tasks to perform and when. These intervals are translated to the situation at Intersnack. The OEM prescribed the interval based on the operating hours of the machine. A few tasks that are recommended related to the Seal Jaws are shown in Figure 59. Some of these tasks are also included in the maintenance plan that is created in the case study.

Item	Onderhoudspunt	Taakomschrijving	Beschrijving	Serviceinterval *) 8	40	160	500	1.000	2.000	5.000	10.000	Personeel	Infopagina
Reiniging													
1.1	Werkomgeving, machineonderdelen die in contact komen met het product, zoals de bovenzijde van de machine of de vormset	Reinigen	Stofzuig, verwijder het stof en afval van het product. Kleverige producten: Veeg, indien nodig, schoon met een vochtige doek en een niet-schurend reinigingsmiddel (3). Drogen.	■								①	
Smeermiddel													
3	Smeerpunten verticaal dwarsnaad bekkenaandrijving	Smeren	Spuitpistool: Klübersynth UH 1 14-222 (standaard) HO-tox HD grease no.2				▲					②	"Verticale geleider van de dwarsnaad bekken" in dit hoofdstuk
Elektrisch													
5	Industrial-PC (IPC) - UPS	Vervangen van accu	De serviceinterval is afhankelijk van de temperatuur. Meet de temperatuur direct op de IPC	25 °C -> 4000 verbindingscycli of 6 jaar 35 °C -> 2000 verbindingscycli of 3 jaar 45 °C -> 1000 verbindingscycli of 6 maanden								②	Hoofdstuk 10
6	Elektrische componenten en kabel	Controleren op schade	⚠ Schakel uit en vergrendel de hoofdschakelaar!				●					②	
	1) Pas de periode aan afhankelijk van de mate van vervuiling en de huisregels	2) Water en/of reinigingsmiddelen mogen niet in aanraking komen met het elektrisch systeem	3) Met betrekking tot suikerhoudende producten, bijv.: "Biolube W 22 wateroplosbaar voor de suikerindustrie". (niet giftig, klasse USDA H1, producent: Molyduval)	■ = cleaning ● = controleren/vervangen ▲ = smeren								① = Bedieningspersoneel ② = Opgeleid personeel *) in bedrijfsuren	

Figure 59 Maintenance tasks interval OEM

Spare parts are essential components in maintenance operations, ensuring the continuous functioning of machinery and equipment. There are three classes in which spare parts are categorized according to the manufacturer:

A - Wear parts with a lifespan up to 2000 hours
B - Wear parts with a lifespan of 2000 – 4000 hours
C - Wear parts with a lifespan exceeding 4000 hours or parts that can be damaged

In the partlist is indicated which part needs to be replaced at a specific time. An example is shown below where the PT100 “Weerstandsthermometer” sensor is categorized as a C part and need replacement before 2000-4000 service hours.

Onder-deel Nr. Teil Nr.	**Pos. Nr. Pos. Nr.**	**Onderdeelbenaming**	**A B C**
0001	8-101-877-299	SEALBEK	
0002	8-101-845-045	HOUDER	
0003	8-101-845-046	HOUDER	
0004	8-101-851-230	AANSLUITKAST	
0005	8-101-851-231	AANSLUITKAST	
0006	8-101-847-132	AFSTANDSBUS	
0007	8-101-877-286	VERWARMINGSELEMENT	B
0008	8-101-304-517	WEERSTANDSTHERMOMETER	C

Figure 60 PT100 lifespan according manufacturer

4 Appendix – D - Maintenance job

In this section are the work instructions explained, condition based maintenance, and some of the failures visualized. Next are the created SOPs for the proposed maintenance tasks described.

4.1.1 Work instruction SIMPTWW

The work instruction should consist at least of the indication of the SIMPTWW aspects (Safety, Information, Materials, People, Tools, Where and When). An example of a work instruction is for the check on electric cables of the seal jaws.

Aspect	Details
Goal	Check wiring and connector of the seal jaws
Safety	Heat-resistant gloves, safety goggles, hearing protection
Information	Due to previous breakdowns, perform a semi-annual check to ensure the connectors and wiring of the seal jaws are still in good condition.
Material	N/A
People	Technical Service/Maintenance Lead
Tools	Allen key set and Phillips screwdriver
Where	Line D028
When	During pit stop. Once every 6 months.
Duration	20 minutes

4.1.2 Condition based maintenance analysis

Condition based maintenance measures and analysis asset performance. A variety of methods are used to assess the condition of systems and equipment to determine the most effective time to schedule and perform maintenance.

Within Intersnack are already different techniques used. For instance, infrared thermography is used to detect failures in the control boxes, electrical & pressure measuring devices are used to check functional failures, and oil sample are taken and send externally for analysis. Vibration and ultrasonic analyses are currently not used. The types of (high tech) condition based maintenance techniques are:

- Infrared Thermography:
  Utilizing a thermal imager, this method detects radiation emitted from equipment to monitor the mechanical and electrical conditions of motors, assess liquid levels, inspect refractory insulations, examine bearings, and more.

- Oil Analysis:
  A routine practice for assessing mechanical wear and tear, oil analysis examines the fluid properties of lubricants. It ensures that the right additives are present, viscosity is at optimal levels, and samples are free from contaminants.

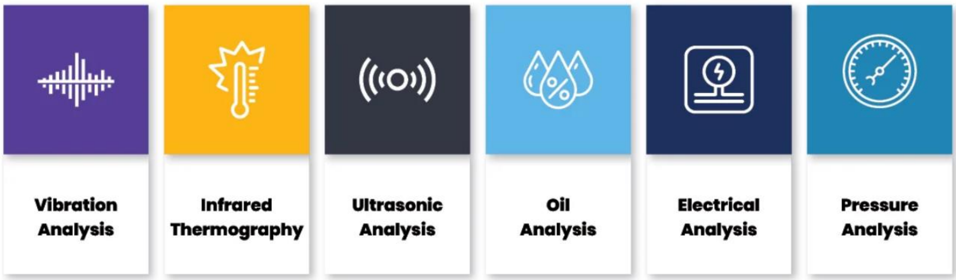
- Electrical Analysis:

To prevent electrical equipment failures caused by fluctuations in electricity supply, technicians use clamp-on ammeters to measure circuit current. Corrective measures are then taken to maintain a consistent flow of current.

- Pressure Analysis:
  Monitoring pressure is crucial in pipelines transporting air, fluid, or gas. Pressure analysis systems assist technicians in identifying fluctuations and maintaining stable pressure levels.

- Vibration Analysis:
  This technique gauges the levels of vibration in equipment to identify issues such as bearing failures, imbalances, bent shafts, resonance, and mechanical looseness.

- Ultrasonic Analysis:
  By utilizing ultrasonic sound frequencies, this analysis method identifies faults within equipment. It is applied as a contact method for pinpointing mechanical failures and as a non-contact method to detect pressure leaks in compressed gas systems.



4.2 Example maintenance task

The proposed monthly maintenance task consists of multiple PM jobs that need to be executed during this maintenance time slot. These tasks are determined during the creation of the maintenance plan. These tasks are clustered since they have the same interval and maintenance set-up. The seal jaw has to be removed outside of the machine to correctly perform the maintenance tasks. The standard operating procedure of removing the seal jaw is described in the Standard Operating Procedure Figure 63. The maintenance actions that need to be executed in are shown in Figure 61. There are several inspection points listed in the tasks. Each task is a short instruction included and if needed pictures for clarification.

PO-Model

In the PO-model are the different PO-jobs created. The PO-model is the cluster of the different maintenance tasks. The maintenance tasks are the PO Jobs.

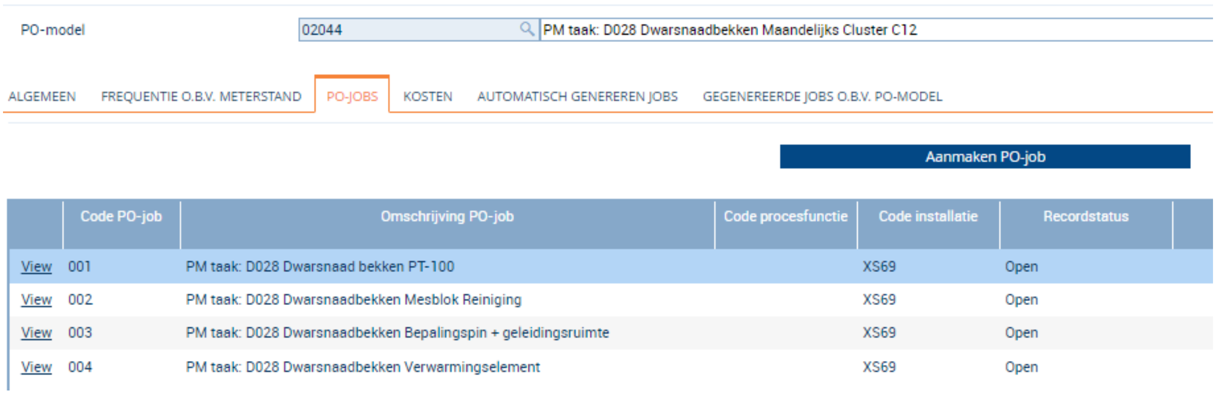


Figure 61 PO-Model Maintenance task

PO-Job

In the PO-job are the different fields (Figure 62) filled in to further specify the task. Depending on the specific maintenance tasks of the PO-job are the fields filled in. The important fields that should be filled in are:

- Work instruction: Clear and concise job description
    - Inspection point are indicated if needed
- Material – Description of the articles related to the task
- Executed by: who needs to execute the maintenance task
- Appendix: information files about the task/component

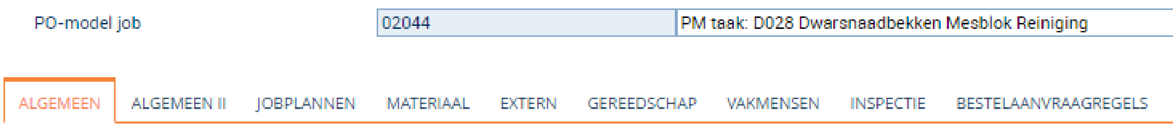


Figure 62 PO-job fields

WERK INSTRUCTIE		
SOP - Bekkenwissel		Intersnack
Datum vrijgave:	16-1-2024	
Versie:	1	
Document eigenaar:		
Document autorisator:		

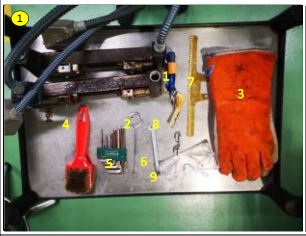
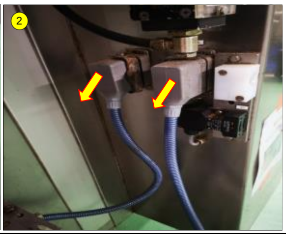
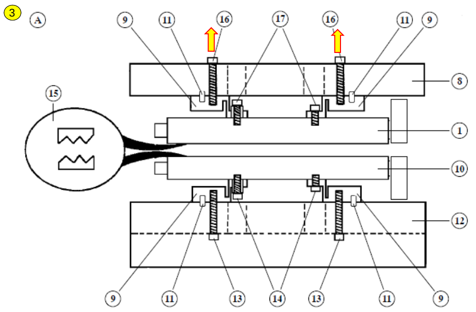
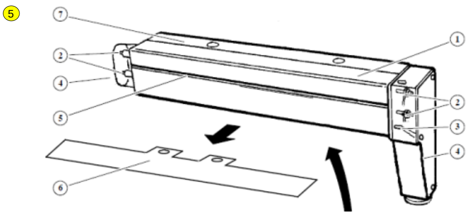
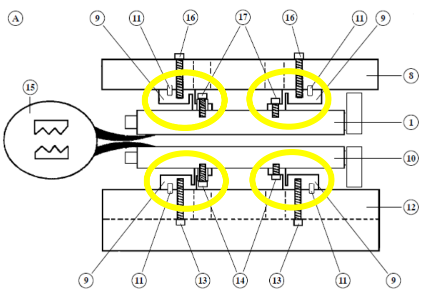
Nr.	Omschrijving	Foto's
1	Benodigde materialen: - Schoonmaaktang **(1&2)** - Handschoenen **(3)** - Kopere borstel **(4)** - Inbus set **(5)** - Steeksleutel 10 **(6)** - Schoone mes **(7)** - Meshouder blok **(8)** - Veiligheidsbril **(9)**	1  2 
2	Zet de machine stil, maak de stekkers los	
1	Benodigde materialen: - Schoonmaaktang (1&2) - Inbus set (3) - Vet (HACCP) (4)	  
	LET OP! Werk voorzichtig	**VOORZICHTIG** **Hete oppervlakken door hete machineonderdelen.** **De langsnaad bek(ken) en de dwarsnaad bekken kunnen warm zijn na het gebruik van de machine.** **Het aanraken van hete oppervlakken kan brandwonden veroorzaken.** ► Raak geen onderdelen aan die op bedrijfstemperatuur zijn. ► Draag veiligheidshandschoenen bij het verwerken van dergelijke onderdelen. ► Als de langsnaadarm is geopend, dient u speciale aandacht te besteden aan de linkerzijde van de hete langsnaad bek.
3	Verwijder het mes, zie de SOP voor de verwijdering van het mes.	3 
4	Verwijder de schroeven (16). **Let op: Bek kan vallen!**	
5		5 
	Verwijder de mesbek (1), samen met de geisoleerde blok(ken) (9)	
6	Verwijder de contrabek op de zelfde wijze als stap 4 en 5	6
6	Plaats van dwarsnaad bekken in omgekeerde volgorde. **Bepalingspin (/pluggen) (11) bepalen de positie van het bekkenhuis.**	6

Figure 63 SOP - Removal of the Seal Jaw

4.2.1 SOP - Knife replacement

WERK INSTRUCTIE		Intersnack
SOP - Meswissel		
Datum vrijgave:	16-1-2024	
Versie:	1	
Document eigenaar:		
Document autorisator:		

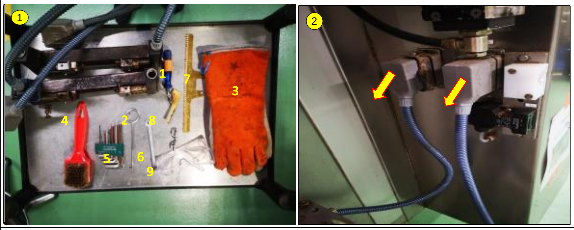
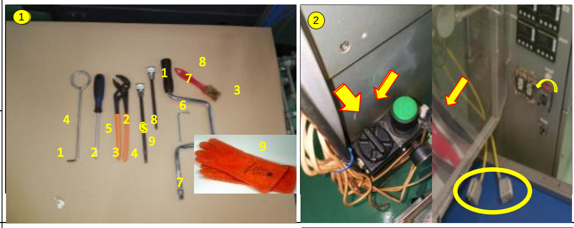
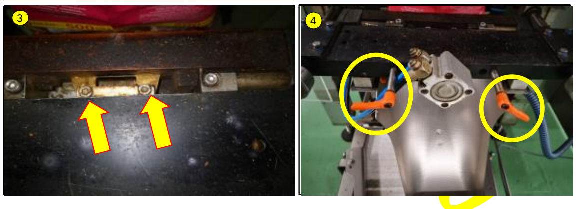
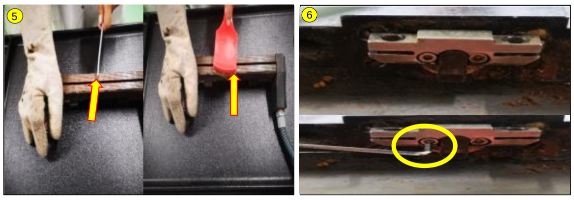
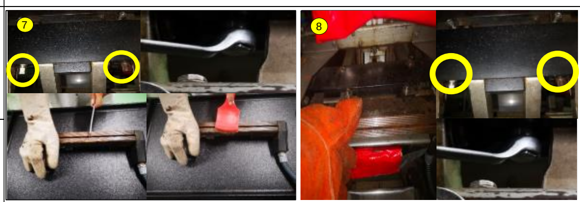
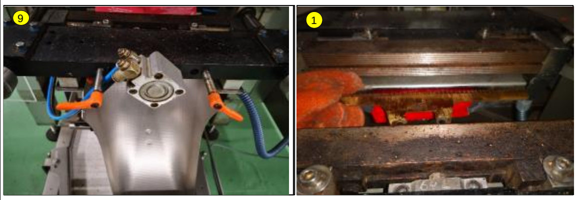
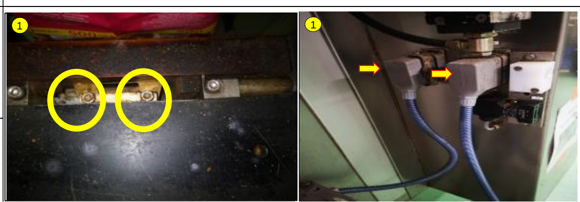
Nr.	Omschrijving	Foto's
1	Benodigde materialen: - Schoonmaaktang **(1&2)** - Handschoenen **(3)** - Kopere borstel **(4)** - Inbus set **(5)** - Steeksleutel 10 **(6)** - Schoone mes **(7)** - Meshouder blok **(8)** - Veiligheidsbril **(9)**	
2	Zet de machine stil, maak de stekkers los	
1	Benodigde materialen: - Schoonmaaktang **(1&2)** - Handschoenen **(3)** - Kopere borstel **(4)** - Inbus set **(5)** - Steeksleutel 10 **(6)** - Schoone mes **(7)**	
2	Zet de machine stil, maak de stekkers los	
3	draai de twee inbussen van het mes los en haal het mes eruit.	
4	draai de knevels los en maak de mesbek los	
5	maak de bekken schoon (als de bekken warm zijn worden ze beter schoon).	
6	met inbus sleutel 3 wissel de meshouder blok.	
7	maak de tegen bek met een steek/ringsleutel 10 los en maak de bek schoon.	
8	plaats de tegenbek op zijn plaats en met behulp van sleutel 10 maak hem vast.	
9	Plaats de mesbek op zijn plaats en met behulp van knevels maak hem vast.	
1	Monteer het schone mes terug op de houder.	
1	zet het met met behulp van inbussleutel vast.	
1	stekkers mogen weer er in.	

Figure 64 SOP - Knife replacement

4.3 Ultimo Maintenance job

4.3.1 Creating Maintenance job

The practical actions to implemented the maintenance jobs in Ultimo are described in this section. At the component process function level (or installation level), a PO model for inspection and a PO model for preventive maintenance can be created. PO model jobs are linked to both PO models, these PO model jobs are standard work lists that can be modified after each inspection or maintenance event to improve the work the next time.

The maintenance jobs are included into workable packages. The workable packages are created with the option PO-model jobs. Using PO models and their associated maintenance jobs, Ultimo can show which periodic maintenance jobs need to take place within a given period. From this list, preventive maintenance can be planned and finalized.

The important actions that need to be included in the periodical maintenance job are:

- Name of the PM tasks: PM job-"Process Function"-"Part"-"Specific task ……"
- Execution Date: Specify the day and week for time-based execution, considering the date when scheduling occurs post-PO job generation at Intersnack.
- Frequency: Define the number of times maintenance occurs per day, week, month, or year.
- Weeks-based Maintenance: Perform maintenance according to weeks listed in the table.
- Dynamic Scheduling: Uncheck to schedule maintenance based on the original date; if checked, the next maintenance considers the execution date.
- Last Maintenance: Enter the date of the last similar maintenance for accurate job generation.
- Subject Group: Choose Technical Services (default) or IWS subject group if the team performs the task.
- Maintenance Job Type: Select Periodic/Preventive Maintenance or Inspection/Condition Monitoring. Depending on the selected maintenance policy.

The actions to perform before implementing the maintenance task in the system are:

- Include the documentation
  - For instance, pictures and drawings of the parts
- Include the maintenance job instruction, format examples are:
  - SOP & OPL
  - SIMTWOOD
  - Detailed task description

4.3.2 Harmonizing maintenance jobs

The asset planner provides a graphical overview of all planned maintenance activities. This allows the maintenance department to align activities with the production schedule. With the asset planner is it possible to get an overview of asset availability and the maintenance to be performed. This enables quick visual insights into staff and activity scheduling. The schedules can also be filled in per employee using a graphical planner, enhancing clarity and ease of use.

The maintenance jobs are planned using the graphical overview of periodic maintenance activities in Ultimo. A short overview of the actions to perform to create the plan the tasks is described below:

1. Select date range
2. Select location
3. Choose type of PO tasks
4. Select whether to automatically generate PO (selection necessary for a graphical annual overview)
5. Optionally, choose selection regarding Department(s)
6. Select Job Types
7. Optionally, choose selection regarding Process Function
8. Click on the "Search PO Models" button (date range)
9. Graphical overview of selected PO models

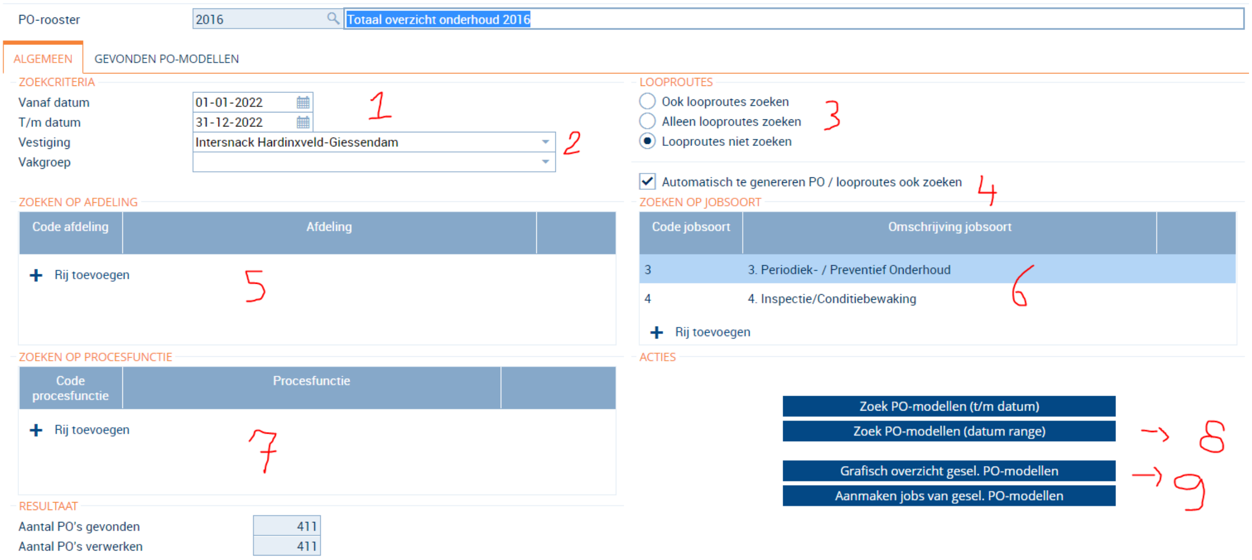


Figure 65 Steps in Ultimo PO model

In the graphical overview can a selection be made on year, quartal, and month. The overview helps to determine the workload in a specific period. The Maintenance Lead and Preventive Maintenance Coordinator need to schedule the tasks. In the overview are the maintenance clusters shown. When pressing a cluster are all the specific maintenance tasks shown.

Figure 66 Example Maintenance job overview Ultimo

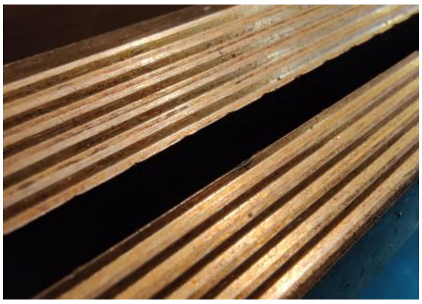
4.3.1 Failure examples of the Seal Jaws components

Multiple failures op parts of the seal jaws are indicated in this section. Indicating some of the failure modes that occurred during the time period.

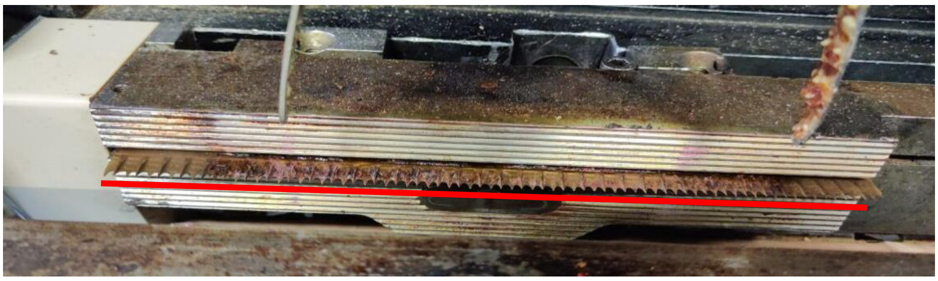
Dirt accumulated on the cutting knife

Bended knives

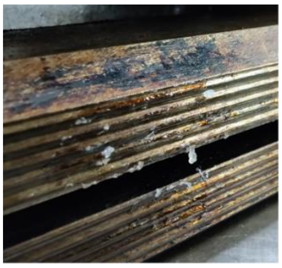
Due to hitting the seal beam (left) or hitting accumulated dirt in the free space (right).

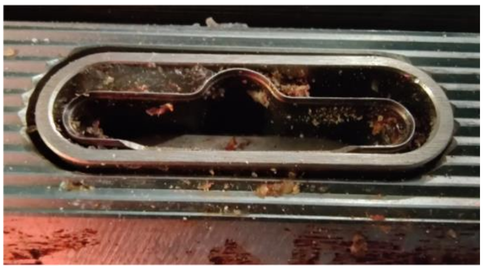


Knives angled wrong unevenly from the seal beam.



Dirt accumaltion (seal pattern beam and euroloch cutter)



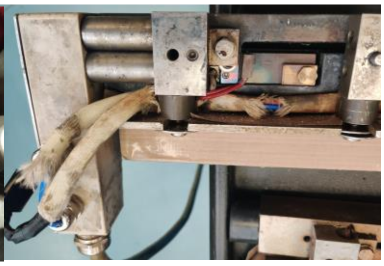


Bolts

Wrong bolts are used


Thread on the bolt is gone

Electronical cable failures


Missing cover protection