UNIVERSITAT POLITÈCNICA DE VALÈNCIA

Escuela Técnica Superior de Ingeniería Industrial

Study on the implementation of the Lean Manufacturing Method in an animal feed company

Trabajo Fin de Grado

Grado en Ingeniería en Organización Industrial

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PROJECT ERASMUS

Study on the implementation of the Lean Manufacturing Method in an animal feed company

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

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GREETINGS

"I dedicate this project to all those people who have been part of my life in these last four years, but especially to my family, who have never stopped believing in me even when I didn't do it myself. To Dani, for holding my hand and accompanying me on the road. And my greatest role model, my grandmother, a woman who has always fought for the people she loves, has raised an entire family and always with a smile."

ABSTRACT

The purpose of this Final Degree Project is to evaluate the current state of a company in the animal feed sector, located in the Region of Murcia, Spain.

The Project Will focus on identifying and solving productivity and organizational problems using Lean Manufacturing tools.

One key issue identified is the need to improve organization within specific areas and sections of work. Addressing other related problems, they all center around automating production processes and improving overall organizational efficiency among employees and sections.

In essence, a structured methodology Will be adopted for each identifies problem, involving steps such as diagnosing the problem, root cause analysis, comprehensive study before proposing a solution, feasibility of solutions, implementation to assess its impact, and eventual standardization. This process relies on both numerical indicators and the insights of plant engineering and operators to guide decision-making and continuous improvement efforts.

Keywords: Lean Manufacturing, Logistics, Production systems, Kanban

RESUMEN

El objetivo de este Trabajo de Fin de Grado es evaluar el estado actual de una empresa del sector de la alimentación animal, ubicada en la Región de Murcia, España. El proyecto se centrará en identificar y resolver problemas de productividad y organización utilizando herramientas de Lean Manufacturing.

Un desafío crítico identificado es la necesidad de mejorar la organización dentro de áreas y secciones de trabajo específicas. Otras cuestiones relacionadas giran en torno a la automatización de los procesos de producción y la mejora de la eficiencia organizativa general entre los empleados y las secciones.

En esencia, se adoptará una metodología estructurada para cada problema identificado, que involucrará pasos como el diagnóstico del problema, el análisis de la causa raíz, el estudio integral antes de proponer soluciones, la viabilidad de estas, la implementación para evaluar los resultados y la eventual estandarización. Este enfoque aprovechará tanto las métricas cuantitativas como los conocimientos de la ingeniería y los operadores de la planta para guiar la toma de decisiones y las iniciativas de mejora continua.

Palabras Clave: Lean Manufacturing, Logística, Sistemas de producción, Kanban.

RESUM

L'objectiu d'este Treball de Fi de Grau és avaluar l'estat actual d'una empresa del sector de l'alimentació animal, situada a la Regió de Múrcia, Espanya. El projecte se centrarà en identificar i resoldre problemes de productivitat i organització utilitzant ferramentes de *Lean *Manufacturing.

Un desafiament crític identificat és la necessitat de millorar l'organització dins d'àrees i seccions de treball específiques. Altres qüestions relacionades giren entorn de l'automatització dels processos de producció i la millora de l'eficiència organitzativa general entre els empleats i les seccions.

En essència, s'adoptarà una metodologia estructurada per a cada problema identificat, que involucrarà passos com el diagnòstic del problema, l'anàlisi de la causa arrel, l'estudi integral abans de proposar solucions, la viabilitat d'estes, la implementació per a avaluar els resultats i l'eventual estandardització. Este enfocament aprofitarà tant les mètriques quantitatives com els coneixements de l'enginyeria i els operadors de la planta per a guiar la presa de decisions i les iniciatives de millora contínua.

Paraules Clau: Lean Manufacturing, Logística, Sistemes de producció, Kanban.

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1. DESCRIPTIVE REPORT

1.1 Introduction

In the dynamic and competitive world of the agri-food industry, continuous improvement is an essential strategy for achieving operational excellence and maintaining a sustainable competitive advantage. With the joint work of engineers, chemists, biologists, veterinarians and researchers, the aim is to position the company as a leader in its sector. This principle focuses on the constant optimization of processes, products and services, fostering a culture of innovation and efficiency that enables companies to adapt quickly to changing market demands and technological advances.

The present research work focuses on the implementation of continuous improvement in a feed mill, a crucial sector for the food supply chain and animal welfare. Through a detailed analysis, the methodologies and tools used to identify and eliminate waste, improve capacity and increase productivity will be explored. In addition, case studies will be examined and specific recommendations will be presented to foster a culture of continuous improvement in the factory.

As main challenges are feasibility, due to resources such as space, time and money; automation, since many processes are currently performed with the help of operators; and last but not least, the management of the different work teams, since as a future industrial organization engineer, if there is something I am passionate about in this profession is its human side.

1.2 Objetive of the Project

The objective of this Final Degree Project is to analyze the problems of a company in the agri-food sector and to implement different continuous improvement tools using Lean Manufacturing tools. The objective pursued by any company is to maximize its profits in order to obtain a good performance. This methodology for improving manufacturing efficiency was conceived last century in Japan by Taiichi Ohno, director and consultant for Toyota. Ohno visited the United States, where he studied the country's leading productivity and waste reduction pioneers such as Frederick Taylor and Henry Ford (continuous work flow, shift rotation, automation...). Ohno was impressed by the overemphasis Americans placed on high-volume mass production to the detriment of variety. When he visited supermarkets it had an immediate inspiring effect; Ohno found in them a perfect example of his idea of managing reduced inventories, eliminating unnecessary steps and controlling primary activities and giving control to the one doing the work (in this case the customer) in support of the value chain.

The objective is to analyze the company's problems and apply Lean Manufacturing tools that help eliminate all waste and operations that do not add value to the product or processes, increasing the importance of each activity performed and eliminating what is not required. On the other hand, it serves to implement a philosophy of continuous improvement that allows companies to reduce costs, improve processes and eliminate waste to increase customer satisfaction and maintain profit margins and quality.

In addition, the possibility of expanding the plant, reorganizing the space and automating different operations will be studied.

1.3 Project justification

The purpose of this project is twofold: on the one hand, the academic justification and, on the other, the professional one.

From the academic point of view, this work is necessary to finish the Degree in Industrial Organization Engineering, thus being able to capture in it the knowledge learned throughout the career, in addition to expanding the capacity for analysis and problem solving in order to provide the company with a series of ideas that make it can improve its productivity to continue being a benchmark in its sector.

In relation to the professional justification, the idea of this work arises after contacting one of the company's workers who agreed to collaborate by providing data and on the basis that the company wanted to implement some Lean Manufacturing tools and analyze its situation to check and update whether the measures that had already been applied were being fulfilled or had become obsolete.

1.4 Structure of the document

This document is organized to systematically present the analysis, findings, and recommendations of the Final Degree Project. The structure ensures a clear and logical flow of information, covering all essential aspects of the project.

- **Introduction:** Provides an overview of the project, its background, and the primary objectives.

- **Project Objectives:** Clearly states the specific goals to be achieved.

- **Project Justification:** Explains the reasons for undertaking the project and its significance.

- **Company Overview:** Offers detailed information about the company, including its history, structure, and operations.

- **Industry Context:** Describes the broader industry in which the company operates, including key trends and challenges.

- **Process Description:** Details the main processes involved in the company's operations.

- **Methodology:** Explains the methodologies and tools used in the project, including Lean Manufacturing principles.

- **Current Situation Analysis:** Examines the existing state of the company's processes and identifies areas for improvement.

- **Improvement Proposals:** Presents the proposed solutions to address identified issues.

- **Conclusion:** Summarizes the key findings, impacts of the improvements, and provides recommendations for future actions.

This structure ensures that each aspect of the project is thoroughly examined and presented in a coherent manner, facilitating a comprehensive understanding of the project's scope and outcomes.

2. COMPANY

2.1 Introduction

This project presents a comprehensive analysis of a leading company in the manufacturing and commercialization of high-quality animal feed. It has been decided not to mention its name due to confidentiality of certain data, so from now on it will be referred to as the company "Nana". The company, with a long-standing history in the agricultural sector, is distinguished by its commitment to animal welfare and sustainability. The following sections will explore the company's history, products, services, sustainable practices, market impact, and focus on innovation and development.

2.2 History and trajectory

- **Foundation and Growth**: The company was founded in 1968, marking the beginning of a journey of constant growth and expansion both nationally and internationally. Since its inception, the company has shown adaptability and evolution, positioning itself as a benchmark in the sector.
- **Evolution and Modernization**: Over the decades, the company has modernized its facilities and processes, incorporating the latest technologies to ensure high-quality products. This continuous adaptation has been key to maintaining its competitiveness and relevance in the market.

2.3 Products and services

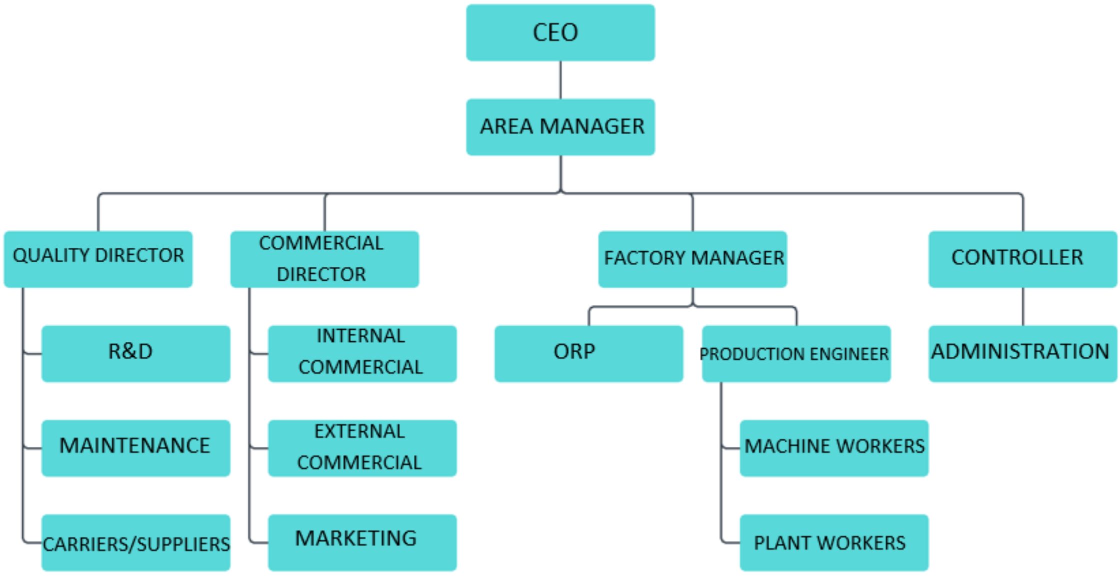
- **Product Range**: The company offers an extensive variety of feeds for different animal species, including bovine, porcine, poultry, ovine, caprine, and pets. Each product line is designed to meet the specific nutritional needs of each species.
- **Customized Formulation**: In addition to its standard products, the company develops customized nutritional solutions tailored to the specific requirements of its clients and their animals.
- **Innovation and Development**: A specialized research and development team continuously works on improving formulas and production processes, ensuring that the products remain at the forefront of animal nutrition.

2.4 Sustainability and enviroment

- **Sustainable Practices**: The company is committed to implementing sustainable practices, focusing on minimizing environmental impact and promoting a circular economy in its operations.

- **Social Responsibility**: It actively participates in initiatives that promote animal welfare and environmental preservation, reflecting its commitment to corporate social responsibility

2.5 Organigram



PICTURE 1: ORGANIGRAM

2.6 Products and services

NANA, a prominent animal feed company in Spain, offers a diverse range of products and services designed to meet the nutritional needs of various animal species. Below is an overview of their key offerings:

Products

1. **Livestock Feed**:
   - **Cattle Feed**: Formulated to meet the nutritional needs of dairy and beef cattle.
   - **Pig Feed**: Includes specialized feeds for piglets, sows, and finishing pigs, focusing on growth, reproduction, and overall health.
   - **Poultry Feed**: Covers broilers, layers, and breeders, emphasizing optimal growth, egg production, and health.

2. **Aquaculture Feed**:
    - Feeds designed for different species of fish and crustaceans, focusing on growth, health, and feed conversion efficiency.
3. **Pet Food**:
    - Nutritionally balanced feed for pets, including dogs and cats, designed to meet their specific dietary requirements.
4. **Specialty Feeds**:
    - Includes medicated feeds, organic feeds, and customized feed solutions to address specific health issues or nutritional deficiencies.

Services

1. **Nutritional Advisory**:
    - Expert advice from nutritionists and veterinarians to optimize feed formulations and improve animal health and productivity.
2. **Technical Support**:
    - On-site technical support to assist farmers with feed management, animal health issues, and improving farm productivity.
3. **Research and Development**:
    - Continuous investment in R&D to develop innovative feed solutions, improve feed efficiency, and address emerging challenges in animal nutrition.
4. **Sustainability Initiatives**:
    - Programs aimed at promoting sustainable farming practices, reducing environmental impact, and ensuring the responsible use of resources.
5. **Training and Education**:
    - Training programs and workshops for farmers and industry professionals to enhance their knowledge of animal nutrition and farm management practices.
6. **Quality Assurance**:
    - Rigorous quality control processes to ensure the safety and nutritional adequacy of their feed products, including laboratory testing and traceability systems.

NANA offers a comprehensive range of animal feed products and services designed to meet the diverse needs of livestock, aquaculture, and pets. Their focus on innovation, quality, and sustainability ensures that they provide high-quality feed solutions and support to their customers. This commitment helps NANA maintain its position as a leading provider in the animal feed industry.

3. THE FEED MILL SECTOR IN SPAIN

3.1 Structure of the feed mills sector

The feed production industry in Spain has undergone significant changes over the past decade, solidifying its position as a leading producer within the European Union. This final paper provides an overview of the evolution of feed production in Spain, highlighting key trends, challenges, and the industry's response to external pressures.

GRAPHIC 1: Territorial distribution of cooperative feed mills. Source: OSCAE 2009

3.2 Steady Growth

The feed production sector in Spain has experienced consistent growth over the past ten years. In 2018, the total production reached 24.8 million tons, with 23.6 million tons designated for livestock production (EFEAgro). This marked a substantial increase compared to previous years and set the stage for further expansion.

Especie	t pienso producido 2022	% de producción sobre el total	t pienso producido 2021	Diferencia datos sobre 2021 (%)
Porcino	18.211.767	48,49	18.969.813	-4,0
Bovino	7.788.606	20,74	7.914.639	-1,6
Avicultura	7.289.141	19,41	7.245.609	0,6
Ovino/caprino	1.957.925	5,21	2.044.184	-4,2
Animales de compañía	1.039.868	2,77	1.087.814,10	-4,4
Conejos	477.199	1,27	443.822	7,5
Multiespecie	358.068	0,95	385.200	-7,0
Equino	226.446	0,60	239.667	-5,5
Peces	161.835	0,43	168.354	-3,9
Otras especies	32.585	0,09	40.454,10	-19,5
Animales de peletería	13.325	0,04	14.193,80	-6,1
TOTAL	**37.556.764**		**38.553.750**	-2,6

TABLE 1: Tons (t) of compound feed produced by species.

3.3 Leading in the European Union

In 2019, Spain achieved a significant milestone by surpassing 25 million tons in industrial feed production. This achievement allowed Spain to surpass Germany and become the largest feed producer in the European Union for the first time. The 7% increase from the previous year underscored Spain's growing dominance in the market (EFEAgro) (Avicultura).

3.4 Resilience During the Pandemic

The COVID-19 pandemic posed numerous challenges to global industries, yet the animal feed sector in Spain demonstrated remarkable resilience. Recognized as an essential sector, the feed industry maintained robust production levels despite logistical and supply chain disruptions. This resilience was crucial in sustaining the livestock industry during a period of unprecedented uncertainty (Avicultura).

3.5 Recent Challenges

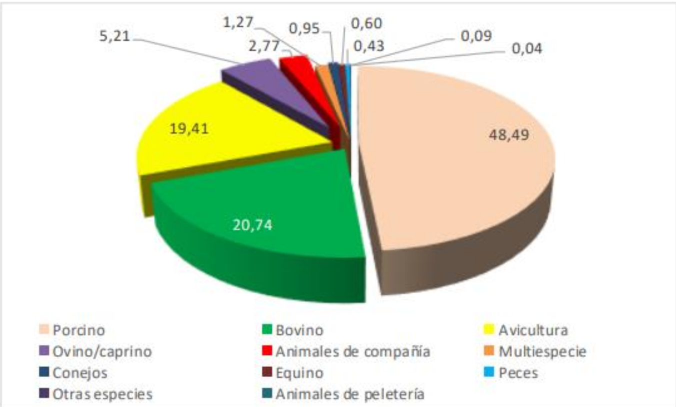
Despite its strong performance in previous years, the Spanish feed industry faced significant challenges in 2022. The production of feed decreased by nearly 5%, primarily due to a decline in demand from the pork sector and supply chain disruptions caused by the conflict in Ukraine (EFEAgro). Ukraine is a vital supplier of cereals, such as corn, which are essential for feed production. The war in Ukraine and subsequent supply issues highlighted the vulnerability of the industry to geopolitical events (EFEAgro).

3.6 Diversification and Sustainability

In response to these challenges, the Spanish feed industry has been exploring various strategies to ensure long-term sustainability and stability. This includes diversifying raw material sources, such as integrating insect-based proteins for aquaculture feeds and utilizing by-products from the human food industry. The focus has also shifted towards promoting circular economy principles and enhancing sustainability practices within the sector (EFEAgro) (NutriNews).

TIPO DE PIENSO	FEFAC/CESFAC (miles de Toneladas)
RUMIANTES	9.040
PORCINO	12.292
AVES	4.343
OTROS	174
TOTAL	25.849

TABLE 2: Estimated data on feed production in Spain, year 2022.



GRAPHIC 2: Percentage breakdown of total compound feed production, by species of destination.

Especie	t pienso producido 2022	% de producción sobre el total	t pienso producido 2021	Diferencia datos sobre 2021 (%)
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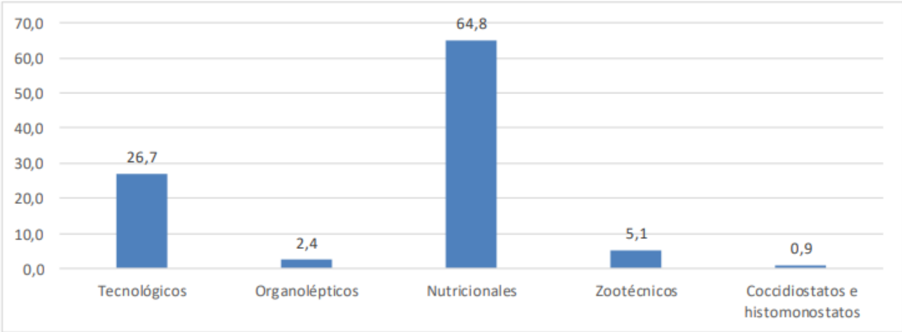
TABLE 3: Tons (t) of compound feed produced by species.



GRAPHIC 3: Percentage of additives used directly in feed manufacture by group - 2022

GRUPO DE ADITIVOS	t 2022
Tecnológicos	101.527,6
Organolépticos	9.084,5
Nutricionales	246.344,3
Zootécnicos	19.470,2
Coccidiostatos e histomonostatos	3.495,0

GRAPHIC 4: Direct consumption of additives in feed manufacture. By additive group, tonnes (t).

3.7 Feed mills as enterprises

Feed manufacturing industries are companies that may have different legal that can have a diverse legal nature, which, as we have seen, is often cooperative cooperatives, but also about 60% of them are public and private limited about 60% are corporations and limited companies, and only 5% are sole proprietorships, self-employed and Communities of Property.

These factories are companies with an average age of 21.36 years old on average. Their location is more frequent on the isolated outskirts of towns (50.37%) than in industrial parks (30.69%) or in industrial parks (30.69%) or in urban centers (18.94%).

With an average of 14.4 employees, 67% are industries considered as micro-enterprises in considered to be microenterprises in terms of employment, 28% are small companies and only 4% are medium or large companies.

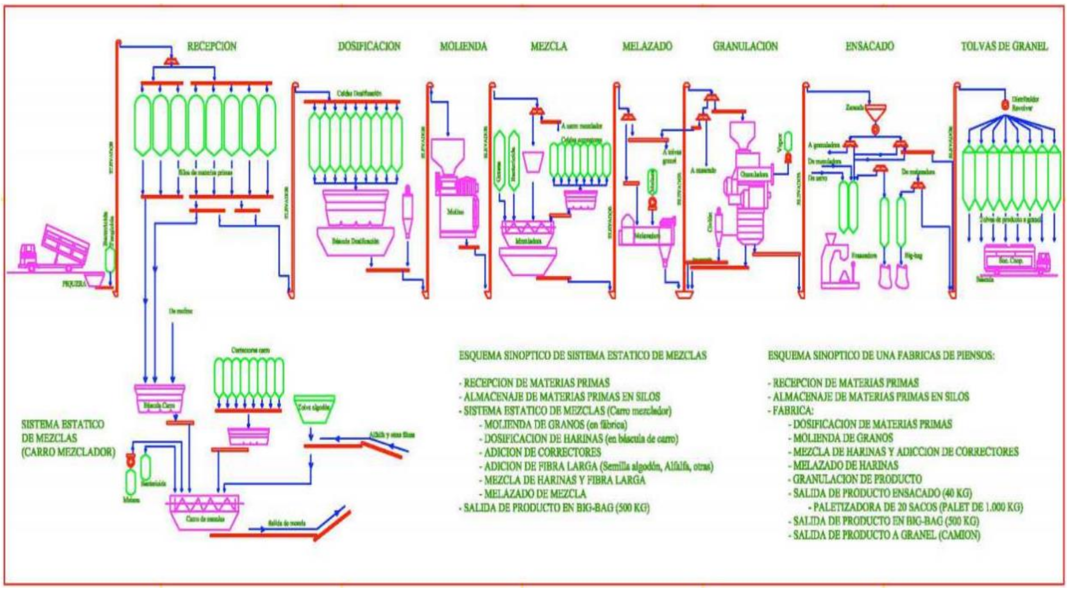
Forty-nine percent of the factories resort to temporary employment to cover peak production to cover production peaks, although, in contrast to other industries in the primary than other industries in the primary food processing sector, such as wineries, oil mills or fruit and vegetable processing plants, the fruit and vegetable plants, temporary employment is not very high, with 68.14% of the jobs are permanent and only 31.86% are temporary jobs. The average number of days worked is 261.91 days per year, with an average of 11.40 hours per day.

The storage capacity for raw materials is of 24,871m2 and an average of 101,031 m3, while the storage capacity of processed feed storage is 3,170 m2 and 15,356 m3 on average.

4. TYPOLOGY OF THE PROCESS

The basic process of compound feed manufacturing consists of a reception pit and raw material storage silos, a hopper for dosing these raw materials prior to milling and mixing, and finally, a bagging system for the finished product. Depending on the needs, this model can be expanded with a static mixing system (mixer wagon) to include long fibre, a feed greasing and/or molassing system, a granulator machine, an automatic bagging-palletizing equipment, or bulk product storage hoppers for distribution to farms by truck. Feed mills are automated for most of the manufacturing process, facilitating the production, bagging and storage of the feed produced.

PICTURE 2: General view of a feed mill



PICTURE 3: Overview of the conventional feed manufacturing process. Source: Energy Efficiency Manual, AGACA, 2009.

4.1 Reception of raw materials

The feed manufacturing process begins with the arrival of the raw materials at the factory. These raw materials can be classified into two types:

-macro ingredients: cereals, legumes, liquids such as molasses and oils.

-micro ingredients: they serve to complete the formulas, they can be additives such as amino acids, vitamins and minerals.

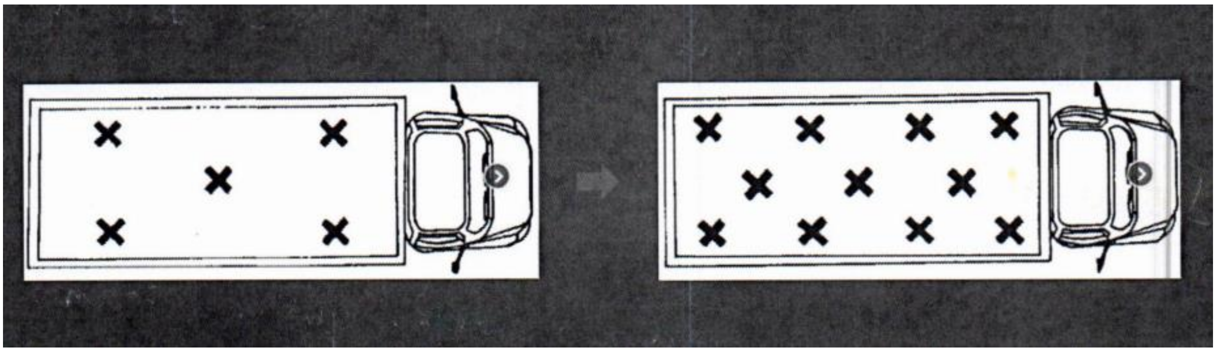
With the arrival of these ingredients, the corresponding quality control begins. Samples are taken of the goods received and even a check is made of what the lorry has previously transported. Once it has been accepted, the unloading process into the silo is carried out automatically.

All products are coded and processes are automated under the supervision of a management programme.

Once we have the formula of the feed we want to produce, the computer weighs each of its ingredients.

On the other hand, in the case of ingredients added by hand, the operator scans the barcode on the bag and the computer allows him to continue with the process.

The addition hopper opens and closes automatically to receive the required products.



PICTURE 4: Quality control

4.2 Milling

It is the first processing that raw materials undergo in the production of feed. There are raw materials that it is not desirable for them to pass through the mill. For this purpose, a by-pass screen is installed. The mill is used to achieve the right particle size and shape depending on the presentation of the feed: flour or granules.

When the feed is in the form of meal, the particle size must allow for good granulometry must allow a good flowability of the feed on the farm. For this purpose, it is sufficient that the level of 'fines' (particles passing through a 0.5 mm sieve) is not more than 20%.

should not exceed 20%. If, on the other hand, the feed is presented in the form of granules, when the meal enters the pelleting machine, it must comply with the following grain size:

- Greater than 1.0 mm up to 10%.

- Greater than 0.5 mm up to 45%.

- Greater than 0.3 mm up to 25%.

- Less than 0.3 mm minimum 20%.

PICTURE 5: Mill

PICTURE 6: Dosing hoppers and mixer

4.3 Mix

This is the packaging which aims at the homogenisation of the set of raw materials that make up the ration The most common mixer in feed mills is the horizontal mixer with a single motor and two concentric propellers with double direction of movement, although vertical mixers are also used, especially in the input of raw materials to the mill. The horizontal mixer with a single motor and propeller requires a mixing time (generally) of 3.5 to 4 minutes and its shaft rotates at 18-33 rpm, depending on the diameter and design. The motor shaft should always be covered with product and the product should be evenly distributed along the length of the mixer. The mixer should not be filled to more than 60% of its nominal capacity.

The quality of the mix is influenced by a number of factors such as:

1.- Mixing time: this is approximately 4 minutes but will depend on the type of mixer and the ingredients to be mixed.

2.- Granulometry: very coarse or extremely fine particles are detrimental to the mixture.

Depending on the proportion of the ingredient, the following maximum particle size is recommended:

- For 1 g/Tm..........45 _m diameter

- For 200 g/Tm.......270 _m in diameter

- For 1 kg/Tm.........440 _m in diameter

- For 5 kg/Tm........720 _m in diameter

3.- Density and shape of the particles: the heavier particles will tend to go to the bottom will tend to go to the bottom and the rounder ones will flow better. will flow better.

4.- Other factors: the addition of liquids causes adhesions and therefore adhesions and therefore decreases the efficiency of the mixer. Likewise, adhesions are also caused by electrostatically charged particles.

4.4 Addition of liquids: fats and molasses

The purpose of adding liquids in a feed factory is varied: to provide energy (animal and vegetable fats), sugars (molasses), amino acids, vitamins (choline), antifungals or bactericides, pigmenting agents, flavourings, moisture (water), etc.

In general, the addition of liquids to the feed is usually done when the feed is in the form of meal. The homogenisation of the liquid in the meal depends on several factors: type of product, particle size (the finer the grind, the better the specific surface area and the better the absorption), product moisture (water rejects fat), temperature (the higher the better), dosage (the jet will be directed at the flours, never at the walls).

PICTURE 7: Molassor

The dosing of liquids can be done by means of counters or by weighing. The weighing system is usually used when several liquids are added to the mixer and has the advantage of accuracy and premixing. Volumetric counters are nowadays very accurate and allow simple and economical dosing.

It is necessary to monitor the cleanliness of the nozzles in the mixer and the direction of the jet, as well as to carry out dosing controls. After the injection is finished, it is recommended to blow out with air to prevent dripping and to clean the line.

The two most important liquids in terms of quantity in a factory are fats and molasses. The mixer is the right place for the incorporation of fats, vitamins, amino acids, etc. Molasses makes the mixer too dirty, so it is incorporated into the molasses mixer. The level of fat incorporation into the mixer shall not be higher than 3-5%.

The molasses injection machine is the appropriate place for molasses injection. This equipment is usually installed after the mixer. The addition of liquids requires an automatic control system, as it is a continuous process and the quantity of liquid to be added is determined by the flow rate of flour.

4.5 Pelleting

The first treatment that the meal of a feed to be pelleted undergoes is a thermal homogenisation. The equipment is located between the feed hopper of the pelletiser and the pelletiser itself. It is a continuous turbulence mixer at 300 rpm which produces a homogeneous mixture of water vapour and molasses with the flours.

The process of granulation means subjecting the flour to a combined effect of compression and ‘extrusion’.

PICTURE 8: Pelletizer

The granulation process is carried out in several stages:

-**Hydrothermal conditioning:** this consists of preparing the feed into meal for the compression-extrusion process. This is done with steam injected into a homogeniser directly on the ground mixture, and in other cases by modifying the conditions of pressure, temperature and treatment time as required.

-**Compression-extrusion:** this is carried out in the granulator itself. The most common granulators in feed mills have a vertical matrix with flour compression rollers. Compression is carried out by the roller on the flours and against the matrix.

-Cooling-drying: In this process, the humidity and temperature of the granule is reduced

and temperature of the granules is reduced for better preservation. There are three types of coolers: vertical, horizontal and counter-current.

PICTURE 9: Feed pellets at the exit of the pelleting process

In recent years, feed conditioning technology has evolved considerably. This development has been driven by the requirements on physical quality, nutritional improvement, microbiological higiene as well as the flexibility in the incorporation of new and of new and varied raw materials. Particularly noteworthy is the increased use of liquids, especially fats and molasses. In all cases, it is a matter of managing the physical parameters such as pressure, temperature and time, which are the determining factors in conditioning. All of this is aimed at obtaining a good quality feed, an aspect that is becoming increasingly important both for commercial reasons and for its influence on production rates.

4.6 Warehousing and distribution

This is the last part of the manufacturing process, when the feed is ready in the form of meal or pellets. It is stored in silos or prepared for the market. In the bagging part, each batch has its own barcode so that it adopts its own traceability. Normally the animal feed sacks are stored inside the factory, they do not have a dedicated warehouse, so there is a certain lack of control over the level of inventory.

PICTURE 10: Factory

(Asociación Galega de Cooperativas Agrarias, 2009)

5. LEAN MANUFACTURING

5.1 Definition of Lean Manufacturing

Lean Manufacturing is a management methodology focused on maximising customer value by reducing waste and continuously improving processes. Originating from the Toyota Production System (TPS), Lean Manufacturing seeks to do more with less, optimising the use of resources such as time, materials and labour.

5.2 Fundamental Principles of Lean Manufacturing

The principles of Lean Manufacturing can be summarised in five key concepts:

1. **Value:**

Define value from the customer's perspective.

Only those activities that transform products in a way that the customer is willing to pay for are considered to generate value.

2. **Value Stream:**

Identify all the activities required to create a product, from concept to delivery to the customer.

Analyse each stage to determine whether or not it adds value, eliminating activities that do not.

3. **Flow:**

Ensure that the production process flows without interruption.

Reduce lead times and intermediate inventories so that products move continuously through the production stages.

4. **Pull:**

Produce only what the customer demands.

Use "pull" rather than "push" production systems, avoiding overproduction and excess inventories.

5. **Perfection:**

Encourage continuous improvement in all processes.

Create a culture of Kaizen (continuous improvement) where all employees actively participate in identifying and solving problems.

PICTURE 11: Wastes of LM

5.3 Lean Manufacturing Tools

To implement the principles of Lean Manufacturing, several tools and techniques are used, each with its own focus and purpose:

- **5S:**

A methodology for organising and maintaining a clean and efficient workplace. The five 'S's are: Seiri (Sort), Seiton (Sort), Seiso (Clean), Seiketsu (Standardise) and Shitsuke (Sustain).

- **Value Stream Map (VSM):**

A tool to visualise and analyse the flow of materials and information throughout the production process. It helps to identify waste and areas for improvement.

- **Kaizen:**

A continuous improvement philosophy that involves all employees in the search for incremental improvements. Kaizen events are held to solve specific problems and improve processes.

- **Kanban:**

A visual system that helps manage material flow and production. It uses cards or signs to indicate when more products need to be produced or materials replenished.

- **Poka-Yoke:**

Mechanisms that prevent defects and errors in the production process. Devices or procedures are designed to make it difficult or impossible to make mistakes.

- **TPM (Total Productive Maintenance):**

An approach to maximise the efficiency of equipment through preventive maintenance and the active participation of all employees. It seeks to eliminate the six major losses: equipment failures, adjustments and changeovers, slow speed operations, minor stoppages, process defects and reduced throughput.

5.4 Benefits of Lean Manufacturing

Implementing Lean Manufacturing can provide numerous benefits to an organisation:

-Improved Efficiency: By reducing waste and optimising processes, companies can increase their productivity and operational efficiency.

-Cost Reduction: Eliminating non-value adding activities and continuous improvement can reduce production costs.

-Higher Quality: Identifying and correcting errors before they occur, along with continuous improvement, results in higher quality products.

-Customer Satisfaction: By focusing on customer value and responding quickly to customer demands, companies can improve customer satisfaction.

-Work Environment Improvement: Workplace organisation and cleanliness, along with employee participation in continuous improvement, contribute to a safer and more motivating work environment.

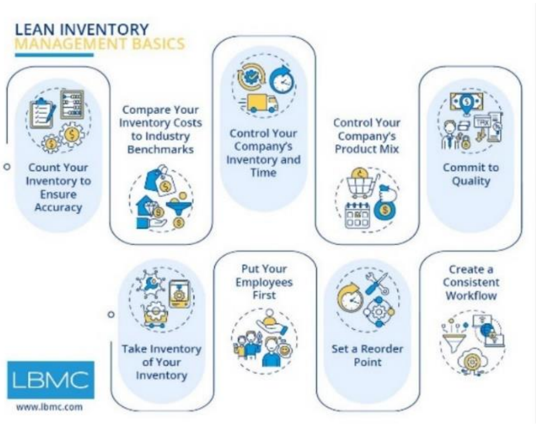
5.5 Continuous improvement (Kaizen spirit):

1. Abandon fixed ideas, reject the current state of affairs.
2. Instead of explaining what cannot be done, reflect on how to do it.
3. Immediately implement good proposals for improvement.
4. Do not strive for perfection, win 60% from now on.
5. Correct a mistake immediately and on the spot.
6. Find the ideas in the difficulty.
7. Look for the real cause, respect the 5 "why's" and then look for the solution.
8. Take into account the ideas of 10 people instead of waiting for the ideal genius of just one.
9. Test and then validate.

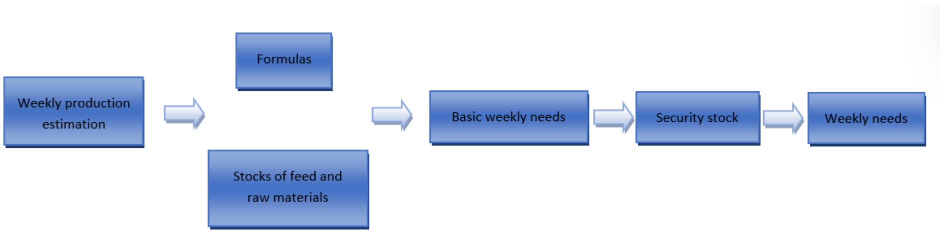
10. Improvement is infinite.

5.6 Why is inventory so important?

- -Shortage control (<0.5%)
- -Control of product expiry dates
- -It allows to question if the storage planning is correct.
- -Inventory translates into euros. Necessary to know the economic indicators of the company.
- -Indirect verification of the correct dosage (solids and liquids).
- -Allows to detect caking or structural problems in silos.
- -Allows to detect errors made in previous entries.



PICTURE 12: Lean inventory



GRAPHIC 5: Periodic stock revision

Lean manufacturing has evolved over the past century from early industrial engineering concepts to a comprehensive philosophy for operational excellence. Rooted in the innovations of Frederick Taylor, Henry Ford, and most notably the Toyota Production System, lean has become a universal approach to improving efficiency and quality in various sectors. The principles and tools of lean manufacturing continue to guide organizations in their pursuit of operational excellence and customer value.

6. ANALYSIS OF THE CURRENT SITUATION

After explaining in more detail the feed manufacturing process, the machinery and the general operation of the factory, data can be collected and various indicators such as OEE can be applied to help interpret certain results. It should be noted that although theory indicates a number of best practices that could be implemented, not all of them are feasible due to lack of resources such as space, time or money. It is therefore necessary to adjust to the real and current needs of the plant.

6.1 Planning

Planning is a crucial step in the production process, setting the framework for the entire operation. The factory works from Monday to Friday, 24 hours a day, in 8-hour shifts. For this shift, the available time is 8 hours, with a theoretical production capacity of 30 tons per hour. This translates to a production target of 240 tons for the shift. Effective planning ensures that all resources are aligned towards achieving this goal, laying the foundation for evaluating performance and identifying areas for improvement.

- **Available Time**: 8 hours.
- **Theoretical Production Capacity**: 30 tons per hour (t/h).
- **Production Target for the Shift**: 240 tons (8 hours x 30 t/h).

6.2 Availability

Availability measures the proportion of time that production is actually happening versus the total available time. In this case, the actual productive hours are 6 out of the available 8 hours, resulting in a productive capacity of 180 tons. Downtime, caused by stops, startup times, changes, breakdowns, and waiting times, reduces the effective working hours. With an availability rate of 75%, it highlights the need to minimize downtime to enhance productivity.

- **Actual Productive Hours**: 6 hours.
- **Reasons for Downtime**: Stops, startup times, changes, breakdowns, waiting times.
- **Productive Capacity Based on Availability**: 180 tons (6 hours x 30 t/h).
- **Availability**: 75% (6 productive hours / 8 available hours).

6.3 Performance

Performance assesses how well the production equipment operates relative to its theoretical maximum capacity. Despite a theoretical rate of 30 tons per hour, the actual production rate achieved is 25 tons per hour due to microstoppages and reduced machine speed. This results in an actual production of 150 tons for the shift, yielding a performance rate of 83%. Understanding and addressing the factors causing reduced performance can help in optimizing production rates.

- **Actual Production Rate**: 25 tons per hour.
- **Reasons for Reduced Performance**: Microstoppages and reduced machine speed.
- **Actual Production for the Shift**: 150 tons (6 hours x 25 t/h).
- **Performance**: 83% (25 t/h actual / 30 t/h theoretical).

6.4 Quality

Quality evaluates the amount of good product produced compared to the total production. Out of the 150 tons produced, 10 tons need reprocessing due to milling issues, leaving 140 tons ready for dispatch. This gives a quality rate of 93%. Maintaining high quality is essential for customer satisfaction and operational efficiency, and reprocessing impacts overall productivity and costs.

- **Production to be Reprocessed**: 10 tons due to milling issues.
- **Final Production for Dispatch**: 140 tons.
- **Quality**: 93% (140 final tons / 150 produced tons).

6.5 OEE (Overall Equipment Effectiveness)

Overall Equipment Effectiveness (OEE) is a comprehensive metric that combines availability, performance, and quality to provide an overall efficiency percentage. For this shift, the OEE is calculated as the product of availability (75%), performance (83%), and quality (93%), resulting in an OEE of 57%. This indicates that only 57% of the theoretical production capacity was realized, with 140 tons produced against a potential of 240 tons. Improving OEE involves addressing the various factors impacting availability, performance, and quality to enhance overall production efficiency.

- **OEE Calculation**: Availability (75%) x Performance (83%) x Quality (93%).
- **OEE**: 57%.
- **Actual Production for the Shift**: 140 tons against a theoretical capacity of 240 tons.

6.6 Conclusions:

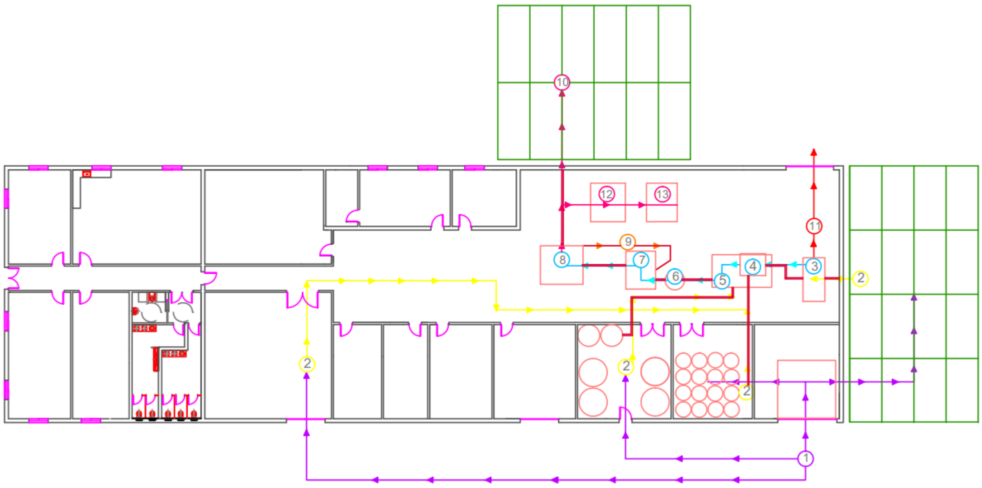
1. **Low Availability (75%)**:
    - 25% of the available time is lost due to stoppages, startups, changes, and breakdowns. It's crucial to identify the exact causes of these interruptions and work on solutions such as preventive maintenance, reducing changeover times, and better managing startup times.
2. **Suboptimal Performance (83%)**:
    - The production speed is below the maximum machine capacity due to microstoppages and operating at reduced speed. Improving operational efficiency by optimizing production processes and reducing microstoppages can increase performance.

3. **Quality Issues (93%)**:
    - 7% of the production needs reprocessing due to milling issues. Implementing Poka-Yoke systems to prevent errors and improving quality control processes can help reduce the amount of rework.
4. **Low OEE (57%)**:
    - The combination of low availability, suboptimal performance, and quality issues results in an OEE of 57%. This value indicates a significant margin for improvement in all aspects of production.
5. **Total Production**:
    - The final production of 140 tons versus a theoretical capacity of 240 tons highlights significant losses in the process. Achieving improvement in each OEE component (availability, performance, and quality) can significantly increase production.

6.7 Recommendations:

1. **Improve Availability**:
    - Implement a preventive maintenance program.
    - Reduce changeover and startup times by standardizing procedures and training personnel.
2. **Increase Performance**:
    - Analyze and reduce microstoppages.
    - Optimize machine speed through technical adjustments and process improvements.
3. **Improve Quality**:
    - Implement stricter quality controls in milling.
    - Use error prevention techniques (Poka-Yoke) and continuous training of personnel in good production practices.
4. **Continuous Monitoring**:
    - Use continuous monitoring and analysis tools to identify and correct issues in real-time.
    - Foster a culture of continuous improvement (Kaizen) in the factory.

6.8 Definition of the working area.

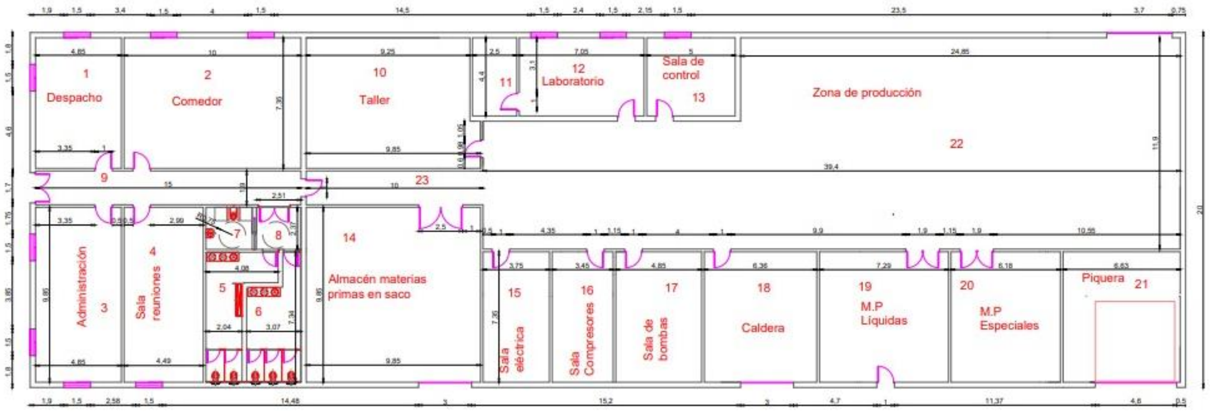


PICTURE 13: Factory flow chart

PROCESS FLOW LEGEND			
1	➡	Input flow of raw materials	Reception of raw materials
2	➡	Flow of dosed raw materials	Raw material dosage
3	➡	Production process flow	Grinding
4	➡	Production process flow	Pre-mix hopper
5	➡	Production process flow	Mix
6	➡	Production process flow	Pregranulation silo
7	➡	Production process flow	Granulation
8	➡	Production process flow	Pellet cooling and screening
9	➡	Production process flow	Fines recirculation
10	➡	Final product flow	Storage of finished feed and distribution
11	➡	Flow process waste	Waste
12	➡	Final product flow	Bagging machine
13	➡	Final product flow	Palletiser

TABLE 4: Process flow diagram

The green area outside are the storage silos. This is what the factory looked like before the improvements were implemented.



Picture 14: Floor plan

1. Dispatch
2. Dining room
3. Administration
4. Meeting room
5. Locker room and toilets
6. Locker room and toilets
7. Adapted bathroom
8. Entrance
9. Corridor
10. Workshop
11. Library
12. Laboratory
13. Control room
14. Material warehouse
15. Electrical room
16. Compressors room
17. Bomb storage
18. Boiler
19. Liquid raw materials
20. Special raw materials
21. Entrance
22. Production área
23. Hallway

7. DEVELOPMENT OF THE FIRST IMPROVEMENT PROPOSAL

7.1 Introduction

In the animal feed manufacturing industry, efficient management of storage space is a constant challenge. The fluctuating demand for products, the need to maintain an adequate inventory of raw materials and finished products, and the incorporation of new production lines can quickly saturate the available space. This situation can lead to a series of operational problems, including production delays, difficulties in internal logistics, and increased safety risks.

An innovative and effective solution to maximize storage space in an animal feed factory is the implementation of a power screw to create a mezzanine. This approach not only optimizes the use of existing vertical space but also improves inventory organization and accessibility. Installing a mezzanine using a power screw offers a robust and flexible alternative, allowing the factory to efficiently manage growth without the need for costly expansions or relocations.

7.2 Current Storage Issues

In many animal feed factories, storage space is at its limit due to several reasons:

1. **Increase in Production**: The growing demand for products requires the production of larger volumes, which in turn increases the need for space to store both raw materials and finished products.
2. **Product Diversification**: The introduction of new formulas and types of feed for different animals increases the variety of stored products, which can complicate the management of available space.
3. **Structural Limitations**: Many facilities were designed without anticipating significant expansions, limiting the ability to add additional storage capacity without major restructuring.

7.3 Proposed Solution: Implementation of a Power Screw to Create a Mezzanine

Implementing a power screw for mezzanine construction is a strategic solution that directly addresses these challenges. A power screw, also known as a lead screw, is a mechanical device that converts rotational motion into linear motion, allowing the lifting and supporting of heavy structures with precision and safety.

Benefits of the Mezzanine:

1. **Optimization of Vertical Space**: Utilizing unused vertical space transforms empty areas into functional storage zones without affecting the operational floor space.

2. **Increase in Storage Capacity**: Creating a mezzanine adds a new storage surface, doubling or even tripling the plant’s capacity without requiring a physical expansion of the building.
3. **Improvement in Organization and Accessibility**: Implementing a mezzanine allows for better inventory organization, facilitating the access and handling of materials and products, which can significantly improve operational efficiency.
4. **Flexibility and Scalability**: Mezzanines built with power screws can be adjusted and scaled according to the factory's changing needs, providing a long-term and adaptable solution.

7.4 Theory

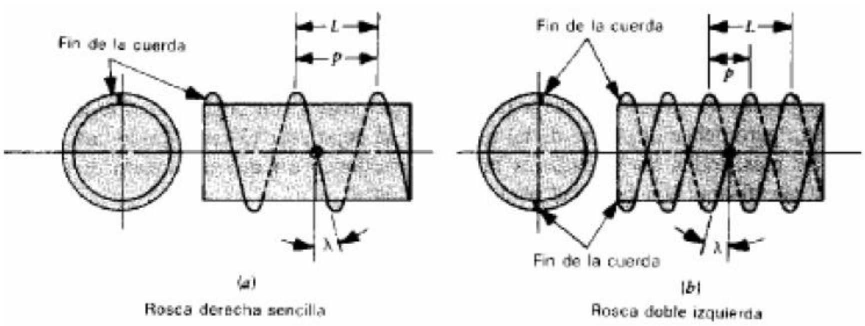
Power screws are used to convert rotational motion into a slow translational motion along the screw axis. Power screw applications can be grouped into two categories:

- Screws used to achieve large linear forces, such as those used in lifting systems or presses.
- Screws used to generate high precision linear movements, such as those used in micrometers or those used in machine tools.

Thread forms, terminology and specifications

The figure shows a helical thread, defining the pitch p, the helix angle λ and the lead L. Almost all bolts and screws have a single thread, but worm screws and power screws sometimes have double, triple and even quadruple threads.

The pitch is the distance between two consecutive threads of the thread measured in the direction of the bolt axis, while the lead is the distance travelled by the nut in one complete revolution, so both quantities coincide in single-threaded bolts.



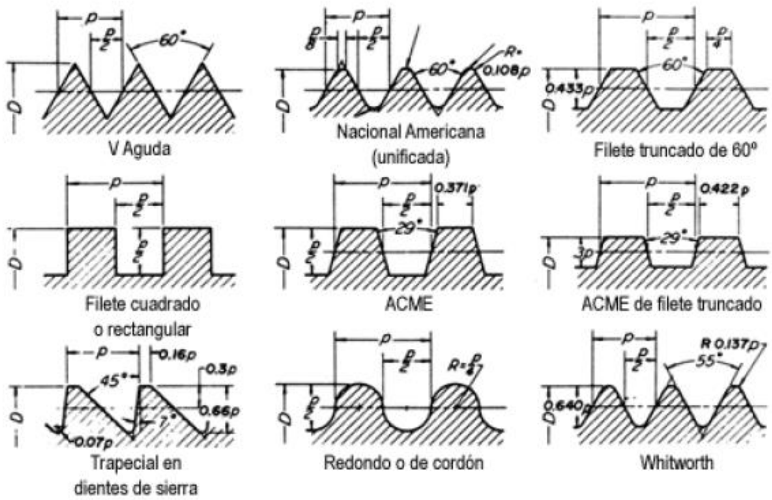
PICTURE 15: Single right-hand thread and double left-hand thread

If it were unrolled one full turn, a triangle would be formed which generates the relation:

$$\tan(\lambda) = \frac{L}{\pi \cdot d_m}$$

Where λ is the helix angle, L the lead, p the pitch and dm the mean diameter.

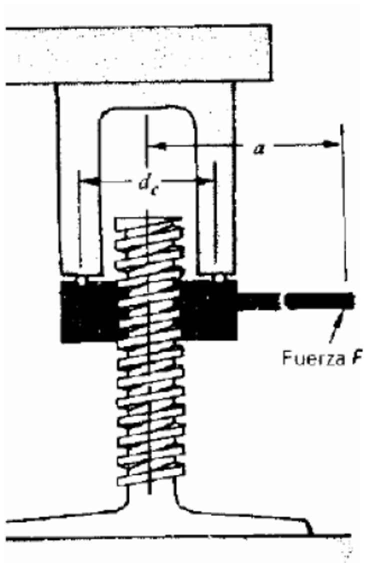
The following figure shows most of the standard thread forms used for power screws.



PICTURE 16: Standard thread forms used for power screws

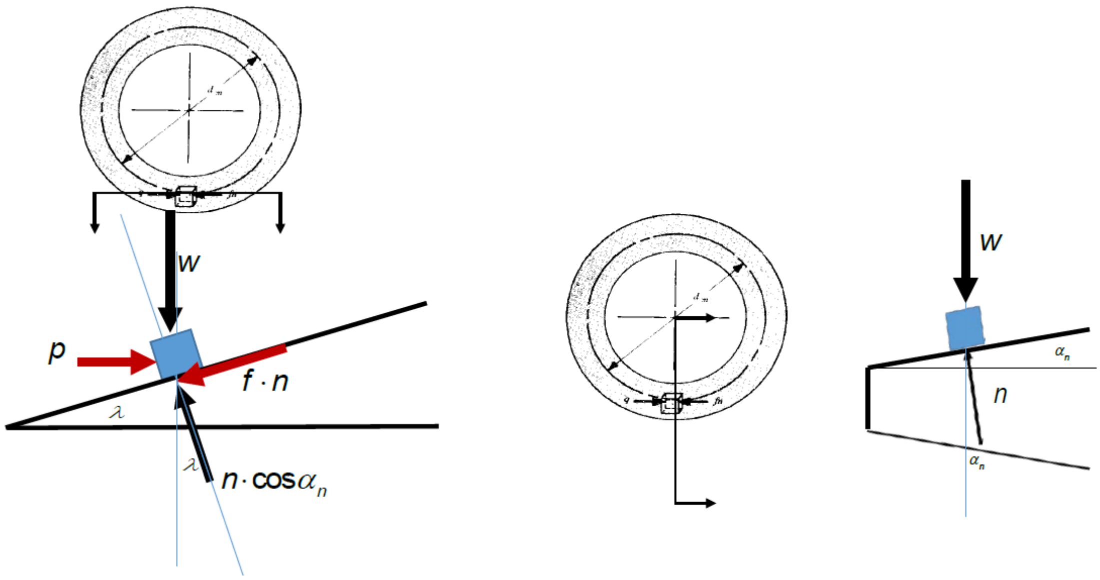
7.5 Force analysis

Let us calculate the torque T that must be applied to the nut of the bolt in the figure to lift the load.



PICTURE 17

The figure shows an infinitesimal segment of the nut on which a differential load w acts. The normal force is n, the coefficient of friction between the nut and the bolt is f, and q is the differential force applied on this element to lift the load.



PICTURE 18

Applying the condition of equilibrium of forces in the tangential and axial direction of the differential element leaves:

$$\sum F_t = 0 \rightarrow q - n \cdot f \cdot cos(\lambda) - n \cdot cos(\alpha_n) \cdot sen(\lambda) = 0$$

$$\sum F_a = 0 \rightarrow w + n \cdot f \cdot sen(\lambda) - n \cdot cos(\alpha_n) \cdot cos(\lambda) = 0$$

By subtracting n from the sum of axial forces:

$$n = \frac{w}{cos(\alpha_n) \cdot cos(\lambda) - f \cdot sen(\lambda)}$$

Substituting into the equation for the summation of tangential forces:

$$q = w \cdot \left(\frac{f \cdot cos(\lambda) + cos(\alpha_n) \cdot sen(\lambda)}{cos(\alpha_n) \cdot cos(\lambda) - f \cdot sen(\lambda)} \right)$$

The torque corresponding to the force q is q·(dm/2). Integration over the full surface area of the rope in contact generates the same equation except that w is replaced by the total weight being lifted W. Thus, the torque required to lift the load will be:

$$T = Q \cdot \left(\frac{d_m}{2}\right) = \frac{W \cdot d_m}{2} \cdot \frac{f \cdot cos(\lambda) + cos(\alpha_n) \cdot sen(\lambda)}{cos(\alpha_n) \cdot cos(\lambda) - f \cdot sen(\lambda)}$$

Since it is usually the (normalised) feed rate and not the propeller angle that is known, we divide the numerator and denominator by cos(λ) and substitute the equation $\tan(\lambda) = \frac{L}{\pi \cdot d_m}$

$$T = Q \cdot \left(\frac{d_m}{2}\right) = \frac{W \cdot d_m}{2} \cdot \frac{f + cos(\alpha_n) \cdot tan(\lambda)}{cos(\alpha_n) - f \cdot tan(\lambda)} = \frac{W \cdot d_m}{2} \cdot \frac{f + cos(\alpha_n) \cdot \frac{L}{\pi \cdot d_m}}{cos(\alpha_n) - f \cdot \frac{L}{\pi \cdot d_m}}$$

$$T = \frac{W \cdot d_m}{2} \cdot \frac{f \cdot \pi \cdot d_m + L \cdot cos(\alpha_n)}{\pi \cdot d_m \cdot cos(\alpha_n) - f \cdot L}$$

7.6 Values of friction coefficients

When a single friction bearing is used, the values of the friction coefficients f under normal operating and lubrication conditions can be obtained from the following table:

	NUT			
SCREW	**Steel**	**Brass**	**Bronze**	**Steel foundry**
Steel	0,15-0,25	0,15-0,23	0,15-0,19	0,15-0,25
Steel (lubricated)	0,11-0,17	0,10-0,16	0,10-0,13	0,11-0,27
Bronze	0,08-0,12	0,04-0,06	---------------------	0,06-0,09

TABLE 5: Values of the friction coefficients

7.7 Self-locking

A self-locking or self-locking bolt is one which requires a positive torque to lower the load; a free running bolt is one whose friction is so low that the load is able to descend under the action of its own weight. Thus the condition for a bolt to be self-locking is T>0, so the condition obtains:

$$f > \frac{L \cdot cos(\alpha_n)}{\pi \cdot d_m}$$

A word of caution at this point, even if a bolt under static conditions is self-retaining, it may still have free travel when exposed to vibration.

7.8 Calculation of the bolt

Stresses on the bolt shank

-Torsion:

Power screws during operation and those used in joints in the tightening process are subject to torsional stresses which cause a maximum tangential stress on the internal surface of the thread (dr) equal to:

$$\tau = \frac{T \cdot r}{J} = \frac{16 \cdot T}{\pi \cdot d_r^3}$$

- Axial load:

The normal stress caused by axial load is calculated by considering the bottom area of the thread:

$$\sigma = \frac{W}{A} \qquad\qquad A = \frac{\pi \cdot d_r^2}{4}$$

When the stresses to be supported by the bolt are dynamic (as in the case of power bolts) it is necessary to consider the effect of the stress concentrator of the threading. As a failure criterion, the distortion energy criterion is used to obtain an equivalent stress:

$$\sigma_{eq} = \sqrt{\sigma^2 + 3 \cdot \tau^2}$$

The permissible voltage for power screws is given in the following table:

Effort	Trapezoidal thread	Sawtooth
Pulsatory	$0{,}20 \cdot S_u$	$0{,}25 \cdot S_u$
Alternant	$0{,}30 \cdot S_u$	$0{,}16 \cdot S_u$

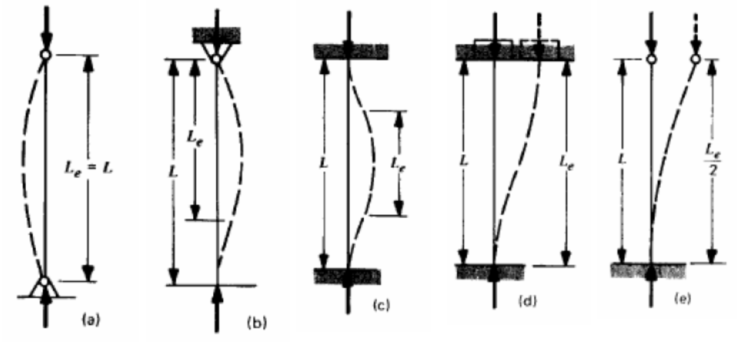
TABLE 6: Permissible voltage for power screws

7.9 Buckling

When the bolt is working in compression, the buckling phenomenon can occur. Euler showed that if a slender column working in compression is loaded above a certain critical load (Pcr), any slight lateral displacement given to the column causes an eccentric bending moment greater than the internal elastic restoring moment and the column collapses. Therefore loads exceeding the Pcr make the column elastically unstable.

$$P_{cr} = \frac{\pi^2 \cdot E \cdot I}{L_e^2}$$

Where E is the modulus of elasticity of the material, I is the lowest moment of inertia of the support section and Le= c·L is the equivalent length obtained depending on the end conditions, as shown in the following table:



C teórica	1	0.707	0.5	1	2
C recomendada	1	0.8	0.65	1.2	2.1

PICTURE 19

The stress that must be reached for buckling to occur is:

$$S_{cr} = \frac{P_{cr}}{A} = \frac{\pi^2 \cdot E \cdot I}{L_e^2 \cdot A}$$

Where taking into account that the relation between the moment of inertia of the section and the radius of gyration is: $I = A \cdot \rho^2$ we are left with:

$$S_{cr} = \frac{\pi^2 \cdot E}{L_e^2 \cdot 1/\rho^2} = \frac{\pi^2 \cdot E}{\lambda^2}$$

where λ=Le/ρ is the slenderness ratio.

It has been found that there are deviations from the ideal behaviour, where buckling failure appears before the critical stress predicted by the theory studied. To address this problem, some empirical modifications have been proposed, the most widely used being the J.B. Jhonson parabola and the Euler curve, which allow distinguishing between long column and intermediate column, while for slenderness ratios lower than 10, short column is considered, where it is no longer necessary to take into account buckling and the critical stress coincides with Sy:

Column type	Boundaries	Critical tension
Short	$\frac{L_e^2}{\rho} < 10$	S_y
Intermediate	$10 < \frac{L_e}{\rho} < \sqrt{\frac{2 \cdot \pi^2 \cdot E}{S_y}}$	Johnson's parable
Long	$\frac{L_e}{\rho} > \sqrt{\frac{2 \cdot \pi^2 \cdot E}{S_y}}$	Euler

TABLE 7

7.10 POWER SCREW

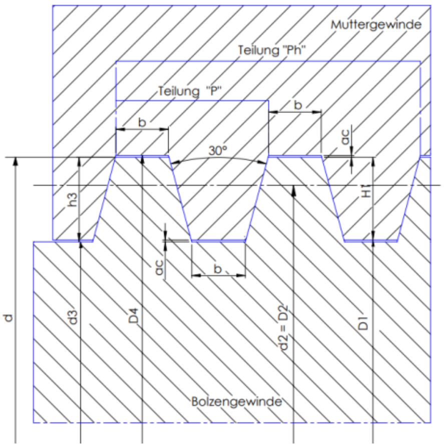
The warehouse will have a mezzanine at a height of 2.5 m to be able to store larger quantities of product. A column lift similar to the one shown in Illustration 17 will be used for lifting. This lift will be able to raise the pallets to the mezzanine so that they can then be distributed on the mezzanine by operators with hand pallet trucks.

PICTURE 20: Power screw

Each pallet supports 40 bags of 25 kg each, making a total of 1000 kg. The problem is going to be oversized in case a greater weight is loaded in the future, establishing 1250 kg.

In the illustration above it can be seen that the electric motor is located at the bottom and that the power screw has bearings at the bottom.

BORNEMANN manufactures custom screws. "We manufacture ACME threaded spindles from your drawings and technical specifications. ACME threads have a flank angle of 29° and are mainly used in the USA. In Europe, on the other hand, the trapezoidal thread according to DIN 103 with a flank angle of 30° has become the norm".



PICTURE 21: Power Screw map

For this application we will take the following screw:

Nominal dimension of thread *d*			Pitch	Pitch diameter	External diameter	Core diameter	
Array 1	**Array 2**	**Array 3**	***P***	$d_2 = D_2$	D_4	d_3	D_1
32			**3**	30,500	32,500	28,500	29,000
			6	29,000	33,000	25,000	26,000
			10	27,000	33,000	21,000	22,000
	34		**3**	32,500	34,500	30,500	31,000
			6	31,000	35,000	27,000	28,000
			10	29,000	35,000	23,000	24,000
36			**3**	34,500	36,500	32,500	33,000
			6	33,000	37,000	29,000	30,000
			10	31,000	37,000	25,000	26,000

TABLE 8: Dimensions

Thread profile dimensions in mm: 1,5 -12 mm

P	1,5	2	3	4	5	6	7	8	9	10	12
a_c	0,15	0,25	0,25	0,25	0,25	0,5	0,5	0,5	0,5	0,5	0,5
h_3 - H_4	0,9	1,25	1,75	2,25	2,75	3,5	4	4,5	5	5,5	6,5
H_1	0,75	1	1,5	2	2,5	3	3,5	4	4,5	5	6
R_1 max.	0,075	0,125	0,125	0,125	0,125	0,25	0,25	0,25	0,25	0,25	0,25
R_2 max.	0,15	0,25	0,25	0,25	0,25	0,5	0,5	0,5	0,5	0,5	0,5

TABLE 9: Thread profile dimensions

The material chosen for the power screw will be AISI 304 steel, which is stainless and ideal for the conditions in the hall where humidity and dirt are high due to the type of product. The mechanical properties of this steel are:

	Inox 304 Propiedades Mecanicas					
Acero	Resistencia a la traccion (MPa) ≥	Esfuerzo de fluencia (MPa) ≥	Elongación en 50 mm (%) ≥	Reduccion de area (%)	Dureza (HBW) ≤	Condiciones
304	585	235	60	70	149	Barra recocida
	690	415	45		212	Recocido y estirado en frío
	860	655	25		275	Estirado en frío de alta resistencia

Modulo elastico	193 GPa (28×10^6 psi)

TABLE 10: Mechanical properties

7.11 Ratio of the transmission speeds from the motor to the screw

Let's consider that the forward speed of the load is 0.05 m/s.

$$v = \omega_t \cdot L$$

As the pitch p=10 mm and the thread is simple, the feed rate is equal to the pitch, so in one revolution it will have advanced a length equal to the pitch.

The rotational speed of the screw needed to develop the required linear speed will be:

$$\omega_t = \frac{v}{L} = \frac{50}{10} = 5\frac{rev}{s} = 300\ rpm$$

By choosing the OMEMOTORS motor with 400 rpm and 2.2 kW.

$$i = \frac{\omega_{motor}}{\omega_t} = \frac{400}{300} = 1{,}333$$

Therefore, the transmission is gear-reduced.

Engine power required to lift the load friction and bearing losses are assumed to be negligible. The propeller angle is:

$$an\lambda = \frac{L}{\pi \cdot d_2} = \frac{10}{\pi \cdot 31}$$

$$\lambda = 5{,}86°$$

The weight of the load shall be:

$$W = 1500 \cdot 9{,}81 = 12262{,}5\ N$$

The thread is trapezoidal with a flank angle of 30°, as shown in the illustration. Therefore, αn=30/2=15°.

The torque to be transmitted to the power screw is calculated by the following expression:

$$T = \frac{W d_2}{2} \cdot \left(\frac{f\pi d_2 + cos(\alpha_n) L}{cos(\alpha_n)\pi d_2 - fL}\right) = \frac{12262{,}5\ \cdot 0{,}031}{2} \cdot \left(\frac{0{,}15 \cdot \pi \cdot 0{,}031 + \cos(15) \cdot 0{,}01}{\cos\,(15) \cdot \pi \cdot 0{,}031 - 0{,}15 \cdot 0{,}01}\right) = 49{,}83\ Nm$$

The coefficient of friction f=0.15 has been obtained from the following table taking into account that the screw is made of steel:

	NUT			
SCREW	**Steel**	**Brass**	**Bronze**	**Steel foundry**
Steel	0,15-0,25	0,15-0,23	0,15-0,19	0,15-0,25
Steel (lubricated)	0,11-0,17	0,10-0,16	0,10-0,13	0,11-0,27
Bronze	0,08-0,12	0,04-0,06	---------------------	0,06-0,09

TABLE 11: Screw and Nut

The required engine power shall be:

$$Pot = T \cdot \omega_t = 49{,}83 \cdot 300 \cdot \frac{2\pi}{60} = 1564{,}66\ W = 1{,}56\ kW$$

The selected engine has a power of 2.2 kW, which is a typical commercial power, so there will be no problem. The safety coefficient will therefore be:

$$X_{motor} = \frac{Pot_{motor}}{Pot} = \frac{2{,}2}{1{,}56} = 1{,}41$$

7.12 Self-retaining

To check the self-retention of the screw we use the following expression:

$$f = 0{,}15 \geq \frac{L \cdot \cos(\alpha_n)}{\pi \cdot d_2} = \frac{0{,}01 \cdot \cos(15)}{\pi \cdot 0{,}031} = 0{,}1$$

The screw is self-locking.

7.13 Safety factor

We only have one power screw and one electric motor at the bottom of the screw jack, so the input torque provided by this is transmitted in its entirety to the screw, which is subjected to the torque T and the weight of the pallet. We have then that:

$$\tau = \frac{16 \cdot T}{\pi {d_3}^3} = \frac{16 \cdot 49{,}83 \cdot 10^3}{\pi \cdot (25)^3} = 16{,}24\ N/mm^2$$

$$\sigma = \frac{4W}{\pi {d_3}^2} = \frac{4 \cdot 12262{,}5 \cdot 10^{-3}}{\pi \cdot (25)^2} = 24{,}98\ N/mm^2$$

$$\sigma_{eq} = \sqrt{\sigma^2 + 3\tau^2} = \sqrt{24{,}98^2 + 3 \cdot 16{,}24^2} = 37{,}62\ N/mm^2$$

As the thread is trapezoidal we have that:

Effort	Trapezoidal thread	Sawtooth
Pulsatory	$0{,}20 \cdot S_u$	$0{,}25 \cdot S_u$
Alternant	$0{,}30 \cdot S_u$	$0{,}16 \cdot S_u$

TABLE 12: Trapezoidal

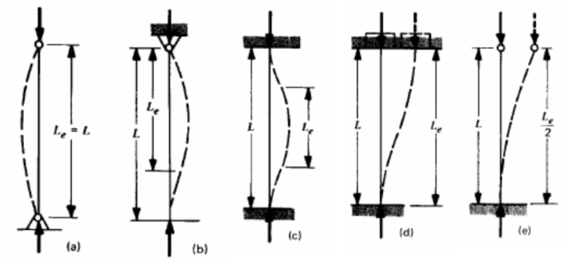
$$\sigma_{adm} = 0{,}2 \cdot S_u = 0{,}2 \cdot 585 = 117\ N/mm^2$$

The safety coefficient is:

$$X = \frac{\sigma_{adm}}{\sigma_{eq}} = \frac{117}{37{,}62} = 3{,}10$$

7.14 Buckling safety factor

The power bolt is recessed at its ends. The equivalent length will then be that of case c) in the following picture:



C teórica	1	0.707	0.5	1	2
C recomendada	1	0.8	0.65	1.2	2.1

PICTURE 22: Buckling safety factor

$$L_e = c \cdot L_{máx} = 0{,}5 \cdot 2{,}5 = 1{,}25\ m \qquad I = \frac{\pi {d_3}^4}{64} = \frac{\pi \cdot 25^4}{64} = 19714{,}76\ \ kg \cdot mm^2$$

$$A = \frac{\pi {d_3}^2}{4} = \frac{\pi \cdot 25^2}{4} = 490{,}63\ mm^2 \qquad \rho = \sqrt{\frac{I}{A}} = \sqrt{\frac{19714{,}76}{490{,}63}} = 6{,}34\ mm$$

$$\lambda = \frac{L_e}{\rho} = \frac{1{,}25}{0{,}00634} = 197{,}16$$

These limits are calculated to determine the type of column:

Column type	**Boundaries**	**Critical tension**
Short	$\frac{L_e^2}{\rho} < 10$	S_y
Intermediate	$10 < \frac{L_e}{\rho} < \sqrt{\frac{2 \cdot \pi^2 \cdot E}{S_y}}$	Johnson's parable
Long	$\frac{L_e}{\rho} > \sqrt{\frac{2 \cdot \pi^2 \cdot E}{S_y}}$	Euler

TABLE 13: Type of column

Given that $\sqrt{\frac{2\pi^2 E}{S_y}} = \sqrt{\frac{2 \cdot \pi^2 \cdot 1{,}93 \cdot 10^5}{235}} = 127{,}32 < \lambda = 197{,}16$ the column is long.

Using Euler's formula we have that:

$$P_{cr} = \frac{\pi^2 \cdot E \cdot I}{{L_e}^2} = \frac{\pi^2 \cdot 1{,}93 \cdot 10^5 \cdot 19714{,}76}{1250^2} = 24034{,}14\ N$$

The safety coefficient is:

$$X = \frac{P_{cr}}{W} = \frac{24034,14}{12262,5} = 1,95$$

Given that:

$$\sqrt{\frac{2\pi^2 E}{S_y}} = \sqrt{\frac{2 \cdot \pi^2 \cdot 1,93 \cdot 10^5}{235}} = 127,32 < \lambda = 197,16 \text{, the column is long.}$$

Using Euler's formula we have that:

$$P_{cr} = \frac{\pi^2 \cdot E \cdot I}{{L_e}^2} = \frac{\pi^2 \cdot 1,93 \cdot 10^5 \cdot 19714,76}{1250^2} = 24034,14\, N$$

The safety coefficient is:

$$X = \frac{P_{cr}}{W} = \frac{24034,14}{12262,5} = 1,95$$

The material chosen and the configuration of the power screw is therefore valid for lifting the pallets to the mezzanine.

7.15 5S

The implementation of a power screw in a feed mill can be an efficient solution to improve inventory management and storage, especially when considering the principles of the 5S methodology. The 5S is a Japanese quality management system focused on organization, cleanliness, and maintaining a productive work environment. These five phases are: Seiri (Sort), Seiton (Set in Order), Seiso (Shine), Seiketsu (Standardize), and Shitsuke (Sustain). Below is a detailed explanation of how a power screw can be integrated with each of these phases:

1. **Seiri (Sort)**:
   - **Implementation of the power screw**: Helps identify and separate high-turnover materials from those that are not used frequently. With an automated transportation system, more precise control over inventory can be maintained, classifying products according to their use and relevance.

   - **Benefit**: Reduces the time and effort in inventory management, ensuring that only the necessary products are available at the right time.

2. **Seiton (Set in Order)**:
   - **Implementation of the power screw**: Facilitates orderly and systematic storage of feed. Products can be strategically located for easy access and transport, optimizing the available space.
   - **Benefit**: Improves efficiency in daily operations as workers know exactly where to find and store each type of feed, reducing search and movement time.

3. **Seiso (Shine)**:
   - **Implementation of the power screw**: Contributes to maintaining a clean work environment, as automation reduces material spills and facilitates regular cleaning of storage areas.
   - **Benefit**: Minimizes the risk of contamination and workplace accidents, promoting a safe and healthy work environment.

4. **Seiketsu (Standardize)**:
   - **Implementation of the power screw**: Allows the establishment of standard procedures for handling and storing feed. Transportation routes and storage locations can be defined and consistently maintained.
   - **Benefit**: Ensures that all employees follow the same procedures, leading to greater consistency and quality in daily operations.

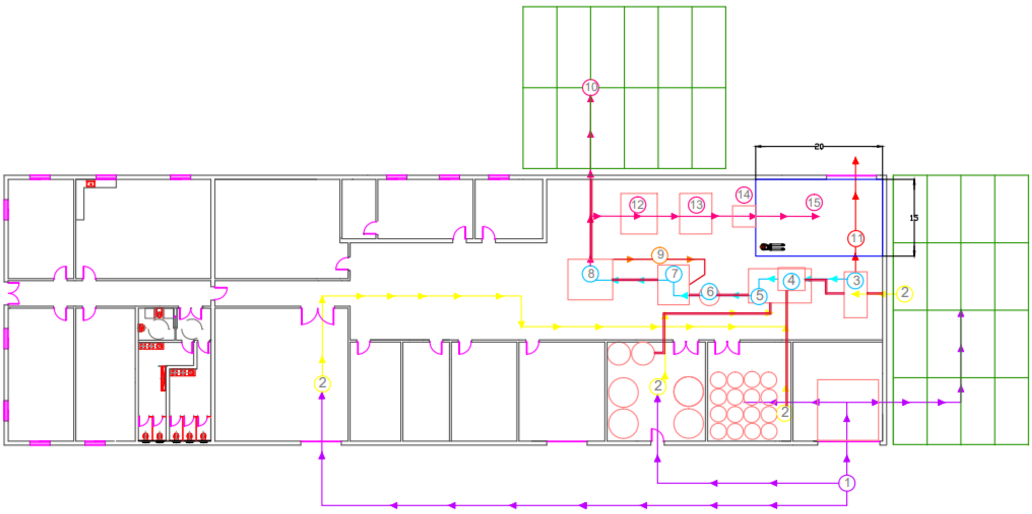
5. **Shitsuke (Sustain)**:
   - **Implementation of the power screw**: Encourages discipline among employees by facilitating adherence to established standards. Process automation requires following specific protocols, helping to maintain organization and order.
   - **Benefit**: Promotes a disciplined and committed work culture, where every worker understands the importance of maintaining standards and contributes to a more efficient and organized work environment.

PICTURE 23: Mezzanine

In conclusion, incorporating a power screw in a feed mill not only improves inventory management but also optimizes the entire work environment when aligned with the 5S methodology. This translates into greater efficiency, safety, and quality in daily operations, significantly contributing to the success of the mill.

7.16 Working area after implementation

The flow diagram after the implementation of the power screw and the mezzanine for the storage of feed bags is shown below. The standard size of each pallet is 800 x 1200 mm, the size of the mezzanine is 20 x 15 m, therefore, about 300 pallets of 1000kg each will fit, but a maximum of 250 will be stored to leave a safety space for the factory operators.



PICTURE 24: Working area after implementation

PROCESS FLOW LEGEND			
1		Input flow of raw materials	Reception of raw materials
2		Flow of dosed raw materials	Raw material dosage
3		Production process flow	Grinding
4		Production process flow	Pre-mix hopper
5		Production process flow	Mix
6		Production process flow	Pregranulation silo
7		Production process flow	Granulation
8		Production process flow	Pellet cooling and screening
9		Production process flow	Fines recirculation
10		Final product flow	Storage of finished feed and distribution
11		Flow process waste	Waste
12		Final product flow	Bagging machine
13		Final product flow	Palletiser
14		Final product flow	Power screw
15		Final product flow	Mezzanine

TABLE 14: Updated process flow diagram

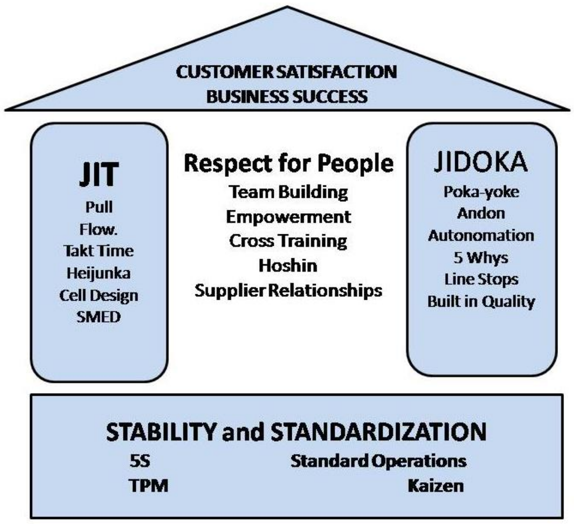
8. DEVELOPMENT OF THE SECOND PROPOSAL FOR IMPROVEMENT

This section will deal with another of the main problems currently faced by the factory. Although most of the processes are automated and only require the supervision of the operators in the event of a fault, the process of adding correctors is carried out manually. This is part of the ingredient mixing process, but as the amount of these correctors to be added is minimal, it is an operator who is responsible for taking the necessary amount with the help of a scale and adding it to the mixture already prepared with the rest of the ingredients. As the company has no plans at the moment to fully automate this process, one way to make the operator's task easier is with the help of Poka-Yokes. To better understand this last concept, a short introduction to the Jidoka methodology is necessary.

8.1 JIDOKA METHOD

What is JIDOKA?

Jidoka is a Japanese methodology and a fundamental pillar of the Toyota Production System (TPS), alongside Just In Time. It translates to "automation with a human touch."



PICTURE 25: Toyota Production System

Jidoka has two distinct meanings:

1. **Traditional Automation:**

- Represents the shift from manual to mechanical processes.
- Once the switch is turned on, the machine operates independently.
- Lacks mechanisms to detect errors or stop the process if anomalies occur.
- This can result in a large number of defective products if the machine malfunctions, making it unsatisfactory.

2. Automatic Defect Control:

- Introduced by Toyota as "jidoka ninben-no-aru," which translates to "automation with a human mind."
- Involves mechanisms to detect abnormalities and defects, and the capability to halt production when such issues are identified.
- Ensures immediate attention to problems, investigation of their causes, and the implementation of corrective actions to prevent similar defects in the future.

PICTURE 26: Jidoka

8.2 Key Aspects of Jidoka

- **Quality Control:** Jidoka inherently includes quality control by making it impossible for defective products to go unnoticed.
- **Immediate Response:** When a defect is detected, the production line stops, forcing immediate attention to the problem.
- **Corrective Measures:** The process includes investigating the root cause of defects and taking corrective actions to prevent recurrence.
- **Application:** While often involving some degree of automation, Jidoka is not limited to mechanical processes. It can also be applied to manual operations to ensure defects are detected and corrected promptly.

In summary, Jidoka enhances quality control by integrating automatic defect detection and response mechanisms, ensuring that production issues are addressed immediately, thereby preventing defective products from progressing further in the production line.

8.3 Purpose of the Jidoka Method

The Jidoka method aims to verify quality within the production process itself by incorporating self-control mechanisms. Each process is equipped with automatic quality controls to detect defects in products or errors in processes. These controls automatically detect issues and alert the operator. The primary objective of this automation is to "build it right the first time," preventing defective products from progressing through the production system.

Jidoka allows the process to have its own quality self-control. For example, if an anomaly occurs during the process, it will stop automatically or manually, preventing defective parts from advancing. This approach contrasts with traditional quality systems, where parts are inspected at the end of the production process. In traditional systems, a station might produce defective parts until the operator notices or defects might not be detected until a batch is complete, leading to wasted time and materials.

Jidoka enhances quality within the process by ensuring only zero-defect parts are produced.

8.4 Objectives of Jidoka

1. Effective personnel management.
2. Quality of the manufactured product.
3. Reduction of production time.
4. Reduction of defective units.
5. Reduction of costs.

8.5 Steps for Implementing Jidoka

The Jidoka method consists of the following steps for implementation:

1. **Problem Localization**: Problems can be detected in both machine-involved processes and human-involved processes. For machines, mechanisms are built within to detect anomalies and automatically stop the machine when issues occur. For human processes, workers are given the authority to press buttons or pull "andon cords," which can potentially stop an entire production line.
2. **Stop the Process**: Once a problem is detected, the process is halted to prevent further issues.
3. **Alert**: An alert signal is issued to inform everyone involved about the problem. Typically, a light system is used to communicate this to all relevant personnel.
4. **Quick Solution to Resume Production**: Rapid solutions are established to correct the immediate effects of the problem, allowing production to resume while a permanent solution is sought.
5. **Investigate and Correct the Root Cause**: The root cause of the problem is identified and a definitive solution is applied. This step is also known as the "Kaizen event." To investigate the cause, it's important to engage at the user level of the process, for example using the "five whys" method to find the root cause. Once the investigation is complete, a permanent solution is installed to prevent the problem from recurring.

8.6 Tools of Jidoka

Genchi Genbutsu

Genchi Genbutsu means "go and see for yourself" and emphasizes solving problems by going to the location or process where the problem exists to resolve it quickly and efficiently. This approach helps in understanding problems, confirming facts, and analyzing root causes.

Chalk Walks

Taiichi Ohno's famous teaching method involves drawing a chalk circle on the production floor near a point of interest. An employee stands in the circle and observes the work area for an extended period, which could be up to a whole day, to understand the process in-depth.

Gemba Walk

Gemba Walks involve observing and understanding how work is done by going to the actual location where the work happens. Observers interact with workers, understand their perspectives, and identify opportunities for improvement. The purpose is to familiarize with processes for continuous improvement, not to solve problems immediately.

Poka-Yoke

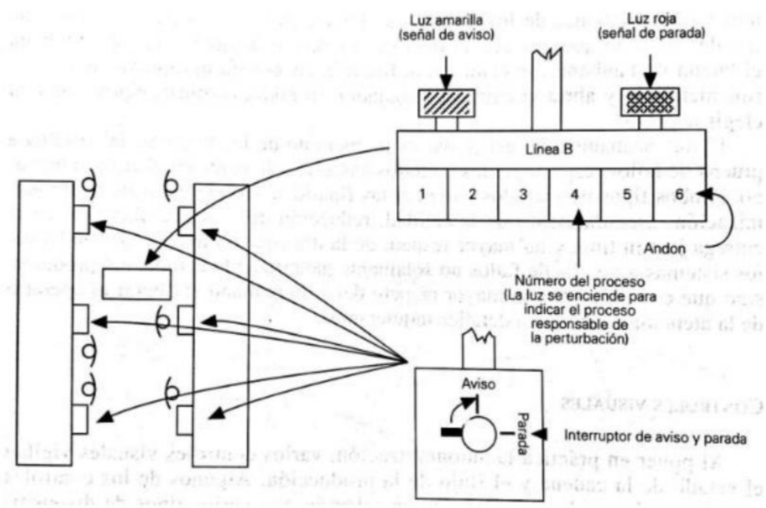
Poka-Yoke devices, or mistake-proofing devices, are mechanical or electronic tools that prevent errors before they occur and make them obvious so workers can correct them. They help ensure product quality by eliminating errors and allowing workers to focus on value-added tasks.

Classification of Poka-Yokes

- **Prevention Poka-Yokes**: These mechanisms signal or stop the process before an anomaly occurs. They can either control the process by stopping it or warn about deviations through alarms or lights without stopping the process.
- **Detection Poka-Yokes**: Used when preventing defects is not feasible. They detect defects early in the process to prevent further issues. They include methods like contact testing, fixed-value testing, and step-motion testing.

Visual Controls

Visual controls monitor the state of the production line and flow. Key tools include Andon and warning lights, standard operation sheets, Kanban tags, and numerical panels.



PICTURE 27: Poka-Yoke

Andon and Warning Lights

Many production lines have warning lights and Andon boards to signal when a process has stopped due to a problem. The lights indicate the type of help needed, and the Andon board shows which process caused the stoppage. This prompts immediate investigation and corrective action.

PICTURE 28: Andon light

Standard Operation Sheets and Kanban Tags

Standard operation sheets detail cycle times, standard operation sequences, and the standard amount of work-in-progress. They help maintain consistency and identify when processes need assistance. Kanban tags control production excess and serve as visual signals for process abnormalities.

Numerical Panels

Numerical panels display production progress, showing the day's production goals and the number of units produced so far. This helps everyone on the line understand whether production is on track and allows for adjustments to meet targets.

PICTURE 29: Control panel

8.7 Proporsal: Ingredient Mixing Control

Problem: During the ingredient mixing process for feed production, it is crucial to avoid incorrect mixes that could affect the nutritional quality and effectiveness of the final product.

Poka-Yoke Solution: Use of color-coded containers for ingredients and implementation of a weight sensor to ensure precise measurements.

Description:

1. **Poka-Yoke Device:**
    - **Color-Coded Containers:**
        - **Color Coding:** Each type of ingredient (e.g., flour, vitamins, minerals) has a specific container with a unique color code.
        - **Usage Restriction:** The containers are designed to fit only with the corresponding dosing and mixing machines for their type of ingredient.
    - **Weight Sensor:**
        - **Precision Measurement:** A sensor that controls the weight of the ingredients being added to the mix.
        - **Sound Alarm:** Emits a sound signal if the weight exceeds the required amount.
        - **Automatic Stop:** The system prevents further addition of ingredients if the weight limit is reached.
2. **Implementation:**
    - **Staff Training:**
        - Operators and technicians are trained on the use of color-coded containers and the importance of maintaining the integrity of mixes.
        - Training includes the operation of the weight sensor and the response to alarms.
    - **Visual Verification:**
        - A visual verification system is established where operators must confirm that the containers used correspond to the correct color and type of ingredient before starting the mixing process.
    - **Sensor Integration:**
        - Install sensors on mixing machines to monitor and control the weight of ingredients added.
        - Integrate the sensors with the machine's control system to ensure automatic stopping and alarm activation.

3. **Benefits:**

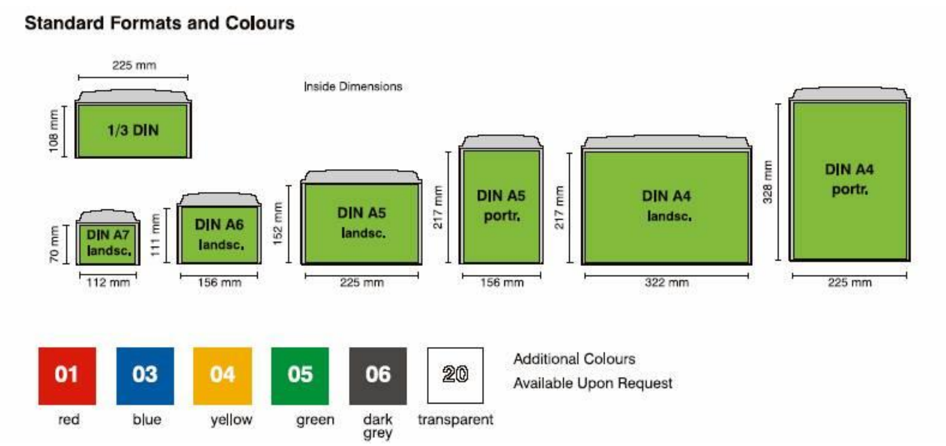
   - **Error Reduction:**
     - Minimizes the risk of mixing incorrect ingredients by providing a double-check system through color-coding and weight control.
   - **Quality Improvement:**
     - Ensures each batch of feed has the precise nutritional composition required.
   - **Food Safety:**
     - Complies with food safety standards by preventing cross-contamination and unwanted mixes.
   - **Process Efficiency:**
     - Increases the efficiency of the mixing process by reducing the time spent on corrections and rework due to ingredient errors.

By combining color-coded containers with a weight sensor, the feed production process becomes more robust, ensuring the quality and safety of the final product while reducing human error and enhancing operational efficiency.

8.8 Standardisation

The following shows how this implementation would be carried out.

Firstly, there will be different containers, each of a different colour and specifically marked with the type of ingredient/corrector it contains, so that it is easy for the operator to visually identify it and have it close to the work station. When he knows which ingredients to use, he scans the label on the container and the container opens automatically if it is correct.



PICTURE 30: Standardisation

The product is discharged until the sensor detects that the required quantity has been deposited. If it falls short or overfills, it will emit a visual and acoustic signal, allowing the operator to identify the error and quickly remedy it.

PICTURE 31: Representation

9. Economic analysis power screw

9.1 Introduction

This detailed economic analysis evaluates the financial impact of implementing a power screw in the animal feed production facility. It considers direct and indirect costs, as well as expected benefits. Below, we outline the costs for materials, labor, and maintenance, along with efficiency and savings benefits.

It should be noted that this analysis is purely indicative, based on projects with similar characteristics. In order to obtain real prices for materials, it would be necessary to take into account variables such as the selection of suppliers, quality, transport costs, etc., which are not taken into account here.

9.2 Detailed Economic Analysis

Initial Costs

a. Materials:

1. **Power Screw and Components:**
    - High-capacity power screw: €20,000
    - Motors and drives: €5,000
    - Sensors and control systems: €3,000
    - Support structure: €2,000
2. **Control and Automation System:**
    - Programmable logic controller (PLC): €4,000
    - Control and monitoring software: €2,000

b. Labor:

1. **Installation:**
    - Engineers and technicians (200 hours at €50/hour): €10,000
    - Electricians and mechanics (150 hours at €40/hour): €6,000
2. **Training:**
    - Staff training on system usage: €1,500

c. Other Costs:

1. **Permits and Licenses:**
    - Administrative costs for permits: €500
2. **Contingencies:**

- Unexpected costs and adjustments during installation: €2,000

Recurring Costs

a. Maintenance:

1. **Regular Maintenance:**
    - Annual inspection and maintenance of the power screw and control system: €2,000
    - Replacement of worn components (annual): €1,000
2. **Software Updates:**
    - Control software updates every 2 years: €500

Expected Benefits

a. Operating Cost Savings:

1. **Labor Reduction:**
    - Savings in labor costs due to automation: €5,000 annually
2. **Operational Efficiency:**
    - Improvement in loading efficiency, reducing operation times: 10% increase in operational efficiency, resulting in estimated savings of: €10,000 annually

b. Improved Inventory Management:

1. **Loading Precision:**
    - Reduction in errors and waste due to precise loading: €3,000 annually
2. **Space Savings:**
    - Better space organization, avoiding additional storage costs: €2,000 annually

9.3 Summary Table

Category	Cost/Benefit (€)	Frequency
INITIAL COSTS		
Power screw and components	30.000	One-time
Control and automation system	6.000	One-time
Installation labor	16.000	One-time
Training	1.500	One-time
Permits and licenses	500	One-time
Contingencies	2.000	
Total initial costs	56.000	
RECURRING COSTS		
Regular maintenance	2.000	Annual
Replacement of components	1.000	Annual
Software updates	500	Every two years
Total recurring costs anually	3.000	
ANNUAL BENEFITS		
Labor savings	5.000	Annual
Operational efficiency	10.000	Annual
Error/waste reduction	3.000	Annual
Storage space savings	2.000	Annual
Total anual benefits	20.000	
NET BENEFIT	First year: -36.000	
	Subsequent years: 17.000	

TABLE 15: Costs analysis

10. Economic analysis Poka-Yoke

10.1 Introduction

This detailed economic analysis evaluates the financial impact of implementing the Poka-Yoke system in the animal feed production facility. It considers direct and indirect costs, as well as expected benefits. Below, we outline the costs for materials, labor, and maintenance, along with efficiency and savings benefits.

10.2 Detailed Economic Analysis

Initial Costs

a. Materials:

1. **Poka-Yoke Systems:**
    - Error sensors: €4,000
    - Process controllers: €2,500
    - Alarm and notification devices: €1,500
    - Installation materials (cables, supports, etc.): €1,000
2. **Software and Integration Systems:**
    - Control and integration software: €3,000
    - Update of existing systems for compatibility: €2,000

b. Labor:

1. **Installation:**
    - Engineers and technicians (100 hours at €50/hour): €5,000
    - Electricians and mechanics (80 hours at €40/hour): €3,200
2. **Training:**
    - Staff training on system usage: €1,200

c. Other Costs:

1. **Permits and Licenses:**
    - Administrative costs for permits: €400
2. **Contingencies:**
    - Unexpected costs and adjustments during installation: €1,000

Recurring Costs

a. Maintenance:

1. **Regular Maintenance:**
    - Annual inspection and maintenance of sensors and systems: €1,000
    - Replacement of worn components (annual): €500
2. **Software Updates:**
    - Control software updates every 2 years: €400

Expected Benefits

a. Operating Cost Savings:

1. **Reduction in Errors and Reworks:**
    - Savings due to the decrease in process errors: €6,000 annually
    - Reduction in reworks and material waste: €3,000 annually
2. **Operational Efficiency:**
    - Improvement in production process efficiency: 5% increase in efficiency, resulting in estimated savings of: €5,000 annually

b. Improvement in Product Quality:

1. **Consistency in Production:**
    - Better consistency and quality of the final product: €2,000 annually
2. **Reduction in Complaints and Returns:**
    - Fewer customer complaints and returns: €1,500 annually

10.3 Summary Table

Category	Cost/Benefit (€)	Frequency
INITIAL COSTS		
Error sensors	4.000	One-time
Process controllers	2.500	One-time
Alarm and notification devices	1.500	One-time
Installation materials	1.000	One-time

Control and integration software	3.000	One-time
Update of existing systems	2.000	One-time
Installation labor	8.200	One-time
Training	1.200	One-time
Permits and licenses	400	One-time
Contingencies	1.000	One-time
Total initial costs	24.800	
RECURRING COSTS		
Regular maintenance	1.000	Annual
Replacement of components	500	Annual
Software updates	400	Every 2 years
TOTAL RECURRING COSTS ANNUALLY	1.500	
ANNUAL BENEFITS		
Reduction in errors and reworks	9.000	Annual
Operational efficiency	5.000	Annual
Consistency in production	2.000	Annual
Reduction in complaints and returns	1.500	Annual
Total anual benefits	17.500	
NET BENEFIT	First year: -8.800	
	Subsequent years: 16.000	

TABLE 16: Costs analysis 2

10.4 Conclusion

Implementing the Poka-Yoke system represents an initial investment of €24,800, with recurring maintenance costs of €1,500 annually. However, the annual benefits of €17,500 from reduction in errors, improvements in operational efficiency, consistency in production, and reduction in complaints and returns make the investment worthwhile in the long term. The return on investment would begin to be seen starting from the second year of operation, ensuring sustainable improvements in the factory's efficiency and quality.

11. Conclusions

This final project has allowed for the evaluation and enhancement of production processes at an animal feed company based in the Region of Murcia, Spain, by implementing Lean Manufacturing principles. Throughout the project, various challenges affecting productivity and organizational efficiency were identified and effectively addressed.

11.1 Key Findings

- **Improved Organization**: Significant improvements in organization within specific work areas and departments were achieved through the adoption of structured methodologies. This included implementing an efficient storage system that streamlined material access.
- **Process Automation**: Automation of critical processes reduced dependence on manual operations, resulting in enhanced accuracy and consistency during production. Integration of weight sensors and automatic stop systems played a pivotal role in achieving these improvements.
- **Enhanced Organizational Efficiency**: Utilization of tools such as 5S and Kanban fostered a culture of continuous improvement, facilitating waste reduction and improving inventory management practices.

11.2 Impact on the Company

- **Reduced Errors**: Implementation of visual controls and weight sensors significantly minimized instances of incorrect ingredient mixes, ensuring consistent nutritional quality in the final product.
- **Improved Quality**: Every batch of feed now adheres to rigorous nutritional standards, thereby enhancing customer satisfaction and compliance with food safety regulations.
- **Enhanced Process Efficiency**: Optimization of mixing and production processes has led to decreased instances of corrective actions and rework due to ingredient composition errors.

11.3 Long-term Benefits

The implementation of these enhancements not only optimized current operations but also laid a robust foundation for future technological advancements and adaptations. This strategic positioning equips the company to effectively address future challenges while maintaining competitiveness in the market.

11.4 Recommendations

To sustain these achievements, it is recommended to:

- **Provide Ongoing Staff Training**: Continuously update employees on new technologies and processes to maintain skill relevancy.
- **Conduct Regular System Audits**: Periodically assess implemented systems to ensure effectiveness and adaptability to evolving market demands.
- **Promote a Culture of Continuous Improvement**: Encourage employees to actively identify and propose new improvement opportunities, fostering an environment of innovation and growth.

In conclusion, this project underscores the transformative impact of Lean Manufacturing principles on enhancing efficiency, productivity, and product quality within the animal feed sector. It establishes a sustainable competitive advantage, positioning the company for sustained success and future growth.

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