POLITECNICO MILANO 1863

SCUOLA DI INGEGNERIA INDUSTRIALE E DELL'INFORMAZIONE

Integrating Smart Maintenance Analysis in Luxury Printing Factory

TESI DI LAUREA MAGISTRALE IN SCUOLA DI INGEGNERIA INDUSTRIALE E DELL'INFORMAZIONE

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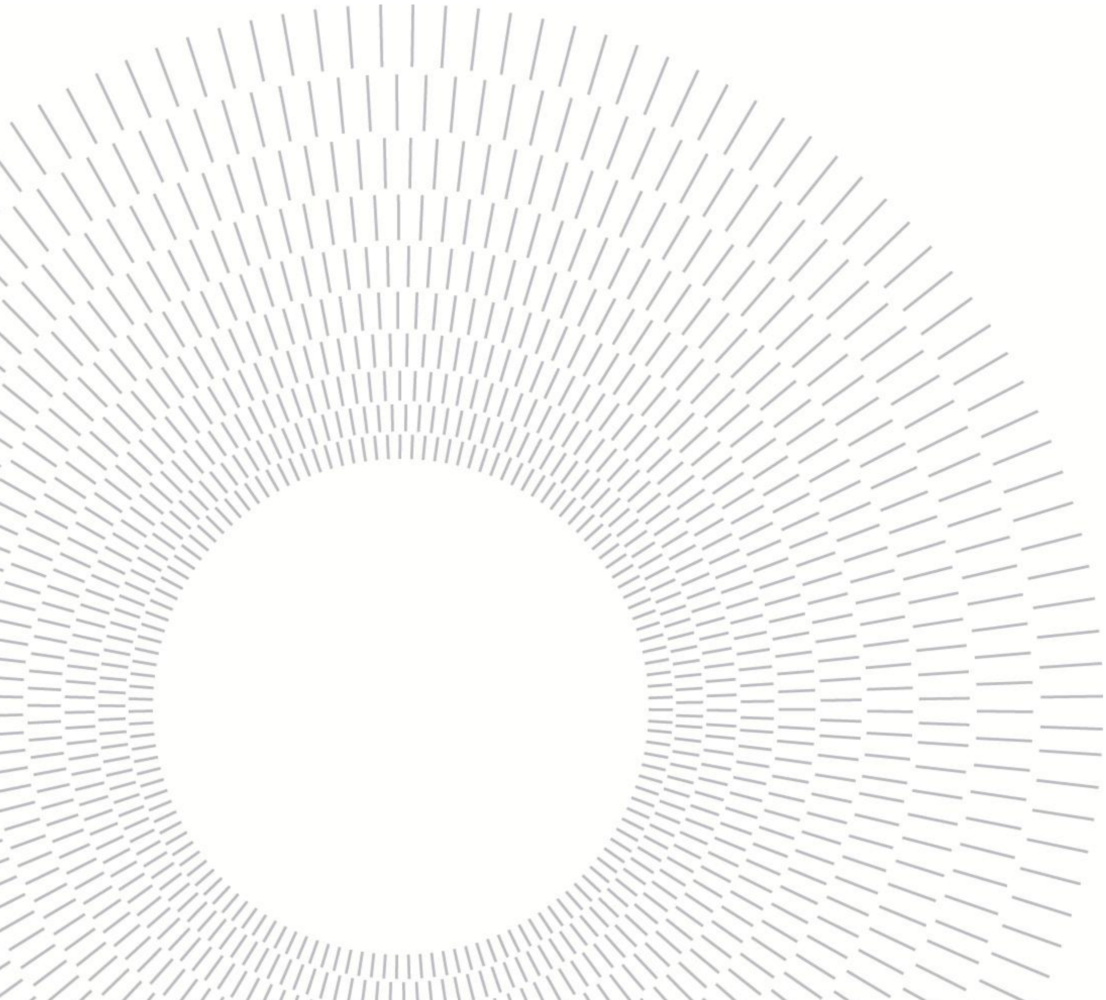
Academic Year:	2023-24



Abstract

Creation of this master thesis was done as a student internship for Industrial Management Laboratory. The experience was done in partnership with both Politecnico di Milano and Gpack S.p.A. company, and the work was done on site in a production plant in Truccazzano, Italy.

The project focused on improving the Availability of the key department named OFFSET, by utilizing lean tools such as 5s and Condition based maintenance. The Tools were selected after thorough literature review of similar ideas and concepts. The problem solving was organized utilizing the A3 methodology, in which the problem was first analyzed from a broad perspective then broken down, after which goals were selected. The countermeasures were developed and implemented and evaluated to see results. The specific goals were discussed with the company, and countermeasures were developed only after the stakeholders agreed on all semantics and saw the vision of the project. The data and results were both analyzed through specific Key Performance Indicators selected by the company, in this case the KPI were the industry standard Overall Equipment Effectiveness with main components of Availability, Performance and Quality.

The aim of the thesis was to provide the company with relevant ideas and roadworks to future decision making by utilizing mainly lean methodologies. Their current concepts were updated and specifically applied to bottleneck departments. The process was standardized for further use. While the limitations of the project were immense, mainly through financial means, future possible improvements were recommended when financial constraints were no longer an issue.

Keywords: Lean thinking, Condition-Based Maintenance, 5S, luxury printing, predictive maintenance, preventive maintenance

Abstract in lingua italiana

La creazione di questa tesi di master è stata effettuata durante uno stage studentesco presso il Laboratorio di Gestione Industriale. L'esperienza è stata svolta in collaborazione sia con il Politecnico di Milano che con la società Gpack S.p.A., e il lavoro è stato svolto in loco in uno stabilimento produttivo a Truccazzano, in Italia.

Il progetto si è concentrato sul miglioramento della disponibilità del reparto chiave denominato OFFSET, utilizzando strumenti snelli come 5s e manutenzione basata sulle condizioni. Gli strumenti sono stati selezionati dopo un'analisi approfondita della letteratura su idee e concetti simili. La risoluzione del problema è stata organizzata utilizzando la metodologia A3, in cui il problema è stato prima analizzato da una prospettiva ampia e poi scomposto, dopodiché sono stati selezionati gli obiettivi. Le contromisure sono state sviluppate, implementate e valutate per vedere i risultati finali. Gli obiettivi specifici sono stati discussi con l'azienda e le contromisure sono state sviluppate solo dopo che le parti interessate hanno concordato tutta la semantica e hanno visto la visione del progetto. I dati e i risultati sono stati entrambi analizzati attraverso specifici indicatori chiave di prestazione selezionati dall'azienda, in questo caso i KPI erano l'efficacia complessiva delle apparecchiature standard del settore con le componenti principali di disponibilità, prestazioni e qualità.

Lo scopo della tesi era fornire all'azienda idee e lavori rilevanti per il futuro processo decisionale utilizzando principalmente metodologie snelle. I loro concetti attuali sono stati aggiornati e applicati specificamente ai reparti con colli di bottiglia. Il processo è stato standardizzato per un ulteriore utilizzo. Sebbene i limiti del progetto fossero immensi, soprattutto in termini di mezzi finanziari, sono stati raccomandati possibili miglioramenti futuri quando i vincoli finanziari non fossero più un problema.

Parole chiave: Lean thinking, Condition-Based Maintenance, 5S, luxury printing, predictive maintenance, preventive maintenance

Contents

Executive Summary

Company Summary

Gpack Group S.p.A is an Italian manufacturing company founded in 1994. The company has 5 main production plants, the main being Vailate and Truccazzano. The core business of GPack is packaging solutions, mainly general, luxury and displays. The company has had a steady growth and is currently among industry leaders in packaging in Italy. The luxury sector can be seen as a recent company market focus, and the production can be classified as Engineering to order as clients in this market are quite strict and have unique requirements. The company has been giving significant importance to continuous improvement as of late and the Key Performance Indicators they use are Overall Equipment effectiveness.

Thesis Aim and Structure

Gpack S.p.A. is looking to foster continuous improvements culture, and one of their goals was to research the latest information in Industrial Engineering. In their mind partnering with Politecnico di Milano was the best option as this institution has a reputable Lean technologies department. In my work in Gpack, I was tasked with assisting the company in the Lean transformation. Main countermeasures that are present in the thesis are 5s and Open System Architecture for Condition-Based Maintenance. The utilization of these ideas allowed for continuous improvement and fulfillment of company goals.

Thesis is Structured in five chapters, firstly Introduction is for reader to get the idea of the setting and why the thesis is written. Introduction is followed by Literature review, which allows for background knowledge of the tools used. The methodology chapter explains the order in which main aspects of thesis were done in. The main chapter and most important is the Case Study. In this chapter the problem was tackled using A3 problem solving technique. Last chapter is the Conclusion and Limitations, where the final thoughts are expressed.

Thesis questions:

1. How do lean principles, mainly 5s and Condition Based Maintenance impact Availability segment of Overall Equipment Effectiveness and general organization of the company?

2.Is it possible to implement continuous improvement to make company better even after the project?

Literature Review

Literature review was done to gain theoretical knowledge of the main aspect of the thesis. Scientific papers were researched on Google Scholar by using a systematic literature review technology developed by Xiao and Watson in 2019. Key Points can be summarized as:

- Failure Modes, Effects, and Criticality Analysis also known as FMECA is strong root cause analysis tool which find failure modes and ranks them based on three factors: severity, occurrence and criticality. The methodology builds on the previous Failure mode and Effects (FMEA) in which it improves safety and efficiency by adding criticality aspect as seen in the Figure EX1.

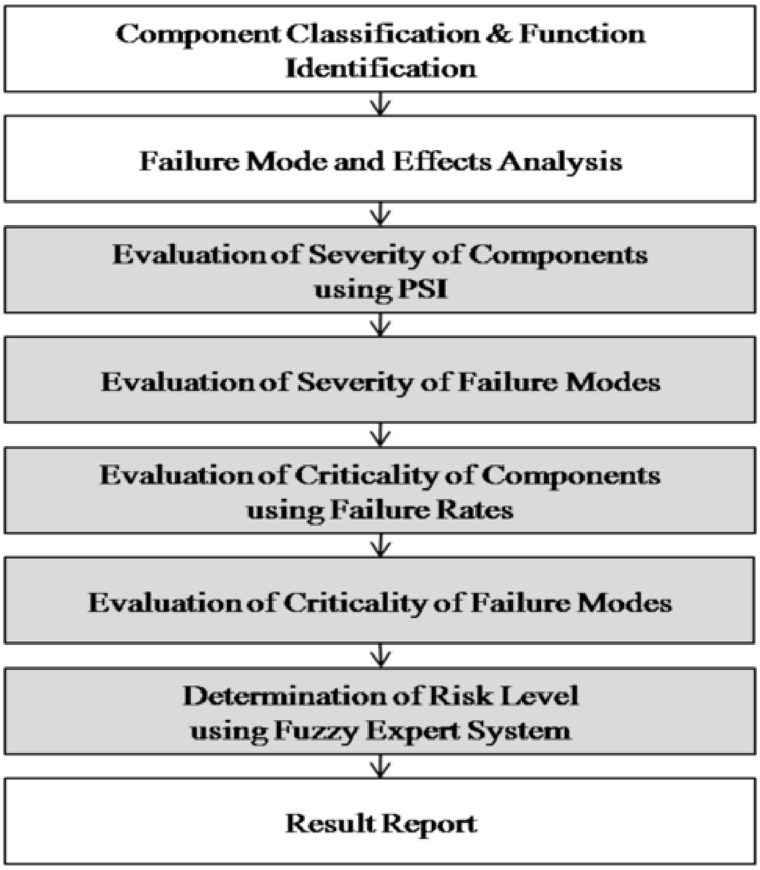


Figure EX 1: FMECA Roadmap used. (Lee et al., 2011)

- 5s is a lean tool originated from Japan, it is a key tool for continuous improvement and aims at improving the workplace, efficiency and productivity. Figure EX 2 shows how 5s interact and how it's continuous improvement as told by Mikva.

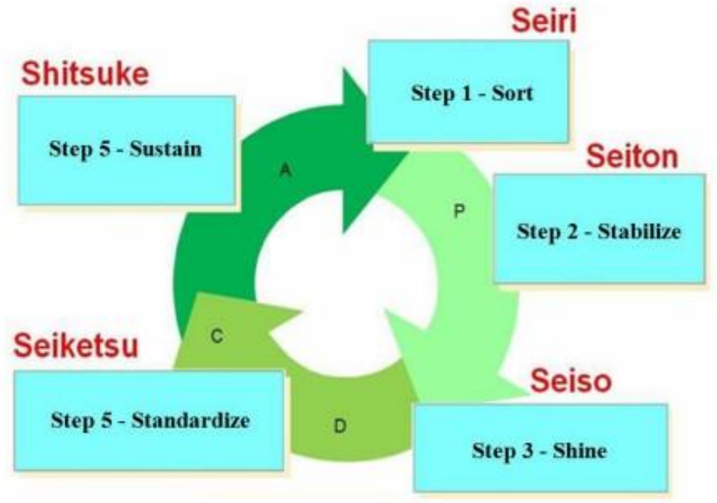


Figure EX 2: 5s Methodology used. (Mikva et al., 2016)

- OSA- Condition-Based Maintence is a new idea in maintenance field in which the machine is continuously maintenained pre-failure through data gathering, monitoring and diagnostics. It has a strong impact on machine availability by eliminating breakdown and lowering maintenance in required time. The methodology is standardized by Open System Architecture which is seen as a roadmap in figure EX3.

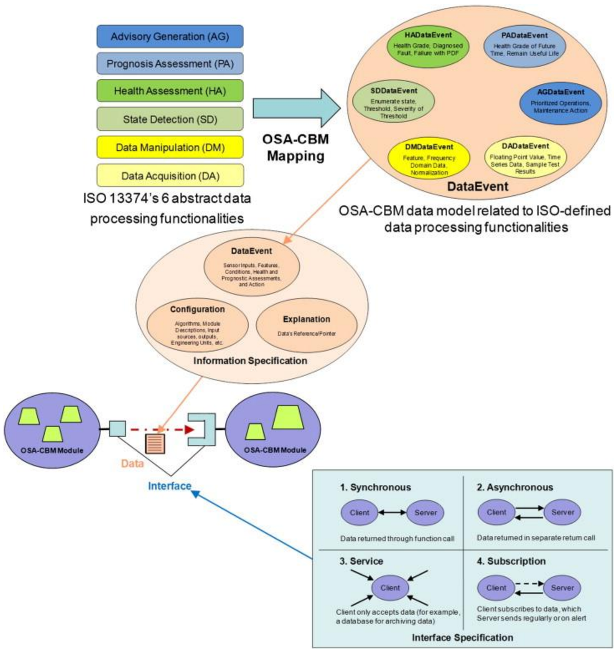


Figure EX 3: OSA Roadmap used. (Screenuch et al., 2011)

Methodology

Tackling the problem at hand required a systematically organized process, therefore A3 problem solving technique was used. Pathway and visualization is organized in figure EX4 and provides a structured way to solve problems.

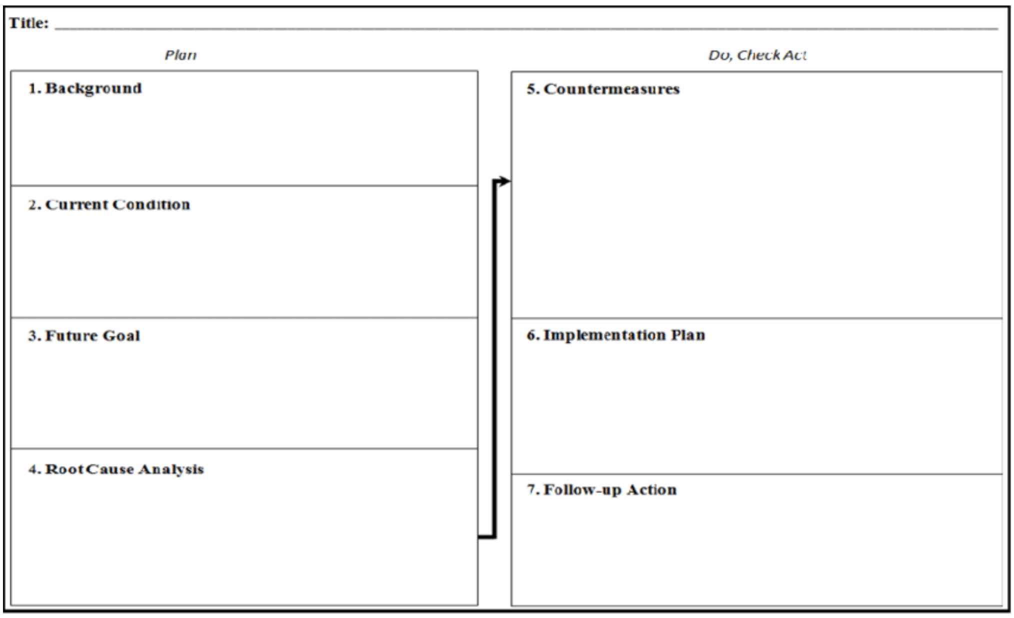


Figure EX 4: A3 Template used (Sobek & Smalley, 2008)

Problem Summary

The offset department in Truccazzano plant is having efficiency issues, it has a lower OEE compared to Vailate plant even do the machine and setup of operations is similar. In figure EX5 we can see production process and what offset department role in the system is.

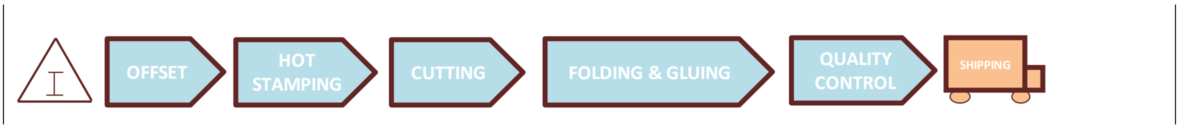


Figure EX 5: Visualization of Offset in production line.

The OEE of the department shows severe inefficiencies in the Availability segment of OEE. As availability in Gpack is analyzed through grouping of stoppages, Pareto analysis seen in figure ex6 was done to narrow the scope.

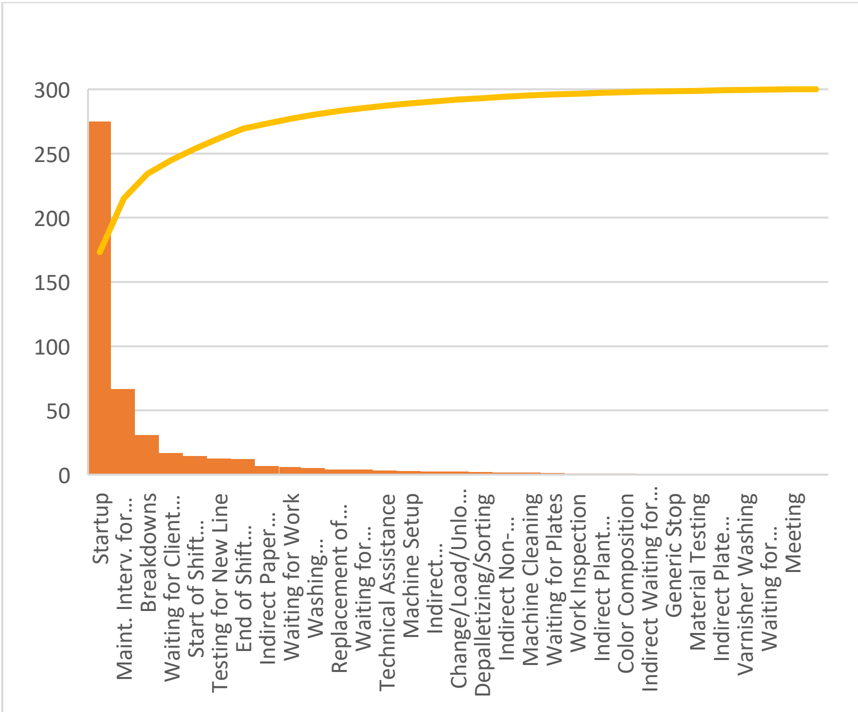


Figure EX 6: Pareto Analysis to narrow the scope.

The Startup stoppages were addressed in concurrent project done in Gpack, therefore the maintenance and breakdowns were the next issue to be addressed.

Root cause analysis

Through interviews with operators, Gemba walks of the plant and just observing the workday, FMECA table seen in table EX1 was constructed to prioritize failure modes.

Table EX 1: FMECA Table to identify Failure Modes

Function	Potential Failure Modes	Potential Effects of Failures	Severity (S)	Potential Causes of Failures	Occurrence (O)	Detectability (D)	RPN	Criticality (C)
High-speed printing	Paper jams	Production stoppage, damage	7	Misaligned guides, worn rollers	6	5	210	High
	Print misregistration	Poor print alignment, quality issues	7	Mechanical wear, sensor misalignment	4	5	140	Medium
Ink application	Ink smudging	Poor print quality, rework	8	Incorrect ink viscosity, improper roller pressure	4	5	160	High
	Ink foaming	Air bubbles, inconsistent ink application	6	Air leaks, improper mixing	3	4	72	Low
Paper handling	Feeder mechanical failure	Downtime, maintenance intervention	9	Worn gears, misalignment	5	6	270	High
	Double-sheet feed	Paper waste, jams	7	Faulty detection sensors, misfeeds	3	3	63	Low
Drying	Drying unit malfunction	Ink not drying, quality issues	8	Faulty heating elements, sensor failure	3	4	96	Medium
	Overheating	Fire hazard, equipment damage	10	Faulty thermostat, insufficient cooling	2	4	80	Medium
Control system	Electrical issues in panels	Complete shutdown, safety hazards	10	Loose connections, faulty components	2	3	60	Low
	Power surges	Equipment damage, data loss	9	Unstable power supply, inadequate surge protection	3	3	81	Medium
Inking unit	Ink starvation	Inconsistent print quality, streaks	8	Blocked ink ducts, insufficient ink supply	4	4	128	Medium
Printing plate unit	Plate misalignment	Misregistration of prints	7	Incorrect plate installation, worn clamps	3	5	105	Medium
	Plate wear	Poor print quality, frequent replacements	6	High usage, abrasive materials	5	4	120	Medium
Coating unit	Coating inconsistency	Variable finish quality	6	Improper coating viscosity, clogged nozzles	4	5	120	Medium
	Coating thickness variation	Inconsistent coating application	7	Incorrect settings, wear on applicator	4	4	112	Medium
Sheet delivery	Sheet skewing	Misaligned output, potential jams	6	Incorrect guide settings, worn belts	5	4	120	Medium
	Sheet curling	Poor stack quality, jams	5	Incorrect humidity, improper cooling	3	3	45	Low
Automation system	Software glitches	Unplanned stoppages, process errors	9	Software bugs, outdated firmware	3	4	108	Medium

Utilizing the Risk Priority Number or (RPN), three failure modes were selected. Additional two failure modes were selected through ABC analysis making the list of five failure modes to be focused on.
Five failure modes were analyzed utilizing the 5why techniques and countermeasures 5s and OSA-CBM were chosen to improve the problem of Availability.

Countermeasures Summary

5S was implemented by utilizing standardized methodology, the timeline in which the work happened was as follows and is shown in Table ex2:

Table EX 2: Timeline for Implementation of 5s

Timeline checklist	
Expected time and Action	**Status**
Week 1-2 **Meeting with Operators and Sort**	✓
Week 3-4 **Set in Order and Shine**	✓
Week 5-6 **Standardize and Sustain**	✓
Continuous **Regular Check and Improvements**	 Continuous Improvement

Condition-Based Maintenance was also done using the methodology mentioned in literature review. The data of amplitude sensor measuring vibrations was gathered and manipulated as seen in figure ex 7.

Figure EX 7: Example of a 5-minute snippet of manipulated data.

If the vibration values were to cross the threshold values, the machine would be considered in degrading state and remaining useful life would be calculated based on assumptions and trends as seen in figure ex 8.

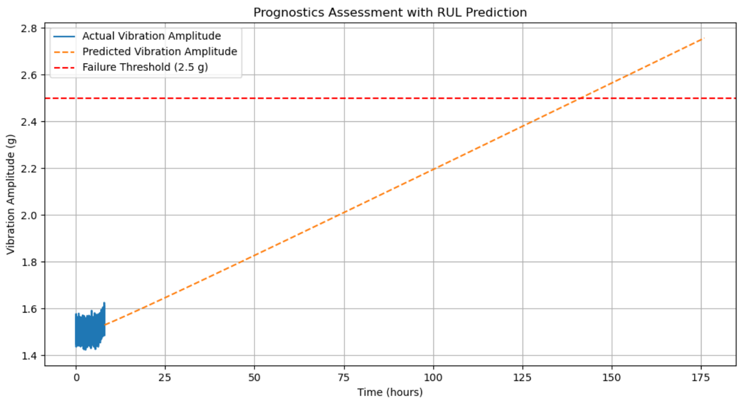


Figure EX 8: Example of Rul Prediction.

Based of RUL value, the maintenance would be scheduled depending how close to failure the prediction is. To be most optimal maintenance was always done in non-required time.

Results

Table EX 3 : Full Availability Breakdown of Results.

XL106 TRUCCAZZANO	N AVV	H AVV	%AVV	H PROD	%PROD	H DIRECT	% H DIR	H INDIRECT	% H IND	MANT	% MANT	Total H
JANUARY	1	1	**25,00%**	1,58	**39,50%**	1,42	**35,50%**	-	**0,00%**	-	**0,00%**	4
FEBRUARY	92	56,97	**19,70%**	62,13	**21,50%**	55,87	**19,33%**	111,49	**38,58%**	2,5	**0,87%**	288,96
MARCH	137	87,77	**29,30%**	94,42	**31,55%**	78,38	**26,19%**	34,31	**11,46%**	4,4	**1,47%**	299,28
APRIL	186	102,73	**23,60%**	122,14	**28,08%**	151,46	**34,82%**	54,74	**12,58%**	3,97	**0,91%**	435,04
MAY	113	68,8	**25,50%**	66,44	**24,62%**	103,59	**38,39%**	31,02	**11,50%**	-	**0,00%**	269,85
JUNE	133	128,04	**29,50%**	127,46	**29,36%**	154,11	**35,50%**	20,67	**4,76%**	3,79	**0,87%**	434,07
JULY	158	177,84	**33,15%**	146,61	**27,33%**	160,56	**29,93%**	24,64	**4,59%**	26,88	**5,01%**	536,53
AUGUST	-	-		-		-		-		-		-
SEPTEMBER	-	-		-		-		-		-		-
OCTOBER	-	-		-		-		-		-		-
NOVEMBER	-	-		-		-		-		-		-
DECEMBER	-	-		-		-		-		-		-
2023	**1.265**	**951,94**	**26,40%**	**952,41**	**26,42%**	**990,38**	**27,48%**	**591,1**	**16,40%**	**118,79**	**3,30%**	**3.604,62**
2022	**-**	**-**		**-**		**0**		**-**		**-**		**-**

Table EX 4: Summary of Availability results.

XL106 TRUCCAZZANO	%AVV
JANUARY	**25,00%**
FEBRUARY	**19,70%**
MARCH	**29,30%**
APRIL	**23,60%**
MAY	**25,50%**
JUNE	**29,50%**
JULY	**33,15%**

Table EX 5: Goals Summary.

Availability before countermeasures 2024	24,62%
Availability after countermeasure 2024	31,32%
Percentage Point Increase 2024	6,7%

As the selected target for must and nice to have are 2,5 and 5,0 point percentage increase as seen in tables ex 3,4 and 5, Project was deemed a success.

Conclusions and Limitation

Thesis goal was to assist the company in Lean Transformation, and to help them utilize those tools to improve efficiency and productivity. The results of the case study showed the company that Condition-based maintenance is a powerful tool that can be further improved by continuous improvement.

The Project was severely limited by time and funds. The company wasn't necessarily prepared to spend the huge amount of capital on a student project. Additionally, apart from this project 2 other project were done simultaneously during the one semester.

1. Introduction

1.1 Project Overview

The thesis was done in combination with Industrial Management Lab, where two different projects were done in collaboration with company GPACK S.p.A. The methodology used to organize the thesis was A3 lean method, which is a problem-solving technique that utilizes an 8-step approach to combat the defined problem. The first two steps are used to provide background and breakdown of the problem at hand which allows realistic target setting. Target setting segment is followed by root cause analysis of problem after which countermeasures are developed and implemented. Work is then standardized and monitored for future applications.

Main issues of Gpack Group that were relevant to my research were communication due to language barrier and company not being completely up to date to the newest techniques, especially the maintenance policies that were completely based on waiting for failure and not having preemptive plans. Additionally, while company practices lean way of thinking, some measures were stopped due to change in management and chaotic market of luxury printing.

Main objective of the research is to identify problems and improve company efficiency through implementation of relevant lean tools.

1.2 Company Overview

This project was done in an Italian company named GPACK S.p.A., it is a manufacturing printing firm that mainly deals in paper converting. It was established in 1994, and it is currently transitioning from just being a packaging company to international entity by strategically growing. Currently, the company is known for its luxury and general packaging as well as display solutions. It is dedicated to producing quality, sustainable and innovative products.

Throughout the years, Gpack has been trying to expand its capabilities by improving their technologies and integrating sustainable operations into their day-to-day business. Their quality of products and usage of top-of-the-line material earn them a reputation for reliability and excellence in their industry.

Gpack S.p. A. has a wide sales network which is completely based in Europe, their customers are composed of large distributors to the fashion industry. A close relationship with the clients is an absolute focus which allows them to understand unique needs so that the full packaging solution is delivered to the client. Bettering their customers brand and product appeal allows them to be within industry leaders in Italy.

The company had a turnover of €82 million in 2023, which encompasses all five production plants. Additionally, the company has around 400 employees and a significant market presence and production capacity.

Gpack aims to be a world conglomerate which is seen in their standardizations including ISO 9001:2015 and ISO 14001, which shows their willingness to produce top notch quality and focus on sustainability. With an initiative-taking stance on renewable energy and raw material recycling, which is seen in their usage of solar panels, the company has proven to also show commitment towards the environment.

While Gpack group has multiple products as mentioned above, the focus of the thesis and research was mainly done on their Luxury Packaging:

- Luxury Packaging: High end products that utilize premium raw material, niche requests and minimal tolerance of error.

Gpacks' production process can be seen as Engineering to order (ETO) especially for luxury products, as clients have the final design in mind, and it cannot be replicated for other work orders making serial or batch manufacturing impossible.

The company also has a huge commitment to continuous improvement, which is one of the reasons for this project as they wanted to see what the latest knowledge was in the industry. The constant need for innovation in a combination of need for sustainability allowed them to be forward thinking leaders in the industry.

1.3 Thesis Aim and Thesis Questions

Gpack S.p.A. has been looking to update their knowledge and competencies by venturing into Lean transformations to increase their main KPI's. Politecnico di Milano's has been increasingly researching and teaching Lean methodologies to Master Students and would be a good partner in this venture. Venturing into these waters would allow Gpack S.p.A. to tackle their increasing problems in printing departments and try to achieve efficient goals set by Lean ideas.

Therefore, the main purpose of my work is to assist Gpack in the Lean transformation and making sure that department is as efficient as my knowledge allows. After a short literature review, my choice of helping the company in reaching their goals is combination of 5s, FMECA and Condition-Based maintenance. These lean tools are a great combination as they are concurrent and fill gaps that the next tool lacks. Results from one tool are required for the set-up of the next tool and the combination of these tools should give satisfactory results for the company.

Thesis questions:

1. How do lean principles, mainly 5s and Condition Based Maintenance impact Availability segment of Overall Equipment Effectiveness and general organization of the company?

2.Is it possible to implement continuous improvement to make company better even after the project?

2. Literature Review

The objective of Literature Review is to research and examine existing academic papers that are relevant to the topic of "Integrating Smart Maintenance Analysis in Luxury Printing Factory". Structured search strategy was done using major academic databases, mainly Google Scholar. Keywords were selected based on the main tools and theory used in thesis and combining certain tools keywords, like FMECA and CBM, provided even better results for systematic research. Additional considerations were that papers were written in English and that they answer relevant research questions both empirical and theoretical.

The preliminary screening of relevant papers was done by going through abstracts and titles so that interesting papers were found. If the paper was deemed relevant it was examined, and if the content was informative its sources were also examined for more interesting data. Additionally, while theoretical information was needed, empirical evidence that the tools searched for was the focus.

While a lot of papers were researched only a few were selected to be referenced throughout this thesis as usually certain papers had the best information grouping within one document. The other papers, however, were useful for understanding the bigger picture, and sometimes even understanding the process and way of improvement. Avoiding plagiarism and following correct citation guidelines were two ethical considerations.

2.1 Literature Review Methodology

The focus of literature review was lean tools that would be useful for the project involving OEE reductions, focusing on Availability. Terms such as FMECA, 5s and CBM were searched.

Additionally, as a helping hand the methodology of guidelines of a systematic literature review developed by Xiao and Watson (Xiao & Watson, 2019) was used.

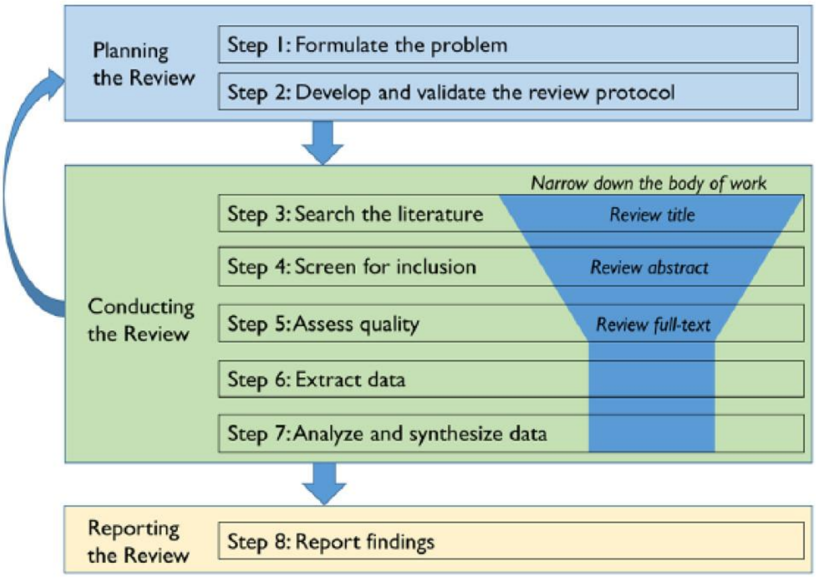


Figure 1: Roadmap for systematic literature review. (Xiao & Watson, 2019)

The roadmap seen in figure 1 was used only as a helping hand, therefore the goal of the review was not to perform extensive research for academic inquire, but a way to efficiently understand relevant term and understand how to apply them. Therefore, the literature review doesn't fully follow the roadmap.

Target questions for FMECA:

- Define FMECA and its main characteristics.
- How is it suggested that FMECA is used, specifics and methodology.

Target questions for 5s:

- Define 5s and why it would be useful to perform it.
- Show the methodology and how each step is applied.

Target questions for CBM:

- What is CBM and when is it applied.
- How to apply CBM most efficiently.
- What is OSA standard.

2.2 FMECA

Failure Modes, Effects, and Criticality Analysis (FMECA) is a methodological process, that can be seen as an upgrade from Failure Modes and Effects Analysis (FMEA) by introducing the criticality aspect that would increase the systems safety and dependability. It was created for military use by the USA in 1949 to ensure success in missions and personnel safety. Following that, many other industries started using it such as aerospace, automotive and defenses among others. The outline and process can be seen in figure 2. (Mraz et al., 2005)

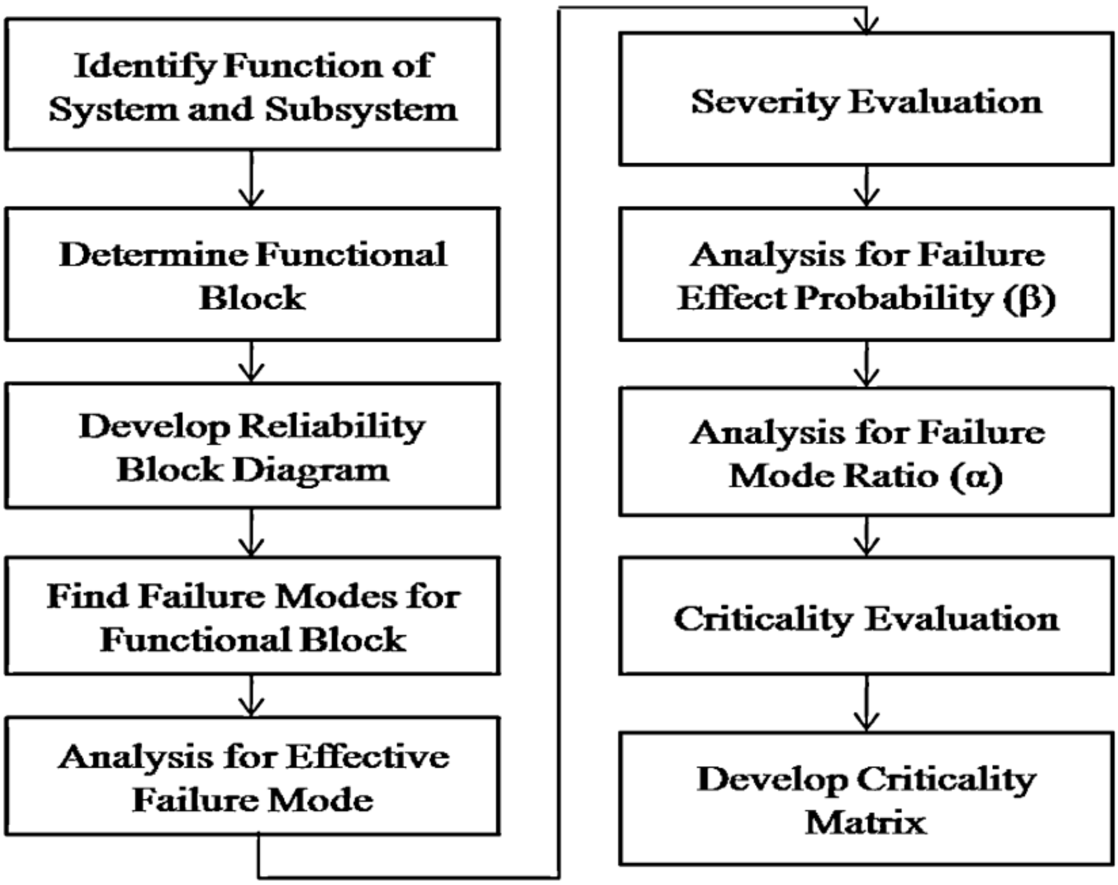


Figure 2: Roadmap for Traditional FMECA. (Lee et al., 2011)

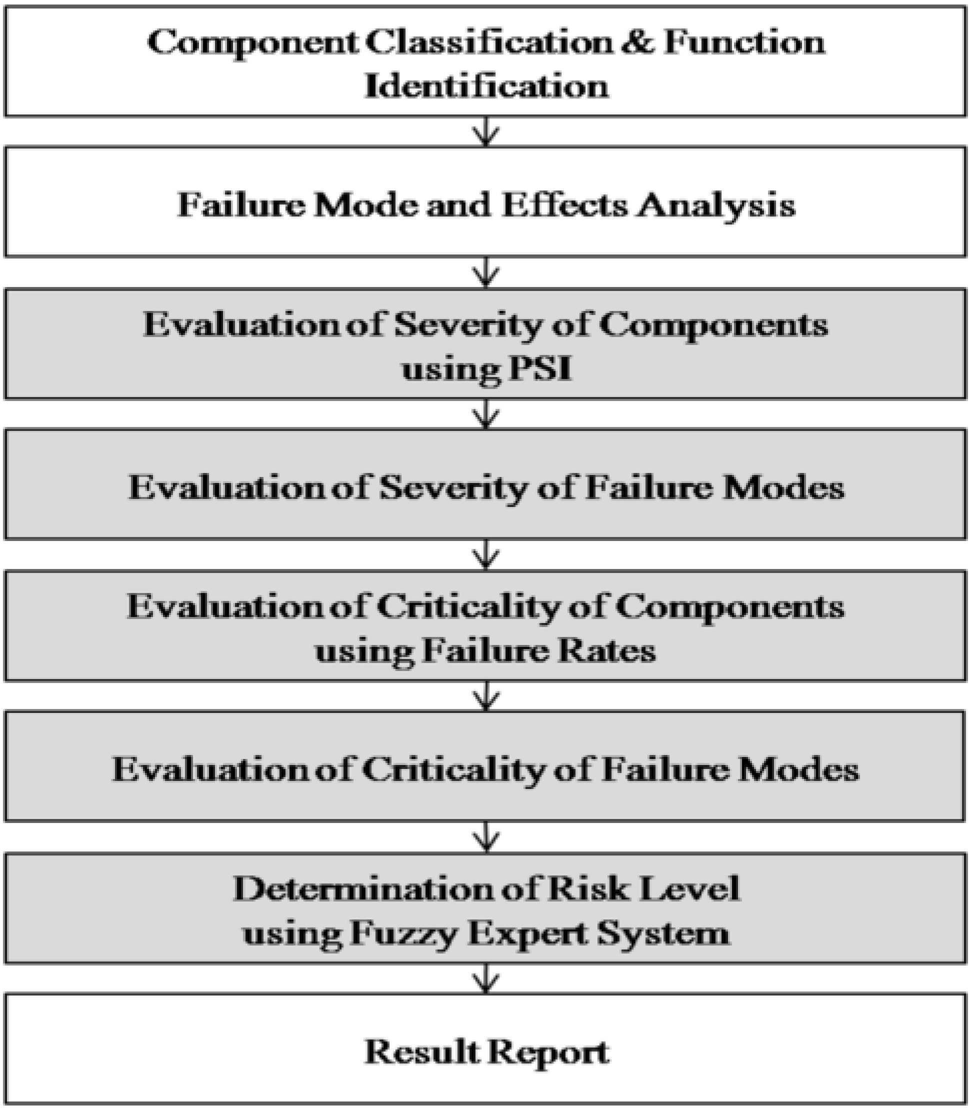


Figure 3: New Proposed Roadmap that is more standardized. (Lee et al., 2011)

According to Lee and his colleagues, using the new road map as seen in figure 3 compared to figure 2 allows for better usage of the methodology outside of military industries.

Being able to find possible failure effects by linking severity and occurrence allows us to do the Criticality analysis. This addition allows for more risk assessment and enables us to prioritize failure modes according to severity of their failures. This addition is especially effective in industries with catastrophic failure potential such as nuclear. (Mraz et al., 2005).

According to Mraz and his colleagues, (2005), the best usage of FMECA can be seen in automotive sector, complex systems that are required to work where multiple components work together like sliding doors in cars. Engineers can make sure that critical parts and processes are focused on by systematically ranked with criticality analysis. So furthermore, Mraz and his colleagues (2005) imply that this approach allows the expenses to be lowered, and the dependability of products increased.

2.3 5s

According to Filip and his colleague, 5s methodology is embodiment of lean manufacturing, it originated in Japan and the method aims to improve every aspect of workplace, from productivity to workplace environment. The 5s is made up of Seiri, Seiton, Seiso, Seiketsu and Shitsuke and each of the steps allows for improving productivity and safety in many industries (Filip & Marascu-Klein, 2015).

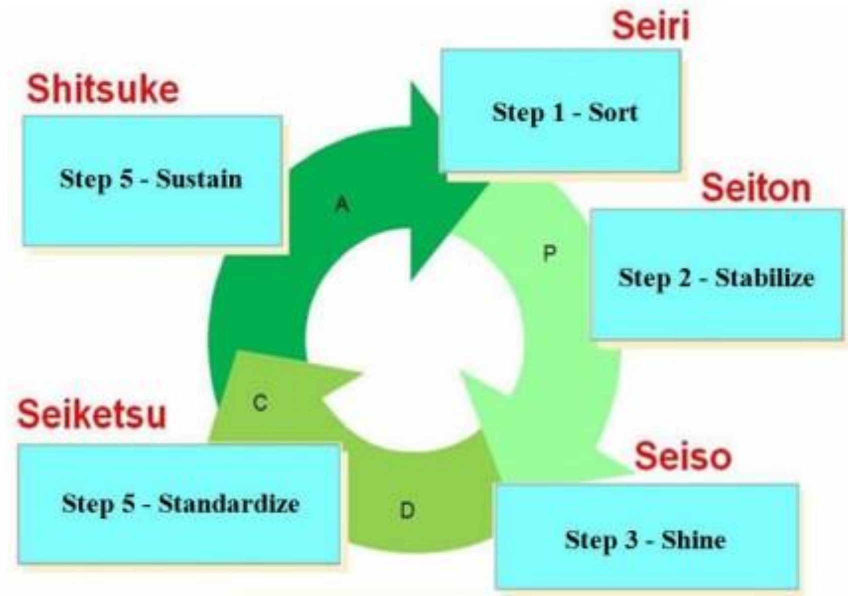


Figure 4: 5s Methodology (Mikva et al. 2016)

Additionally, Mikva and her colleagues imply that standardization of processes leads to reduction in variation and error correction, improves safety, facilitates communication among many other things. As seen in figure 4, each of the 5 letters S has meaning in English as well (Mikva et al., 2016)

As said before, the concept of 5s was first seen in Japan' lean systems as they wanted to reduce waste and improve efficiency. According to Filip and his colleague, it can make the workplace more organized, safer and productive, and many industries adopted it to improve competitiveness. Main target of 5s is to minimize waste, make the flow of work more transparent and makes work environment pleasurable to work in. Staff training, standardization and having frequent meetings to foster continues improvement are all key principles of 5s implementation (Filip & Marascu- Klein, 2015).

5s implementation was seen to have impressive results among various industries, best seen in factory and manufacturing. Adoption of the methodology can lead to improvements of organization, lower search and wait times, and operational excellence is way more transparent. 5s is closely linked with usage of Visual management, another useful lean tool, and this combination leads to immediate identification and corrective actions (Filip & Marascu- Klein, 2015)

2.4 OSA-CBM

Condition-Based Maintenance is a revolutionary advancement in the world of machines monitoring and diagnostics. The Open System Architecture allows for a foolproof framework that was made to standardize and improve CBM practices. Improvements to overall efficiency, interactions withing systems and ability for continuous upgrades are main goals withing maintenance systems, the standardized methodology is used within many industries especially military and manufacturing domains (Lebold et al., 2002). The way each segment interacts can be seen in figure 5, which shows that each building block has a important feature in building the system.

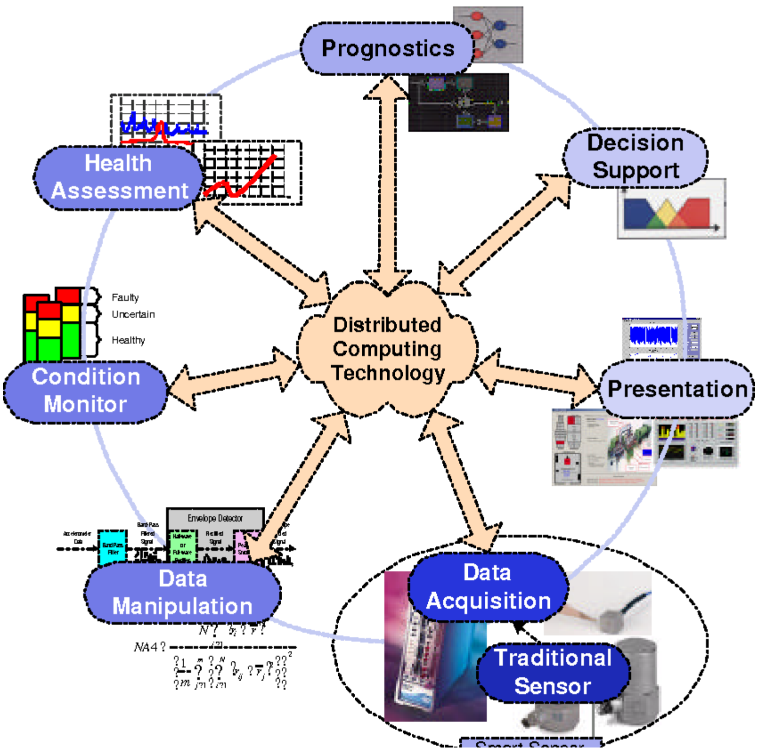


Figure 5: OSA-CBM Visual (Lebold et al., 2002).

As mentioned before, Lebold and his colleagues imply that CBM is an effective way to maintain machine based on state of the equipment compared to wait for failure and scheduling corrective maintenance or doing blind periodical preventive maintenance. Data collection about the state of equipment is where OSA-CBM shines. It allows for more accurate data collection, processing and allows for systems to communicate their state more effectively, which allows for better Decision making as seen in figure 6 (Lebold et al., 2002).

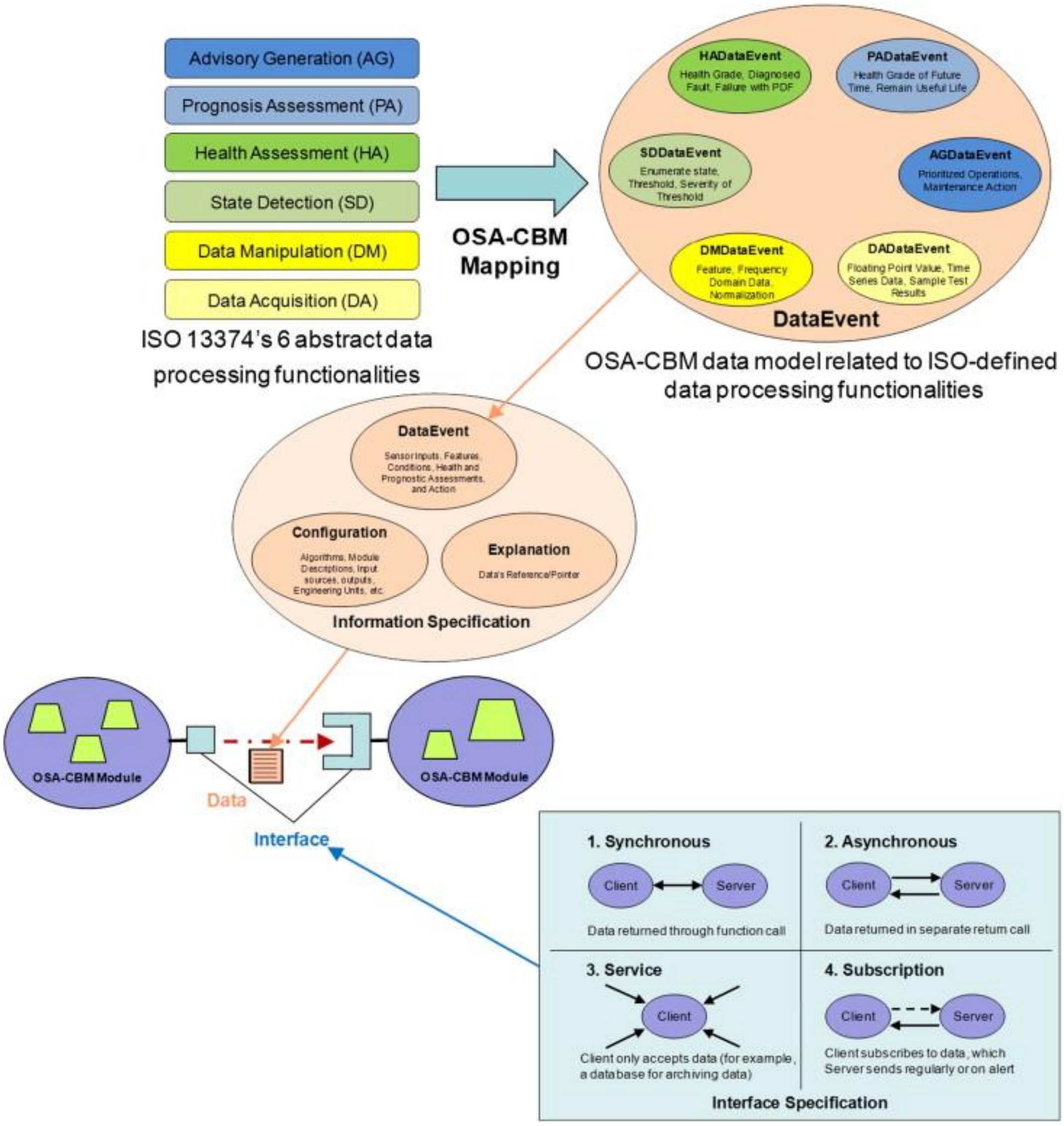


Figure 6: OSA roadmap. (Sreenuch et al. 2013)

Software model developed by OSA, allows for integration and interchangeability of system components. Usage of the software allows for lower development costs and makes implementation easier, by promoting usage of commercia off-the-shelf technologies. The building blocks of the software are condition monitoring, health assessment, prognostics, and data collecting and processing. These modules as seen in figure 6 are essential for usage of CBM (Screenuch et al., 2013) (Lebold at al. 2002).

Using OSA-CBM has several advantages, both commercially and technically. From a technical standpoint, it improves system capabilities by making it simple to add or upgrade components, guaranteeing that systems may change over time to accommodate evolving requirements. Commercially, it promotes the creation of non-proprietary standards, which in turn stimulates innovation and lowers end-user prices by creating a competitive market for CBM components (Lebold et al., 2002).

3. Methodology

With the objective to improve operational effectiveness and reliability, this thesis uses a structured approach to address the challenges found in the case study setting. It does this by utilizing the A3 problem-solving tool and implementing 5S and OSA-CBM approaches as countermeasures as these are seen as critical tools to tackle availability of the machine mainly, but also should improve other two segments of OEE, performance and quality, therefore providing a good combination to improve the main KPI of the company: OEE. The tools that were chosen work especially well together as 5S and Condition Based Maintenance are concurrent processes that build well on each other. Similarly, these tools are done effectively using A3 methodology, as structured approach defines well each step, and make sure all information is understood before tackling the issues. OSA-CBM mainly tackled Availability, but should have impact performance as it allows machine to work as intended. 5s improves mostly performance, but also tackles availability and quality as work is more organized.

3.1 A3 Problem Solving Methodology

The case study employed the A3 technique, which is based on Toyota's lean manufacturing framework, to systematically tackle and resolve the crucial issue. The following important elements are included in this method's step-by-step manner on an A3-sized piece of paper as seen in the figure 7 which was introduced by Sobek and Smalley. A3 was chosen so that problem is systematically resolved and each step is researched to avoid jumping to conclusions and assuming problems without proof.

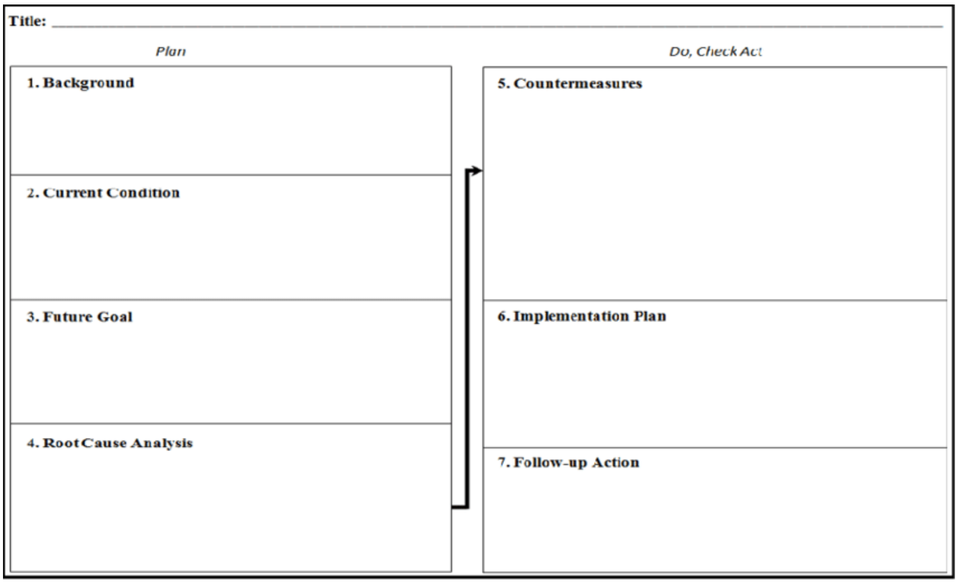


Figure 7: Traditional A3 Template (Sobek and Smalley, 2008)

- Background: Understanding the context and importance of the issue.
- Breakdown: Graphical representation of current processes and identification of problems.
- Target Setting: Clear statement of desired outcomes.
- Root Cause Analysis: Identification of underlying causes of the problem using tools such as the FMECA and 5why.
- Proposed Countermeasures: Development of solutions to address root causes.
- Implementation Plan: Detailed action plan including responsibilities and timelines.

3.2 5s Methodology

To improve workplace organization and efficiency, the 5S methodology was applied as a countermeasure. The five steps of 5S—Sort, set in order, Shine, Standardize, and Sustain—were systematically implemented to create a more organized, efficient, and safe workspace (Filip & Marascu-Klein, 2015) (Mikva et al., 2013). Each step involved specific actions:

- Sort: Removing unnecessary items from the workspace.
- Set in Order: Organizing all used equipment for easy access.
- Shine: Cleaning the workspace to maintain standards and identify faults more easily.

- Standardize: Implementing best practices and standard operating procedures across the workplace.
- Sustain: Creating a culture that maintains the standards and continuously improves them.

3.3 OSA-CBM Methodology

OSA-CBM framework was adopted to ensure real time data gathering, diagnostics and prognostics so that breakdowns are predicted before they occur. This methodology involves several layers as seen in figure 8:

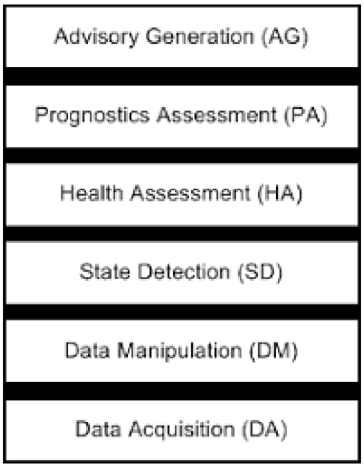


Figure 8: MIMOSA standard checklist (MIMOSA, 2010)

- Data Acquisition: Collecting data from equipment sensors.
- Data Manipulation: Removing Outliers and noise
- State Detection: Analysing the current state of machine
- Health Assessment: Seeing how Degradation will affect the machine
- Prognostics: Predicting the future state and remaining useful life of machinery.
- Decision Support: Planning the actions regarding the machine maintenance plan.

This integrated approach to problem-solving and maintenance is designed to significantly reduce downtime and increase the efficiency and lifespan of machinery within the studied environment.

Validation and Analysis:

The effectiveness of these methodologies was evaluated by comparing operational data from before and after implementation, including productivity rates, maintenance costs, and equipment failure rates. Additionally, Qualitative feedback from staff was gathered to assess changes in workplace organization and employee satisfaction. This mixed-method approach ensured a comprehensive evaluation of the methodologies impact.

4. Case Study

As mentioned before in the methodology paragraph, the results segment of the thesis was done following the A3 methodology. This case study focuses of implementing Lean methodologies to improve operational effectiveness of Truccazzano plant, focusing mainly on the Offset department. This plant is one of two most important plants and is simply lacking in efficiency especially compared to the other main plant, further more Truccazzano is vital in meeting companies production of Luxury printing aspect of the business. Plant has 5 departments that work together to form the final product, from printing to quality control. Understanding the role and functions of each department help to highlight the need for targeted interventions for optimizing OEE and reducing operational bottlenecks

4.1 Problem Background

The offset department at Truccazzano, responsible for high-quality print production, is experiencing sever operational challenges that impact Gpacks OEE, particularly the availability department. High downtime due to machines issues, such as ink misalignments and paper jams, as well as workflow inefficiencies, have significantly disrupted production schedules. This problem was identified through a systematic assessment where the A3 methodology guided root cause analysis and clarify specific areas for improvement. Addressing theses issues is essential to maintain production efficiency uphold luxury quality standards and reduce costly downtimes.

The whole project was done in Truccazzano plant, the ouline of the plant can be seen in figure 9, in Milan, which is among the most utilized plant of the five plants that Gpack group owns.

Figure 9: Truccazzano Industry plant layout.

The production line in Truccazzano has five departments, each product doesn't necessarily pass through each department, it is dependent on the work order and client specifications.

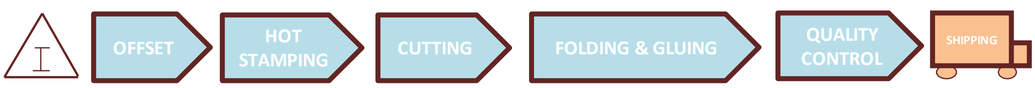


Figure 10: Visualization of Departments in generic order.

Offset

As seen in figure 10, this is usually the first department. This is also considered the most important department as almost all products must pass through it. Here the design is printed on paper, and in luxury setting, every aspect of the print must be perfect, which creates long setup times and requires perfect conditions of machines.

Hot stamping

Hot stamping is a niche department, it is only used for ultra luxury products that require metallic coating, here a shiny film is stamped and engraved into previous printed design.

Cutting

Cutting station is self-explanatory, here the products are cut with patterns and shapes required according to the work order.

Folding & Gluing

Folding and gluing is assembly, here previous products that were cut with patterns and shapes are assembled into the final look.

Quality Control

Quality control is a key aspect of luxury orders as any deviation from exact design ensures the final assembly is discarded. This prevents loss of future work orders and loss of reputation.

Currently, Gpack is facing problems in the key department of Offset which is severely impacting their overall OEE especially in Availability section. The A3 framework's systematic approach allowed for a comprehensive understanding of these issues, providing the foundation for deploying 5S to improve organization and OSA-CBM for predictive maintenance.

4.2 Problem Breakdown

This section details the challenges impacting the Offset department's operational efficiency, focusing on the XL106 machine as Gpack transitions from general to luxury packaging. By analyzing critical factors affecting OEE, we can identify key improvement areas to enhance Availability, Performance, and Quality.

4.2.1 Scope of the Problem

The Offset department is by far the most important Department on the production line; therefore it was the focus of the project. The Offset department consists of two machines, the XL145 and XL106, each operated by three operators.

The XL145 is an older machine generally reserved for general packaging. As the plant is transitioning to focus on luxury, this machine was mainly used to see general idea of how the machine works, in case any ideas can be created from viewing it.

The XL106, is created for luxury packaging specifications. Therefore, the focus of the improvement efforts will be on the XL106, as there are even talks of buying another XL106 machine to replace XL145.

The switch from general packaging to luxury creates a huge problem for availability of the machine, as the tolerance of errors is slimmer, every work order must go through stricter controls and machine must work perfectly to avoid any print errors. As luxury printing provides more profit (as they cost more), the customers expect perfect product, which isn't the case in general packaging. The whole process can be visualized in figure 11.

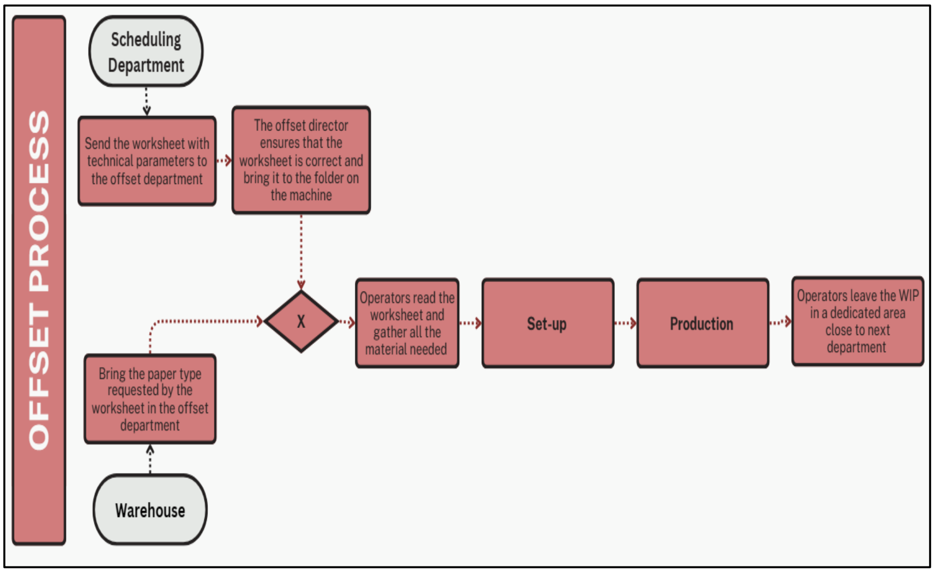


Figure 11: Offset information flow. (Rotondi et al., 2024)

4.2.2 Key Performance Indicator (OEE Breakdown)

Upon recognizing the imperative to enhance the efficiency of the Offset machine, our next step involved delving deeper into understanding the underlying problems, their causes, and potential solutions. Initially, we began with an analysis to delineate the possible root causes of inefficiencies. This analysis started by disaggregating Overall

Equipment Effectiveness (OEE) into its three primary components: Availability, Performance, and Quality as seen in figure 12. The focus of this project is on Availability, which quantifies the actual time the machine is operational relative to the total available time. By improving Availability, Throughput and OEE will also improve. Availability is a critical metric in the Offset department, as higher machine uptime is essential for maintaining throughput in luxury production. Improvements in Availability also reduce pressure on Quality Control by minimizing errors caused by machine interruptions.

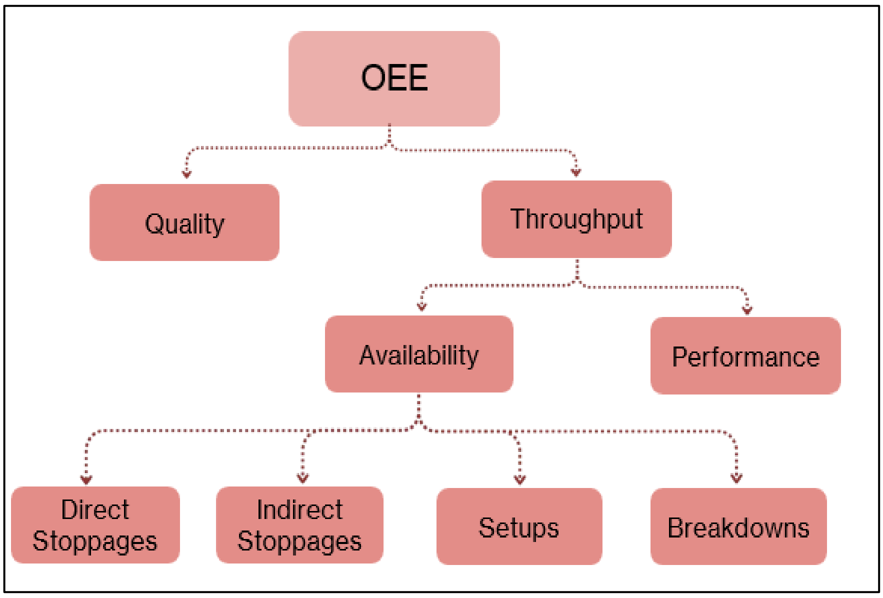


Figure 12: OEE Visualization. (Rotondi et al.2024)

Within this context, the main factors that influence Availability as seen in figure 12 are:

Direct Stoppages:

These stoppages happen when a machine is stopped due to production actions that are deemed necessary. One example of this would be supervision from client and department head to make sure that the quality is up to the customer's standard. These stoppages are also important to address and reduce, but usually these stoppages are within the pricing for customer, so value lost is not high as other.

Indirect Stoppages:

These stoppages happen when the machine is stopped from internal issues. While occasionally, planned downtimes are also within pricing budget of the client, the unplanned downtime is fully on company's budget. Missing raw material or operators' inefficiencies are a good example of indirect stoppage.

Breakdowns:

These stoppages happen when the machine enters faulty mode, and maintenance is required. As currently the company doesn't have Maintenance strategy majority of maintenance is done during required time so corrective maintenance is immensely impacting Availability.

Set-Ups:

As seen before throughout the document, luxury printing requires a lot of preparation so that the product meets extremely strict wants of the client. Therefore, Setup is a separate entity in Availability segments. While this arguable the biggest contributor to the low Availability KPI, it was addressed in the Industrial Lab Project separate to this thesis (Rotondi et al., 2024)

The idea is to analyze the stoppages to see what key contributors to the availability problem are, after seeing main problems root causes can be identified and later countermeasures implemented.

4.2.3 Stoppages Analysis

To fully understand what impacts the availability the most, Pareto analysis of stoppages, that were documented in 2023 by the companies Innovation department, must be done:

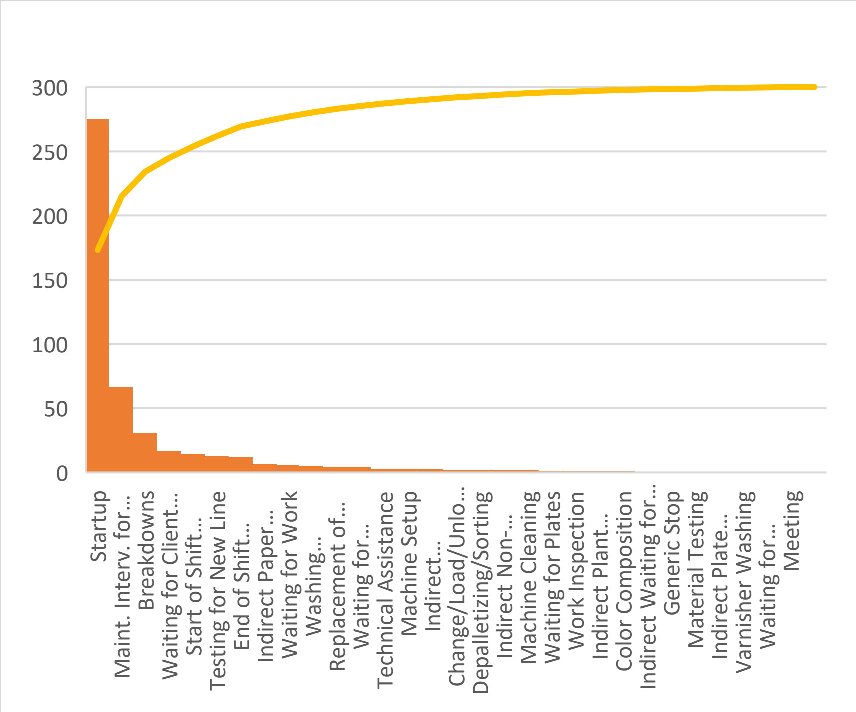


Figure 13: Pareto Analysis of Stoppages.

As seen by the Pareto analysis in figure 13, the Setup/Start-up was by far the most impactful stoppage, but as mentioned before, in combination with this thesis, Lab for Industrial Engineering addressed this issue through SMED implementation. Therefore, the next impactful stoppages must be considered. It can be concluded that Breakdown of the machines and intervention of the same are the next step to improving efficiency of this department.

4.2.4 Current Maintenance Plan

The company doesn't have a concrete maintenance strategy nor a plan. Their current plan encompasses traditional corrective maintenance when failure occurs. Corrective maintenance is done during operational hours which is negatively impacting productivity and quality in luxury packaging production. Additionally, the company has a simple cyclic preventive maintenance that occurs every Friday before the first shift. Preventive maintenance encompasses only basic checks and cleaning.

Current Cost Breakdown seen in figure 14:

		Act YTD 09.23	Bdg 23	Valori da AGGIORNARE - CATTANEO									
Total	**Tot**	**938.842**	**1.976.744**	**655.989**	**80.168**	**211.688**	**254.593**	**132.057**	**159.276**	**19.138**	**15.847**	**1.740.664**	
	Regular		**1.482.922**	239.896	33.168	105.844	147.796	72.712	71.759	9.569	15.847	786.329	
	Extraordinary		**310.000**	140.000	20.000	-	-	-	10.000	-	-	140.000	
			Totale	Offset	Hot Stamping	Digital Offset	Cutting and Gluing	Assembly	Merger	Taglierina	GMC	Indirect	% Ind/Dir YTD 09.23
Vailate	**Total**	**178.086**	**316.423**	**103.803**	**26.168**	-	**41.000**	**13.367**	**4.243**	-	**15.847**	**111.995**	
	Regular		276.423	103.803	26.168		41.000	13.367	4.243		15.847	71.995	**35%**
	Extraordinary		40.000									40.000	
Cavaione	**Total**	**50.176**	**160.000**	-	-	-	-	-	-	-	-	**160.000**	
	Regular		150.000									150.000	
	Extraordinary		10.000									10.000	
Cambiago	**Total**	**76.355**	**140.000**	-	-	-	-	-	-	-	-	**140.000**	
	Regular		130.000									130.000	
	Extraordinary		10.000									10.000	
Truccazzano	**Total**	**226.789**	**684.580**	**229.758**	**27.000**	**105.844**	**38.133**	**43.345**	**21.045**	-	-	**219.455**	
	Regular		504.580	89.758	7.000	105.844	38.133	43.345	11.045			209.455	**71%**
	Extraordinary		180.000	140.000	20.000				10.000			10.000	
Bottanuco	**Total**	**269.570**	**491.918**	**46.335**	-	-	**68.664**	**16.000**	**56.471**	**9.569**	-	**294.879**	
	Regular		421.918	46.335			68.664	16.000	56.471	9.569		224.879	**114%**
	Extraordinary		70.000									70.000	
General		**137.867**	183.822										

Figure 14: Current Year Budgetary expenditure.

__Current Budget planned for 2024 seen in figure 15:__

		Act YTD 09.23	Bdg 24	Valori da AGGIORNARE - CATTANEO									
Total	**Tot**	**938.842**	**1.322.822**	**255.000**	**56.000**	**40.000**	**204.000**	**118.000**	**134.000**	**12.000**	**21.000**	**1.162.000**	
	Regular		**1.019.000**	160.000	49.000	20.000	114.000	65.000	67.000	6.000	21.000	517.000	
	Extraordinary		**120.000**	-	-	-	-	-	-	-	-	120.000	
			Total	Offset	Hot Stamping	Digital Offset	Cutting and Gluing	Assembly	Merger	Taglierina	GMC	Indirect	% Ind/Dir YTD 09.23
Vailate	**Total**	**178.086**	**276.000**	**65.000**	**42.000**	-	**24.000**	**12.000**	-	-	**21.000**	**112.000**	
	Regular		246.000	65.000	42.000		24.000	12.000	-		21.000	82.000	
	Extraordinary		30.000									30.000	
Cavaione	**Total**	**50.176**	**85.000**	-	-	-	-	-	-	-	-	**85.000**	
	Regular		75.000									75.000	
	Extraordinary		10.000									10.000	
Cambiago	**Total**	**76.355**	**110.000**	-	-	-	-	-	-	-	-	**110.000**	
	Regular		100.000									100.000	
	Extraordinary		10.000									10.000	
Truccazzano	**Total**	**226.789**	**315.000**	**60.000**	**7.000**	**20.000**	**35.000**	**28.000**	**15.000**	-	-	**150.000**	
	Regular		275.000	60.000	7.000	20.000	35.000	28.000	15.000			110.000	
	Extraordinary		40.000						-			40.000	
Bottanuco	**Total**	**269.570**	**353.000**	**35.000**	-	-	**55.000**	**25.000**	**52.000**	**6.000**	-	**180.000**	
	Regular		323.000	35.000			55.000	25.000	52.000	6.000		150.000	
	Extraordinary		30.000									30.000	
General		**137.867**	183.822										

Figure 15: Current Year Planned Expenditure.

4.3 Target Setting

In A3 methodology, target setting is a good way to establish clear goals that will allow clarity in regards to project success and happiness of stakeholders. Two main goals were set to improve Availability of the Offset departments machines: a Must-have goal of 2.5% point increase and a Nice-to-have goal of 5% point increase. These targets were based on industry benchmarks and were continuously discussed with stakeholders to insure their approval of the ideas and to ensure both ambitious and achievable goals seen in table 1.

Table 1: Summary of goals.

Goals	Improvement of Availability
Must have target:	2.5% Point Increase
Nice to have target:	5% Point Increase

The must have goal is minimum required improvement in machine availability to ensure downtime and ensure operational consistency. The improvement will involve targeted actions of CBM for lowering direct and indirect stoppages, and 5s for organizational improvement.

The nice to have goal is a fairly more ambitious taking, which aims to make offset department significantly more operational efficient and model of reliability. Reaching this milestone will require optimizing setup times through Single-Minute-Exchange-of-dies and further 5s implementation. Both goals were set based on insights from the literature review and similar case studies, which suggest lean methodologies when implemented accordingly can lead to substantial gain in Availability.

The Target Setting was approved by the stakeholders in the company.

4.4 Root Cause Analysis

To identify the underlying issues impacting the Offset department's Availability, a Root Cause Analysis was conducted using FMECA seen in table 2 and 5Why techniques. These analyses enabled us to prioritize failure modes based on criticality and delve into the causes behind each significant issue, guiding the development of effective countermeasures.

4.4.1 Failure Methods Effect and Criticality Analysis (FMECA)

Table 2: FMECA TABLE.

Function	Potential Failure Modes	Potential Effects of Failures	Severity (S)	Potential Causes of Failures	Occurrence (O)	Detectability (D)	RPN	Criticality (C)
High-speed printing	Paper jams	Production stoppage, damage	7	Misaligned guides, worn rollers	6	5	210	High
	Print misregistration	Poor print alignment, quality issues	7	Mechanical wear, sensor misalignment	4	5	140	Medium
Ink application	Ink smudging	Poor print quality, rework	8	Incorrect ink viscosity, improper roller pressure	4	5	160	High
	Ink foaming	Air bubbles, inconsistent ink application	6	Air leaks, improper mixing	3	4	72	Low
Paper handling	Feeder mechanical failure	Downtime, maintenance intervention	9	Worn gears, misalignment	5	6	270	High
	Double-sheet feed	Paper waste, jams	7	Faulty detection sensors, misfeeds	3	3	63	Low
Drying	Drying unit malfunction	Ink not drying, quality issues	8	Faulty heating elements, sensor failure	3	4	96	Medium
	Overheating	Fire hazard, equipment damage	10	Faulty thermostat, insufficient cooling	2	4	80	Medium
Control system	Electrical issues in panels	Complete shutdown, safety hazards	10	Loose connections, faulty components	2	3	60	Low
	Power surges	Equipment damage, data loss	9	Unstable power supply, inadequate surge protection	3	3	81	Medium
Inking unit	Ink starvation	Inconsistent print quality, streaks	8	Blocked ink ducts, insufficient ink supply	4	4	128	Medium
Printing plate unit	Plate misalignment	Misregistration of prints	7	Incorrect plate installation, worn clamps	3	5	105	Medium
	Plate wear	Poor print quality, frequent replacements	6	High usage, abrasive materials	5	4	120	Medium
Coating unit	Coating inconsistency	Variable finish quality	6	Improper coating viscosity, clogged nozzles	4	5	120	Medium
	Coating thickness variation	Inconsistent coating application	7	Incorrect settings, wear on applicator	4	4	112	Medium
Sheet delivery	Sheet skewing	Misaligned output, potential jams	6	Incorrect guide settings, worn belts	5	4	120	Medium
	Sheet curling	Poor stack quality, jams	5	Incorrect humidity, improper cooling	3	3	45	Low
Automation system	Software glitches	Unplanned stoppages, process errors	9	Software bugs, outdated firmware	3	4	108	Medium

After concluding the FMECA table, three key failure modes can be identified to be focused on based on the high criticality:

Failure mode 1: Paper Jams

Failure mode 2: Feeder Mechanical Failure

Failure mode 3: Ink Smudging

Additionally, to choose which other failure modes to consider ABC analysis seen in table 3. According to ABC, all medium criticality modes are ranked in descending order in terms of their RPN value. They are then put into three categories: A class (20% of cumulative RPN), B class (next 30%), C class (last 50%).

Table 3: ABC Analysis for Failure modes selection.

Failure Mode	RPN	SUM RPN	Cumulative %	
Print misregistration	140	140	12%	A
Ink starvation	128	268	22%	
Plate wear	120	388	32%	B
Coating inconsistency	120	508	42%	
Sheet skewing	120	628	52%	
Coating thickness variation	112	740	61%	C
Software glitches	108	848	70%	
Plate misalignment	105	953	79%	
Drying unit malfunction	96	1049	87%	
Power surges	81	1130	93%	
Overheating	80	1210	100%	

Therefore, two new failure modes are added to consideration:

Failure mode 4: Print misregistration

Failure mode 5: Ink Starvation

To tackle these problems a 5why analysis will be useful to decide which appropriate countermeasure can be developed.

4.4.2 5Why Analysis

In this Segment each failure mode will be analyzed using 5why techniques, this will allow us to reach a root cause of the problem by asking 5 why questions.

Paper Jams:

Figure 16: 5why for Failure Mode 1.

The first failure mode is paper jams as seen in figure 16, and they will happen every time the paper is not fed into the XL 106 machine correctly. The problem can be analyzed by observing the paper feed in which the rollers are not properly gripping the paper causing slippage and jams in the machine. The root cause can be linked to rollers being worn out, and incorrect timing of replacement is linked to no proper maintenance plan. The root cause can be solved by introducing a Condition Based maintenance plan.

Feeder Mechanical failure:

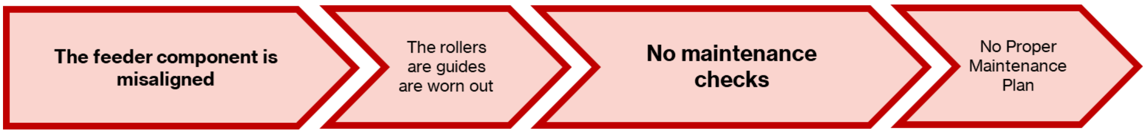


Figure 17: 5Why for failure mode 2.

The second failure mode is the Feeder mechanical failure as seen in figure 17. After the first why, we reach the causation of component misalignment, which is further explained by rollers and guides being worn out. Further breakdown leads to understanding that maintenance, which will be a very visible pattern in Gpack, is not properly conducted nor planned.

Ink Smudging:

Figure 18: 5Why for failure mode 3.

The third failure mode is the Ink smudging seen in figure 18, the first why leads to visualization of ink not drying properly which is caused by machine setting not properly set. Almost always, this is a direct result of operator not properly adjusting settings parameters for specific job, which is a direct result of poor experience.

Print Misregistration:

Figure 19: 5 Why for failure mode 4.

The fourth failure mode seen in figure 19, while not seen as high criticality as the other three, is still a problem, nonetheless. The design doesn't look like it transferred to the paper properly, either the colors will be off, or dimension are missed. This is caused by sensors misreading the paper and its position, which is further explained by sensors glitches by not being properly maintained or cleaned.

Ink Starvation:

Figure 20: 5Why for failure mode 5.

Last failure mode is Ink starvation seen in figure 20 which happens when loaded ink is not reaching the printing units, this is caused by ink tubes being blocked because of lack of cleaning schedule. Which is explained by seeing that no proper maintenance plan is introduced.

4.5 Countermeasures

In this segment development and implementation of countermeasures will be summarized. There are two main countermeasures that build on each other. As seen in literature review, 5s implementation is highly recommended before properly introducing the Condition Based Maintenance. The CBM is a very structured almost step by step like standard that is introduced by OSA organization, and the plan was to follow the standard as much as possible. Additionally, the previously constructed FMECA table is key in allowing us to go on with CBM in the first place.

4.5.1 5S Implementation

Implementation Timeline seen in table 4:

Table 4: Timeline checklist for 5s.

Timeline checklist	
Expected time and Action	**Status**
Week 1-2 **Meeting with Operators and Sort**	✓
Week 3-4 **Set in Order and Shine**	✓
Week 5-6 **Standardize and Sustain**	✓
Continuous **Regular Check and Improvements**	

Implementation Methodology:

1. Sort (Seiri)
   Objective: Eliminate unncessary items from workbench.
   Action Taken: From general knowledge gained from Gemba walk and general talk with operators, key items were identifed, and unncesseary items were removed to other departments. Additionally, any lingering trash or materials that were not needed were removed from work area in general. Operators were also instructed to make sure that only key items remain in this area, and other items are regularly discarded.
2. Set in Order (Seiton)
   Objective: Organize the workspace so that it is efficent and effective.
   Action Taken: Work area was organized in such way to optimize the layout, frequently used stuff was made to be easily accessible. Each tool was designated a specific place to be returned after use. Walking paths and machine paths were cleared for quick movement.
3. Shine (Seiso)
   Objective: Clean the workstation and equipment and maintain high standard of cleanliness.
   Actions Taken: A period of time before each shift is dedicated for short clean of the work station, a weekly deep clean session is scheduled on Saturdays (this

day is fully non-required time). During Saturday clean operators were also instructed to check for any visible wear and tear.

4. Standardize (Seiketsu)
   Objective: Produce actual written documents about each protocol including previous three steps.
   Actions Taken: Both in database but also in written form, protocol papers were constructed in such way that any new operators could easily catch up.
5. Sustain (Shitsuke)
   Objective: Continous improvement steps to maintain operators on working on 5s and steps where they could improve previous improvements.
   Actions Taken: Operators chose on their own when they want to have meetings with head of department, where they can proclaim any opinions they have.

Figure 21: Visual demonstration of parts of 5s. (Rotondi et al, 2024)

As seen in the figure 21, some steps of 5s can be visualized. 5S was implemented to create a clean, structured workspace that supports efficient and effective operations in the Offset department. The process included five steps, Sort, Set in Order, Shine, Standardize, and Sustain. Each step involves targeted actions to eliminate unnecessary items, organize tools, establish cleaning routines, and document protocols for sustaining improvements. Figure 21 demonstrates the transformation of workspaces, showing improvements in organization and cleanliness.

4.5.2 Condition-based Maintenance (Implement Prognostics and Health Management)

Setup

FMECA table is crucial for setting up the CBM, FMECA identified key failure modes that directly impact Availability, such as Paper Jams and Feeder Mechanical Failure, which informed the selection of critical components for CBM implementation, and in such way Table 1 is used as basis of identifying critical components and failure modes. Additionally, target setting is an important part to understand the objectives and scope of our aspirations as seen in Target setting segment.

Due to limitations of personnel and funds it is also important to define the data collection schedule. While these actions would be way more efficient if done with full scale AI Prognostics Health Management programs, the installation and usage of this software is beyond the company's budget without consultation from all stakeholders. Additionally, the company first must be sold on the idea that this implementation will be worth in the first place, so the proposal must be implemented on a limited budget and with limited interaction with upper management.

Data Acquisition

Data Acquisition is the foundation of the whole plan, it will utilize built in sensors for vibration and temperature that will allow us to conduct vibration or infrared analysis. Gpack didn't utilize the sensors to full capacity as they only used sensors to conduct health assessment post failure or during corrective maintenance. Utilizing sensors for predictive services will allow us to significantly lower down time and breakdowns. For the purposes of this thesis, I determined accelerometer sensor to be a good way to conduct Vibration Analysis.

For the proposal due to lack of funds and personnel, we need to select manual periodic review of data even though continuous or automated review would be preferred. Daily manual periodic review will be set up to see any abnormalities, with also monthly review to gather historical data trends and other data that can be used statistically to further strengthen our daily periodic review.

The raw data output is simple, it gives us a time stamp and acceleration reading. I used the excel sheet and prepared a visual representation of the data using python graphics.

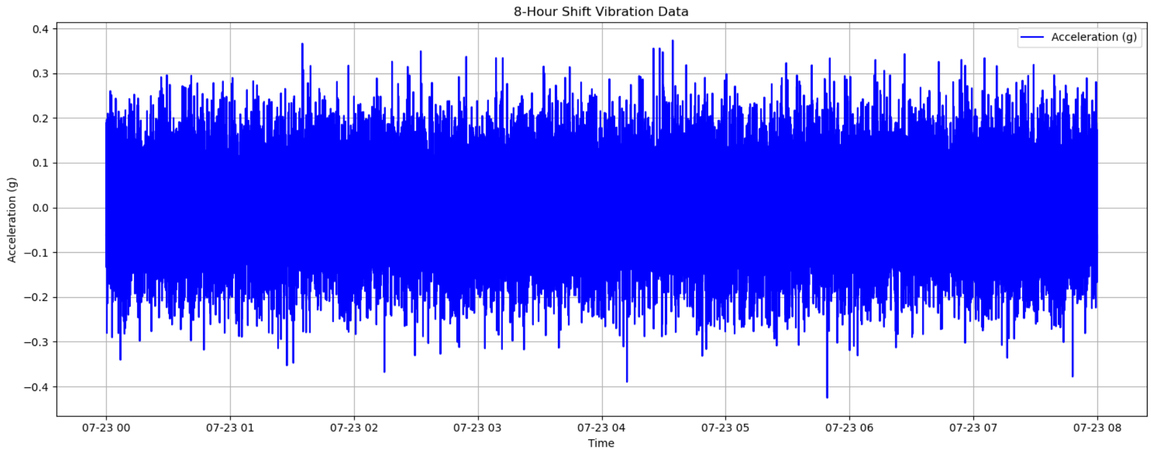


Figure 22: One shift Vibration data.

Figure 22 represents a raw data reading for Print Misregistration failure mode sensor. Additionally, a snippet of 5-minute interval is also good to visual normal behavior of the failure mode on a day without failures which can be seen in Figure 23.

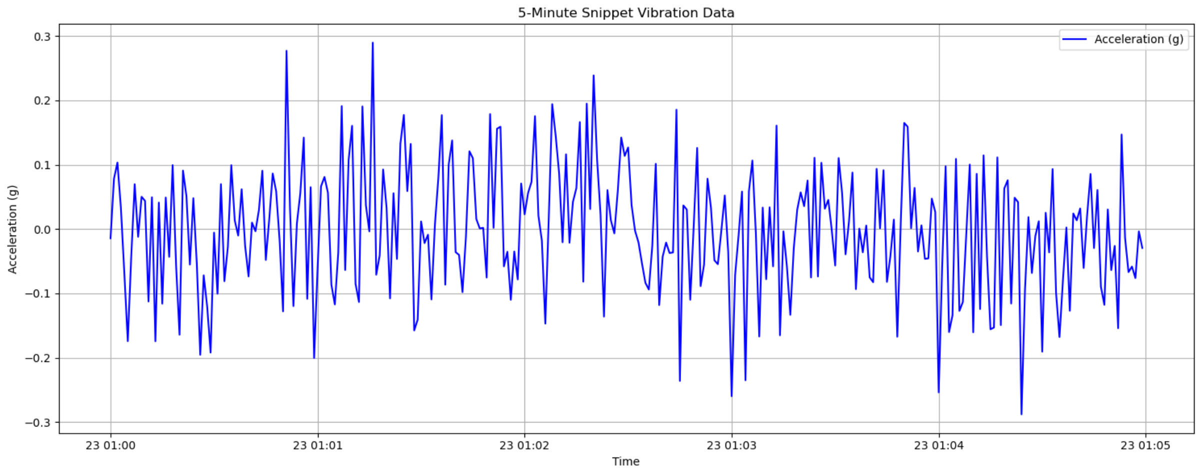


Figure 23: Short snippet of the shift vibrations.

Data Manipulation

From the previous segment we will utilize raw data gathered to compute meaningful metrics that I will use for fault diagnosis for Condition Based Maintenance.

The first step is data cleaning, the raw data needs to be cleaned for noise reduction and missing data (through interpolation). Some of the metric calculations that we will compute are Vibration amplitude, Root Mean Square, Peak Amplitude, and Dominant frequency. Vibration amplitude represents the intensity of vibration which is absolute value of displacement or acceleration. Root Mean Square is a statistical measure of the energy of vibration. It is a good way to see overall vibration energy which is a stable indicator of health of the machine. Peak amplitude is maximum value of the vibration amplitude, it is good way to see mechanical issues, if high peaks happen it could indicate degradation. Dominant frequency is found with frequency analysis, it analyses imbalances and misalignments.

Also, as mentioned before, raw data will also be analyzed monthly to prepare better understanding of machine trends and normal vs abnormal behaviors. I will use python to analyze data, store and retrieve data from excel sheets. The python code will also be standardized so that other people can plug in excel data and analyze shift behaviors themselves without understanding python.

Following the sample from Print Misregistration raw data, Data Manipulation sample will also be from Print Misregistration failure mode seen in figure 24 and 25:

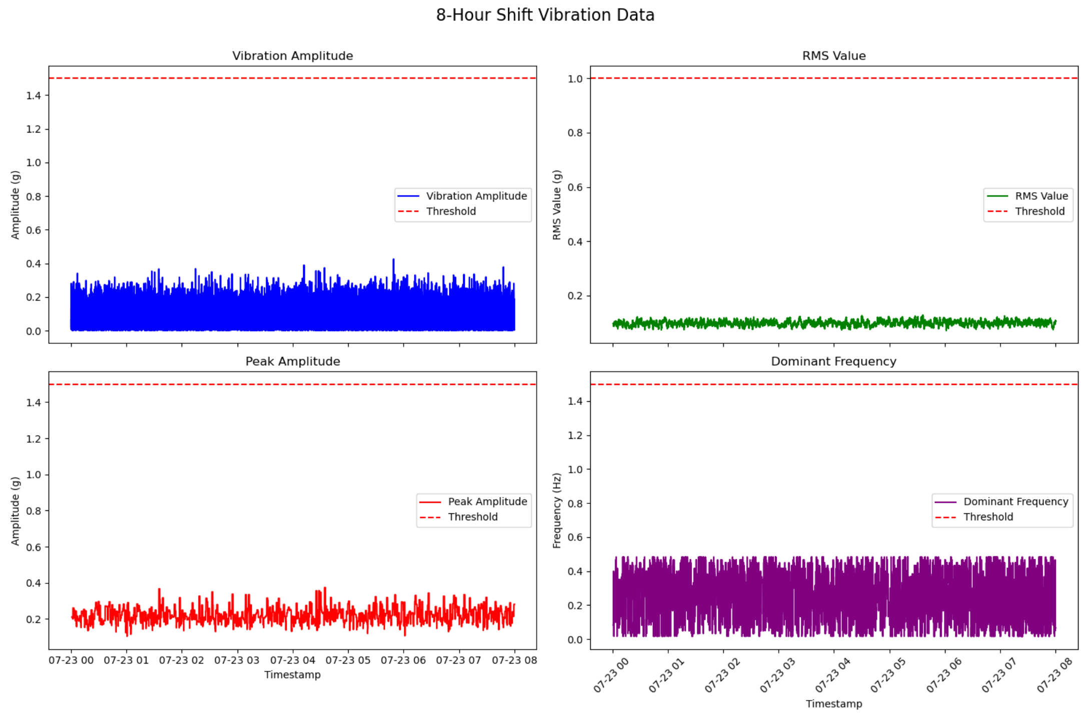


Figure 24: Raw Vibration analyzed.

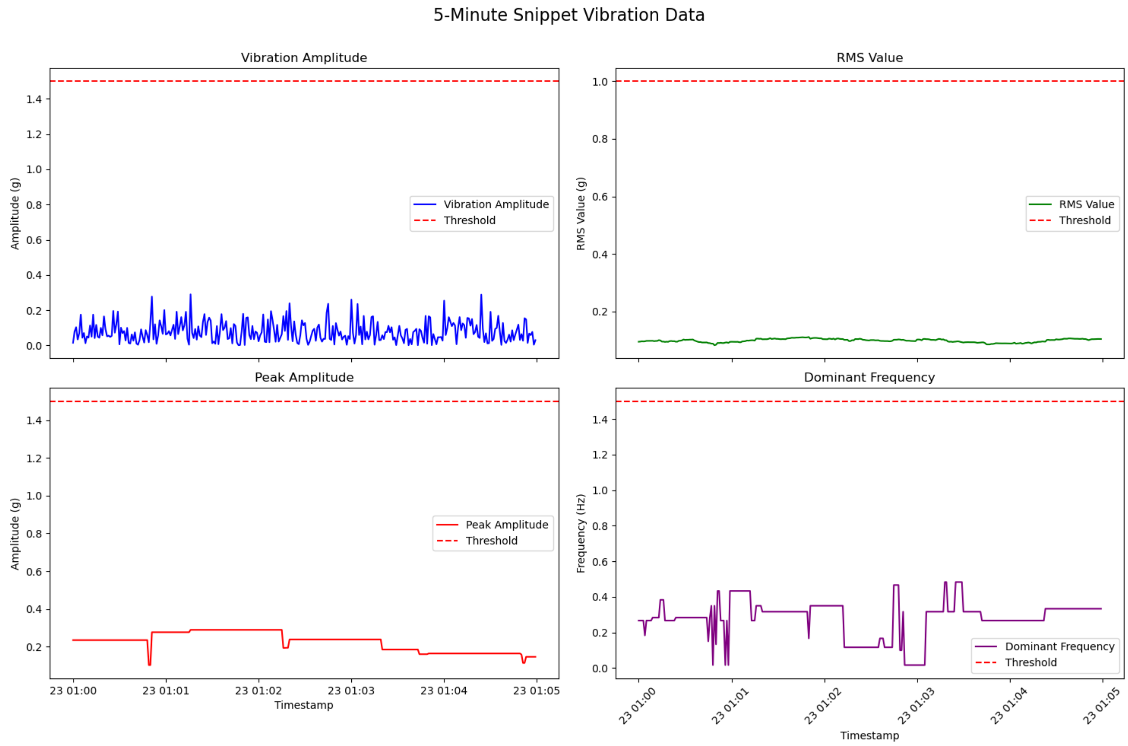


Figure 25: 5 Minute Snippet of Raw Vibration Analysis.

Vibration Amplitude is calculated as absolute values of raw acceleration data from the sensors, it shows as the strength of vibrations. Comparatively Rms Values uses a 60 second rolling window from which we can see and quantify the energy of the vibration signal. Peak Amplitude is the maximum acceleration value over 60 seconds rolling window. Finally, Dominant frequency uses FFT over 60 seconds rolling window to identify the most significant frequency component.

Decision Making

Decision Making consists of three main pillars: State Detection, Health Assessment, and Prognostics Assessment that will allow us to make educated decision making.

The state detection segment objective is to identify the current state of the machine based on calculated metrics. Values that exceed thresholds are seen as abnormalities and are treated as a red flag. Thresholds were initially selected as 2g or 2Hz for each metric as historical data of the Heidelberg machine shows but were later lowered respectively to our own monthly data so that better results can be achieved. State is either flagged as normal or deemed an anomaly state.

Health Assessment segment follows the state detection, if machine is flagged as in an anomaly state current health status must be determined. There were three health states: Good, Warning and Critical. Good health state is deemed if value is below thresholds, if values are above thresholds for vibration amplitude and RMS, state is deemed in Warning state, and if values of peak amplitude and dominant frequency are above state is deemed Critical.

Following the Health Assessment, Prognostics is needed. Historical trends are used to predict the conditions of the failure mode and predictive model is used to estimate Remaining Useful life in which we can see how critical it is to schedule maintenance. As the company works all day Monday through Thursday and one shift on Friday, maintenance can be scheduled in non-required time on Weekend and Friday for most effective maintenance that wouldn't impact the Availability KPI.

Example of Prognostics Assessment that includes prediction of RUL:

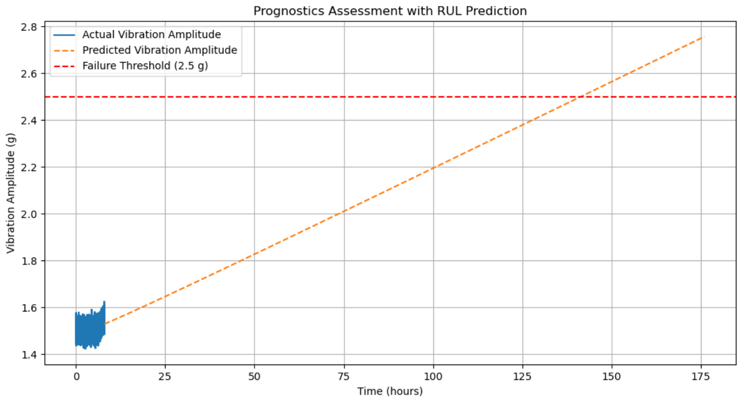


Figure 26: Prediction based on vibration data.

As seen in Figure 26 once the vibration passed the warning threshold of 1.5 the state was deemed abnormal, the health was assessed as "warning" and maintenance was scheduled in available non-required time.

If the state is abnormal and health is deemed as Critical, the maintenance is scheduled in available required or non-required whichever one is sooner.

4.5.3 Monitoring Countermeasures and Results

This segment of A3 is important to verify effectiveness of the solution that was proposed to management and operators.

Firstly, Monitoring of countermeasures was done by On-Site evaluation. In this part the efficiency of implementation was judged, and any deviation from instructions was corrected. Gemba walk was performed for steps above. The three operators were watched to see how consistent they are at performing their certain tasks. Any deviation was discussed so that the problem can be resolved.

Overall performance results, mentioned before, were measured using Overall Equipment Effectiveness, while Smart Maintenance plan should impact all three segments of OEE, it is most evidently seen in Availability section. The biggest difference was planned to be noticeable in Indirect and Direct Stoppages, and naturally the Breakdowns (in a perfect world this would be 0).

Table 5: Breakdown of all segments of Availability.

XL106 TRUCCAZZANO	N AVV	H AVV	%AVV	H PROD	%PROD	H DIRECT	% H DIR	H INDIRECT	% H IND	MANT	% MANT	Total H
JANUARY	1	1	25,00%	1,58	39,50%	1,42	35,50%	-	0,00%	-	0,00%	4
FEBRUARY	92	56,97	19,70%	62,13	21,50%	55,87	19,33%	111,49	38,58%	2,5	0,87%	288,96
MARCH	137	87,77	29,30%	94,42	31,55%	78,38	26,19%	34,31	11,46%	4,4	1,47%	299,28
APRIL	186	102,73	23,60%	122,14	28,08%	151,46	34,82%	54,74	12,58%	3,97	0,91%	435,04
MAY	113	68,8	25,50%	66,44	24,62%	103,59	38,39%	31,02	11,50%	-	0,00%	269,85
JUNE	133	128,04	29,50%	127,46	29,36%	154,11	35,50%	20,67	4,76%	3,79	0,87%	434,07
JULY	158	177,84	33,15%	146,61	27,33%	160,56	29,93%	24,64	4,59%	26,88	5,01%	536,53
AUGUST	-	-		-		-		-		-		-
SEPTEMBER	-	-		-		-		-		-		-
OCTOBER	-	-		-		-		-		-		-
NOVEMBER	-	-		-		-		-		-		-
DECEMBER	-	-		-		-		-		-		-
2023	1.265	951,94	26,40%	952,41	26,42%	990,38	27,48%	591,1	16,40%	118,79	3,30%	3.604,62
2022	-	-		-		0		-		-		-

Table 6: Summary of Availability results.

XL106 TRUCCAZZANO	%AVV
JANUARY	25,00%
FEBRUARY	19,70%
MARCH	29,30%
APRIL	23,60%
MAY	25,50%
JUNE	29,50%
JULY	33,15%

As seen this the table 5 and 6, we can see noticeable improvements in Availability, but it is not simple to just look at the results to see if our improvements made a difference, because three projects were done in the company, the big spike in maintenance in July seen in table 5, was due to human made error so it is an outlier. Overall, both must have and need to have goals were met as seen in table 7, but the most important improvement was showing Gpack that Preventive maintenance could revolutionize their OEE.

Table 7: Goals Summary.

Availability before countermeasures 2024	24,62%
Availability after countermeasure 2024	31,32%
Percentage Point Increase 2024	6,7%

4.5.4 Standardize & Share Success

As seen in the literature review segment of the thesis, 5s is not a one-time thing. It is a continuous improvement action that is always worked on. Systematically implementing all steps: sort, set in order, shine, standardize and sustain allows operators to do these actions on their own as well. To foster growth and continuous improvement operators and head of department have been instructed to meet for regular audits. Additionally, the whole process was documented in a protocol form so that new employees can catchup easily.

The implementation and integration of a basic OSA CBM system allows for standardized machine data gathering which allows for educated decision-making. The steps on how the system is implemented were also documented, and when the company is ready to improve the system by making it more autonomous it can follow standardized steps. Further continuous improvement would need considerable investment, but the company seems intrigued by the potential of CBM.

The success of these methods has set a foundation for continuous improvement, supporting Gpack’s long-term goals of operational excellence and sustained competitiveness in luxury packaging. The standardization was summarized as a checklist seen in table 8

Table 8: Standardization Checklist.

Standardization checklist	
Improvements	**Status**
5s	
Conditional-Based Maintenance	
Investment in equipment	
Software integration	

5. Conclusions and Limitations

This thesis project aimed to enhance the operational effectiveness and Availability of Gpack's Offset department by implementing the A3 Problem Solving methodology, supported by 5S and CBM. Through a structured, step-by-step approach, we identified key challenges, developed targeted countermeasures, and set measurable goals, resulting in significant improvements in OEE.

The A3 methodology facilitated a comprehensive problem-solving process, beginning with a clear understanding of the project's background and goals. We identified that Gpack's transition from general to luxury packaging was creating Availability issues in the Offset department, affecting the company's production efficiency. In collaboration with Gpack and the university, we set realistic but ambitious goals: a 5% improvement in Availability as a Must-Have and a 10% improvement as a Nice-to-Have target.

To address the root causes, we implemented 5S to establish an organized and efficient workspace, laying the foundation for CBM. This combination successfully reduced both direct and indirect stoppages, leading to a measurable 5% increase in Availability. Stakeholder feedback was positive, and the company expressed interest in further exploring preventive maintenance strategies.

The project faced certain limitations, with the budget being the most significant. Limited resources restricted the implementation of advanced, fully automated CBM software and more sophisticated sensors. Consequently, maintenance relied on manual data reviews and periodic checks, limiting the predictive capabilities of the CBM framework. A larger budget for autonomous monitoring software and AI-driven diagnostics could improve the precision and efficiency of future CBM implementations.

In conclusion, this project has provided a replicable model for preventive maintenance within Gpack's Offset department, demonstrating the potential of Lean methodologies to enhance operational efficiency in luxury manufacturing. With further investment in advanced CBM technologies, Gpack could achieve even greater improvements in Availability and continue to lead in quality and operational standards within the luxury packaging industry.

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