POLITECNICO DI TORINO

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Master's Degree thesis

Optimization of the supply chain for a trading company

Supervisor:
Prof. Domenico Augusto Maisano

Candidate:
Luca Cafà

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Abstract

There are rural realities that are able to provide very good quality raw material, but this needs an optimisation process of the system that links these areas to international markets, preserving the initial quality.
This thesis analyses the supply chain related to mango puree, from the cultivation and harvesting of the fruit to its distribution to companies involved in the final processing and sale to consumers. The research was conducted during an internship at Montecarlofruit S.A.R.L., a company based in the Principality of Monaco, which plays a crucial role in the chain by managing the import and export of puree from Mali to destinations worldwide.
Following a presentation of the company and the activities carried out during the internship, the paper analyses the supply chain in detail, using various strategic tools, such as PEST and SWOT analysis, to identify its strengths, weaknesses, opportunities and threats. The research conducted identified the main critical points requiring improvement. They are related to quality and its monitoring, logistical inefficiencies, high costs and risk management.
The goal is to propose concrete and innovative solutions using an analytical approach characterised by the application of Quality Engineering principles in the agri-food sector, not focussing on a single actor, but always maintaining a holistic view to improve the sustainability of the entire ecosystem.

Table of contents

List of figures

List of tables

List of acronyms and abbreviations

ALARP = As Low As Reasonably Practicable

AMANORM = Agence Malienne de Normalisation et de Promotion de la Qualité

AQL = Acceptable Quality Level

BRCGS = British Retail Consortium Global Standard

C.A.G.R. = Compound Annual Growth Rate

CEDIAM = Centre d'Etude et de Développement Industriel et Agricole du Mali

CEO = Chief Executive Officer

CIRAD = Centre de Coopération Internationale en Recherche Agronomique pour le Développement

FMECA = Failure Modes, Effects and Criticality Analysis

GFDRR = Global Facility for Disaster Reduction and Recovery

Horeca = Hotels, restaurants and catering

LCL = Lower Control Limit

LIS = Lean and Integrated System

LNTL = Lower Natural Tolerance Limit

LSL = Lower Specification Limit

LTPD = Lot Tolerance Percent Defective

NOP = National Organic Program

PCR = Process Capability Ratios

PdM = Predictive Maintenance

PGM = Predictive Group Maintenance

RUL = Remaining Useful Life

S.A. = Société Anonyme

S.A.R.L. = Société à responsabilité limitée

UCL = Upper Control Limit

UNTL = Upper Natural Tolerance Limit

UOM = Unscheduled Opportunistic Maintenance

USL = Upper Specification Limit

Introduction

In recent years, the topic of sustainability in international markets has become increasingly central to ensuring that a high-quality product from rural areas can reach the end consumer on a global scale. Within this framework, quality plays a fundamental role and must be maintained from the mango fruit through every step of the supply chain.

This supply chain originates in Mali, where the mango is cultivated and processed into puree and concentrate. The product is then transported to Dakar, from where it is shipped to Rotterdam, where a warehouse handles distribution, or to another port worldwide to be picked up by customers. The clients are multinational corporations or companies that process the puree into baby food, juices, or other mango-derived products, which are then sold to the final consumer.

The objective of the paper is to analyse the entire ecosystem in detail in order to highlight its criticalities and to propose solutions that can optimise it. A continuous process of improvement, focused on eliminating waste, is essential to ensure that this supply chain, which is able to drive the economic and social growth of an entire region through its sustainability, remains competitive against global leaders in mango processing and trade, particularly those based in Asia and Central-South America that have more resources at their disposal. The optimisation of the supply chain is also aimed at making it as scalable as possible in order to launch similar initiatives in other emerging countries around the world, which can offer excellent quality raw material, but need all those processes that connect them with international markets.

Going into more detail, the thesis is organised into five chapters.

The first one tells about Montecarlofruit - the trading company where the research was carried out - its establishment, organisation, customers, and then explores the activities in which it is directly involved or on which it offers support to other actors in the system.

The second describes the activities that were carried out by the candidate during the internship period.

The third chapter deals with the analysis of the supply chain: it begins with an introduction describing the processes carried out, the actors involved, and their responsibilities. Following this, the analysis introduces two methodologies, PEST and SWOT analysis, in order to understand the forces influencing the system as well as its strengths and weaknesses. The results obtained made it possible to focus in greater detail on the main critical points that require improvement.

The fourth chapter presents an introduction to quality within a supply chain, followed by a review of the critical points addressed in the previous chapter, along with proposed solutions to optimize them. In this optimization process, an analytical approach was used, characterized by the application of quality engineering principles and the use of mathematical models and scientific research.

Finally, the last chapter, dedicated to conclusions, summarizes the results obtained, the limitations of the research and potential future developments.

Chapter 1

1. MONTECARLOFRUIT S.A.R.L.

This chapter provides a comprehensive overview of Montecarlofruit, the company where the research was conducted. Montecarlofruit is a dynamic organization renowned for its innovative approaches within the agribusiness sector. The chapter begins by detailing the company's history, its mission and its core values, setting the stage for a deeper understanding of its operational framework.

Subsequently, the chapter describes the organizational structure and the work environment at Montecarlofruit. This section describes the various activities undertaken by the company, illustrating its culture and highlighting the collaborative and international environment that promotes employee engagement and drives continuous improvement.

1.1 Company history

Montercarlofruit is a trading company based in the Principality of Monaco that deals with the import-export of semi-finished agri-food products: *mango puree and concentrate*.

Montecarlofruit identifies, designs and executes development projects in the agri-food sector in fragile territories. It intervenes in both the creation of new production facilities and the revitalization of existing but underutilized production hubs. Additionally, through *off-take agreements*[1], where a resource producer commits to selling certain quantities of products at stable prices for a specified period, it ensures the commercialization of production output.

The first significant project is the collaboration with CEDIAM S.A.[2] (*Centre for Study and Industrial and Agricultural Development of Mali*).

[1] *Off-take agreements* refer to contracts between producers and buyers of a resource or product, where the buyer agrees to purchase the producer's goods within a specified timeframe and often at predetermined prices. These agreements are commonly used in industries like energy, mining, and agriculture to secure financing and stabilize revenues.

[2] *CEDIAM S.A.* is a Malian company specializing in the agro-food sector. The company is involved in the production and processing of agricultural products, focusing on enhancing local value chains and promoting sustainable agricultural practices in Mali.

The two companies can be considered related, as the former exercises significant influence over the latter and, in addition, they have an investor and a manager in common.
In 2010, Montecarlofruit conducted an agronomic analysis in West Africa, in collaboration with CIRAD[3] (*Centre for International Cooperation in Agronomic Research for Development*), to select those areas that could benefit from agro-cultural development.
In 2011, Mali was identified as a country with excellent potential for agro-industrial progress due to its large natural and fertile soils: in particular, it was ideal for the mango fruit.
Consequently, in January 2012, the setup of the entire plant began, which lasted for eight months until August 2012.
To enable this, 171 containers of materials and equipment, as well as engineering excellence, were mobilised from Italy, for an initial investment of USD 16 million.
The final facility (Figure 1) occupies an area of 14 hectares and, despite its location in a rural environment, enjoys advanced technologies.

Figure 1: Production plant in Mali

1.2 Production sites and locations

Montecarlofruit is involved in the development, support of production and sale of semi-finished organic fruit products produced by its partner and supplier CEDIAM.

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[3] *CIRAD* is a French research organization dedicated to agricultural and rural development. It focuses on tropical and subtropical regions, working on innovative research and development projects to enhance agricultural practices, sustainability, and food security in developing countries.

The plant is located in Yanfolila, Mali (Figure 2), and has a state-of-the-art facility equipped with:

- a main production block with offices on the mezzanine;
- an aseptic production line;
- a raw materials warehouse with a capacity of 1.600 tons;
- a packaging facility for stock;
- a finished products warehouse and dispatch centre;
- eight ripening chambers that allow the fruit to reach an optimal growth rate;
- a maintenance centre;
- three 16 cubic metre water wells;
- a 20.000-volt power line;
- a 5.000 kW steam boiler;
- two 900 kVA backup generators;
- a UV treatment and chlorine removal system for the water.

Figure 2: Location of the factory

This plant has the capacity to process 240 tonnes of mangoes per day in pulp and concentrate (10 t/h).

As far as the logistical inflow is concerned, on average, the plant receives 990 lorries full of fruit from all over the region each year (Figure 3).

Figure 3: Received trucks containing harvested mangoes

To optimize logistics flows and meet specific customer requirements, Montecarlofruit collaborates with a strategically located warehouse in Breda (Holland) known as Vriesveem. This facility is part of the Vriesveem Vrieshuizen BV group[4], which manages container reception at the port of Rotterdam. Upon reception, containers are transported either to Vriesveem's own warehouse or to customer-designated warehouses as per commercial agreements.

Additionally, Montecarlofruit's corporate headquarters are situated in the Principality of Monaco. Here, the company operates offices and meeting rooms where its staff carry out various tasks and responsibilities. This central location facilitates efficient management and coordination of operations across different geographical areas.

1.3 Revenues

In recent years, Montecarlofruit has recorded the revenues and tonnes of product sold shown in the following tables.

Table 1 represents the revenues generated by the company as a function of time, between 2018 and 2023.

[4] *Vriesveem Vrieshuizen BV* is a Dutch company specializing in logistics and supply chain management, particularly in the agricultural and food sectors. The group offers a range of services including warehousing, transportation, and distribution, focusing on optimizing supply chain efficiency and ensuring the timely delivery of goods.

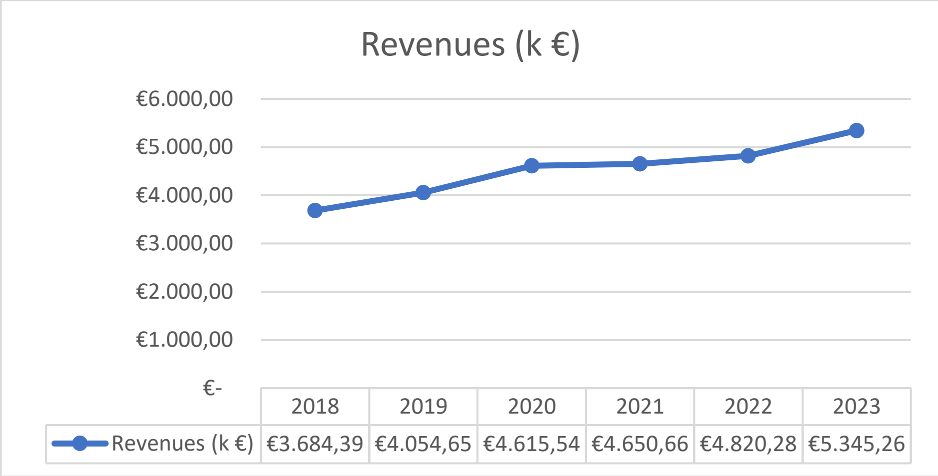

Table 1: Revenues

Revenues show a steady increase from 2018 to 2023. This is due to several reasons and strategic choices implemented by the company:

- excellent product quality, thanks to the excellent raw material, which has allowed the Malian mango to become increasingly known and appreciated in a market where the main historical producers are India and Central America[5];
- an increase in the production of the organic product variant compared to the conventional one, through more and more in-depth microbiological analyses;
- the acquisition of certain globally recognised certifications that instil confidence in customers, e.g. Kosher[6] for Jewish food regulations, Naturland[7] for organic farming and NOP[8] for organic products in the USA;

Table 2 represents the tons of product sold by the company as a function of time, between 2018 and 2023.

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[5] *India and Central America* are renowned for their dominant positions in the global mango market. India, as the world's largest producer, is known for its diverse varieties such as Alphonso and Kesar, which are celebrated for their rich flavor and aroma. Central America, including countries like Mexico and Guatemala, also plays a significant role, offering varieties such as Tommy Atkins and Haden, which are appreciated for their quality and shelf life. These regions have established themselves as key suppliers in international markets due to their extensive production infrastructure and experience in mango cultivation.

[6] *Kosher* refers to the dietary laws observed by many Jewish communities, based on the principles outlined in the Torah and detailed in the Talmud. These laws, known as Kashrut, include guidelines on permissible foods, the separation of meat and dairy products, and specific methods of food preparation.

[7] *Naturland* is a prominent international certification organization for organic farming and sustainable agriculture. Established in Germany, Naturland sets stringent standards for organic farming practices, including the use of environmentally friendly methods, the prohibition of synthetic chemicals and the promotion of biodiversity.

[8] The *NOP* sets standards for organic farming and handling practices, including the prohibition of synthetic pesticides and genetically modified organisms (GMOs).

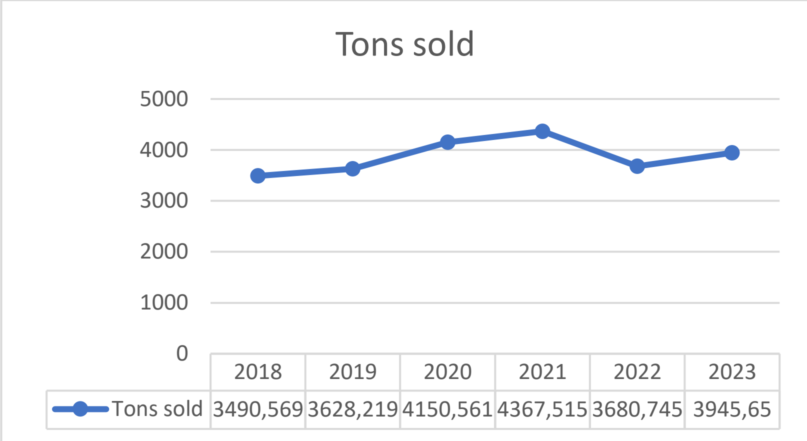

Table 2: Tons sold

This trend shows how Montercarlofruit managed to market its product despite the problems that affected the supply chain on a global scale due to the COVID-19 pandemic. The company has succeeded in this by improving the process of converting the mangoes into puree and concentrate, by recovering the cooling water from the evaporator, and by logistics and customer service, which for central and northern Europe is provided by the depot in the Netherlands.

In addition to the health emergency, it is important to consider other factors affecting this sector. Indeed, adverse weather conditions can affect mango production, reducing the quantity available for sale. But at the same time, social or political problems can also cause damage to business by delaying the start of orders.

Finally, looking at the two graphs at the same time, it can be seen that despite the decrease in tonnes sold in 2022, revenues have increased. In fact, thanks to the quality and recognition of its product, Montecarlofruit was able to raise its price without losing its market share.

1.4 Corporate organization

Owner and founder of the company is the chairman Roberto Ballabeni, a visionary entrepreneur with over fifty years of experience. In all this time, he has created and participated in a number of companies operating in multiple sectors. As an investor, he enabled the creation of Montecarlofruit in 2012 and was also the main investor involved in the creation of the CEDIAM project in West Africa.

At executive level, the main figure is CEO Francesco Caponetti (Figure 4), who has been with Montecarlofruit since 2012, initially as Business Development Director and Chief Project Manager. He currently also holds the position of General Manager and member of the Board of Directors of CEDIAM SA.

Working alongside the CEO is the Chief Financial Officer (CFO), Elena Dutto.

Her competencies cover budgeting and business planning, analysis, accounting and financial control.

There are other employees in the company's offices in Monaco, who ensure that all logistical and organizational tasks are carried out correctly.

As far as company organization in Africa is concerned, Montecarlofruit and CEDIAM work with 42 local cooperatives and 4300 farmers who supply fruit within a radius of 450 km: 90% of them belong to the bottom of the social pyramid. For this very reason, the company prides itself on being a reference point and socio-economic driving force for an entire region.

To optimize the supply chain, the company relies on an operational unit of international experts selected for agro-industrial and engineering operations (Agrifood Team). Leading this team is the plant manager, who coordinates the processing of the raw material (the mango) to obtain the final semi-finished product (puree and concentrate) and, with his team, manage all activities at the Yanfolila factory.

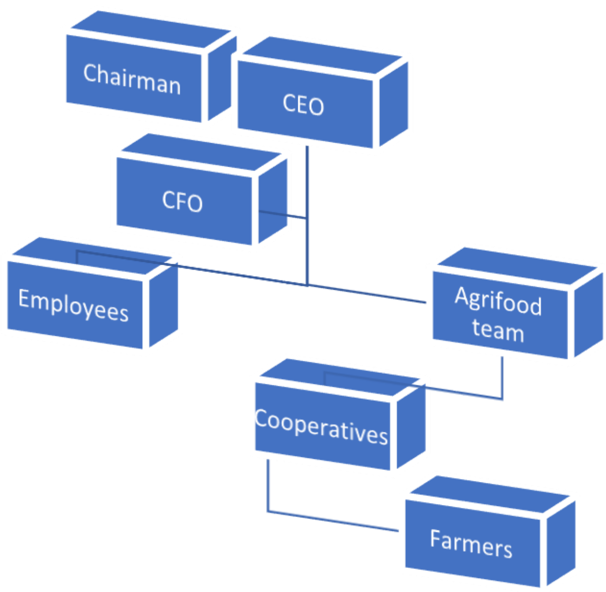

Figure 4: Company organigram

1.5 Customers

Montecarlofruit offers various types of mango puree and concentrate as sales products.

The company's objective is to connect the rural realities of Mali to the international markets, through the construction of an intercultural chain of processes and people.

Montecarlofruit's distribution network is of the *divergent* type[9], as there is only one supplier (CEDIAM) and a diversity of buyers.

The clients consist of large companies that process the mango semi-finished product into fruit juices and baby food, i.e. foodstuffs intended for babies' early childhood.

The main buyers (Figure 5) include:

- Nestlé, one of the largest multinationals operating in the food sector and among its multitude of products offers juices and homogenised products;
- Hero, an agribusiness specialising in baby food and foods for coeliacs;
- Eckes-Granini, a German corporate group involved in the production of fruit juices, drinks, smoothies and syrups;
- True fruits, a young German company that became famous for their fruit smoothies and their unique all-glass packaging;
- Lassonde, a Canadian multinational operating throughout North America. In addition to producing a wide range of products, including fruit juices made from mangoes processed by Montecarlofruit, the company also imports, packages and markets wines and other beverages;
- Mainfrucht, a large German company, develops high-quality, customised fruit and vegetable products from puree and concentrate for the following sectors: baby food, bakery, confectionery, dairy, gastronomy, beverages, ice cream and spirits.

Figure 5: Main customers

[9] *A divergent distribution network* refers to a supply chain configuration where a single distribution point or central hub supplies multiple downstream locations or markets. This type of network is characterized by its branching structure, where goods flow from a central source to various destinations, allowing for the efficient distribution of products to a broad range of customers or locations.

1.6 Company activities

Montecarlofruit stands out in the agri-food sector for its extensive range of activities, spanning from forecasting to distribution, including harvesting, processing, and research and development. This section examines in detail the key operations of the company, ensuring a high-quality final product and continuous innovation. Some of these activities, such as forecasting and distribution, are entirely managed by Montecarlofruit, while others such as harvesting and processing are mainly carried out by CEDIAM, but with the strategic support of the Monegasque company.

1.6.1 Forecasting

The first activity the company has to deal with is forecasting, which consists of making an advance estimate of future demand based on market trends, historical data, predictive harvest analysis and early customer requirements, in order to effectively organise subsequent production activities.

This forecasting plays a fundamental role in the life of the company, influencing several crucial decisions such as procurement, inventory management and production scheduling, which are essential for maintaining operational efficiency and meeting customer demands. The importance of sales forecasting is particularly emphasised in the evaluation of a company's budget. By creating a realistic financial plan that incorporates data from the forecasting period, Montecarlofruit can establish a robust guide for spending and resource allocation throughout the year, especially during the critical early stages of the supply chain.

Montecarlofruit conducts its forecasting activities in September/October for the upcoming year. This schedule allows for an initial harvest of the raw material, mango, in March, followed by meticulous processing and distribution phases.

When formulating its budget, the company must plan the procurement of essential packaging materials such as metal drums and aseptic bags. These items are not readily available in Mali, necessitating their import from Europe and Asia, which requires careful logistical and financial planning.

During the forecast period, Montecarlofruit must also secure spare parts for the scheduled maintenance of industrial machinery. These components, not being available locally in

Africa, need to be imported from international suppliers, underscoring the importance of accurate forecasting and timely procurement.

Another critical aspect tied to forecasting is determining the volume of harvest and production. This volume must be sufficient to meet all demand and prevent *stockouts*[10], ensuring that inventory levels are managed effectively to fulfil customer orders without interruption.

By accurately forecasting demand, Montecarlofruit can develop appropriate logistical and production plans to maintain optimal stock levels. The company utilizes its warehouses in Africa, located near the factory, and its strategic warehouse in Breda, Holland, to efficiently manage inventory and ensure timely delivery to European customers.

The company boasts a loyal customer base, with new clients added each year. Historically, the company has consistently sold its entire production, demonstrating its ability to accurately forecast demand and maintain customer satisfaction.

1.6.2 Harvesting

Montecarlofruit processes different qualities of mangoes (Litz, 2009)[11], which differ in chemical properties and harvest periods, to obtain various types of puree and concentrate, also in the organic variant (Figure 6).

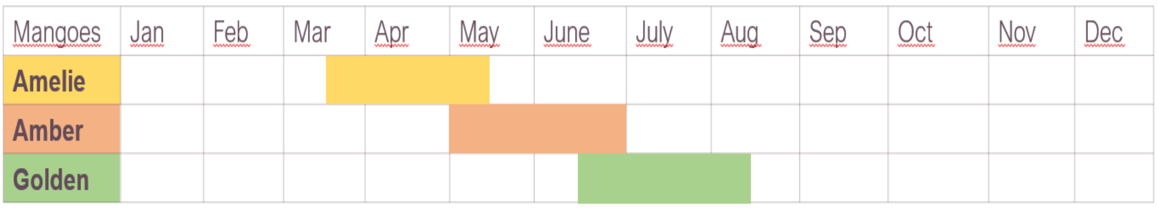

Figure 6: Harvest scheduling

[10] *Stockouts* refer to situations where inventory levels are insufficient to meet customer demand. This occurs when products are out of stock and unavailable for purchase, potentially leading to lost sales, customer dissatisfaction and disruption in the supply chain.

[11] "Litz, R. E. (Ed.). (2009). *The mango: Botany, production and uses* (2nd ed.). CABI." is a fundamental resource for understanding mango cultivation, analysing various aspects of the plant, from botanical characteristics to production. It includes in-depth details on the ripening, sensory qualities and peculiarities of the different mango varieties, providing valuable information for farmers, researchers and companies in the industry.

The first variety of mango harvested from mid-March onwards is the Amelie. Although the Amelie is the least ripe among the varieties, it boasts a very good base flavour. Its flesh is silky and fiber-free, with an oval shape measuring 8-10 cm. The colour of the Amelie can vary from shades of yellow and pale green to a more vivid scarlet red.

Towards the beginning of May, the type of mango harvested changes to the Amber variety. The Amber mango has a more robust appearance and a broader structure, although its overall size ranges from 6-9 cm. This variety comes in both the typical oval shape and a round variant. Its flesh is very sweet and juicy with an intense yellow colour, while the skin is green with red spots and yellow dots.

From mid-June onwards, the Golden mango, the ripest variety, is harvested. This species is highly productive and offers excellent disease resistance. The Golden mango has a delicious essence with sweet but firm flesh. It has the typical oval mango shape, ranging in size from 6 to 8 cm. The shade is the classic shade of the fruit: yellow, with red spots slightly darker than in other varieties (Figure 7).

Figure 7: Types of mangoes

1.6.3 Processing

Once harvested, the mangoes are placed in crates and loaded onto trucks for transportation to the processing plant in Yanfolila.

Upon arrival, the raw material is unloaded and subjected to an initial selection process (Figure 8) to ensure optimal line filling and fruit preservation. The mangoes are selected based on criteria such as weight, diameter, colour, and external quality. Additionally, the mangoes are graded and sorted according to the production capacity used and the type of packing required.

The selected fruit is then stored in specific ripening chambers, which are humidified rooms containing a high concentration of ethylene gas. Ethylene is one of the most widely used ripening accelerators, as it diffuses into the fruit tissues, causing an increase in respiration and the hydrolysis of cellulose. This process is essential because mangoes are climacteric fruits, meaning they can continue to ripen even after being detached from the plant. The use of ethylene gas helps to accelerate the ripening time, ensuring that the mangoes reach the desired level of ripeness before further processing (Siddiq & Kader, 2012)[12].

Figure 8: First mango selection

Upon exiting the ripening chamber, the mangoes are placed onto conveyor belts, which are integral to the plant's operations, facilitating smooth movement between various processing stations. These continuous belts are designed for handling light, bulk loads efficiently, with a seamless surface that prevents any gaps, ensuring the fruit remains intact during transport.

[12] "Siddiq, M., & Kader, A. (Eds.). (2012). *Tropical and subtropical fruits: Postharvest physiology, processing and packaging* (1st ed.). John Wiley & Sons." provides a detailed overview of the post-harvest physiology, processing and packing of tropical and subtropical fruits, including mangoes. In particular, Chapter 6 discusses in depth the post-harvest physiology and storage techniques of mangoes including the use of ethylene, while Chapter 8 focuses on post-harvest handling and storage practices specific to this fruit, offering useful information to ensure quality and extend the shelf life of mangoes.

The mangoes are then guided into a washing tank[13] filled with chlorinated water at a concentration of 5-10 ppm to inhibit and eradicate bacterial growth. For optimal cleaning, the mangoes are also brushed and sprayed with fresh running water as they travel along the conveyor belt exiting the tank. This multi-step cleaning process ensures that the fruit is thoroughly sanitized.

Subsequently, a secondary selection process is conducted, further scrutinizing the raw material for quality. This stage helps in removing any substandard fruit, resulting in a collection of waste material before the actual processing begins.

The mangoes then pass through an *auger dehuller blancher*[14], which serves multiple purposes including pasteurization, enzymatic treatment and external pre-heating. This process facilitates the extraction of pulp and ensures the quality of the semi-finished product. The blancher employs steam to heat the surface of the mangoes, aiding in the softening and loosening of the peel.

The processed mangoes are fed through an *inlet hopper* [15] equipped with an auger, which is a hydraulic device used to maintain a steady flow of material. From here, the mangoes are directed to a stoning stripper. This machine efficiently removes the stones and a significant portion of the peel. The pulp is then extracted by high-speed rotating beaters, which centrifuge the product, ensuring a smooth and consistent pulp for further processing.

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[13] A *washing tank* is a specialized container used in various industries, including food processing and agriculture, for cleaning and sanitizing products. In the context of fruit processing, a washing tank is designed to remove dirt, contaminants and residues from produce through immersion in water or cleaning solutions. These tanks are equipped with mechanisms to ensure thorough and effective cleaning, often incorporating agitation or circulation systems.

[14] An *auger dehuller blancher* is a type of equipment used in food processing to remove the hulls or outer shells of seeds, grains, or legumes, and to blanch the products simultaneously. The auger mechanism helps to dehull the product through mechanical action, while the blanching process involves heating the product to a specific temperature to inactivate enzymes, preserve color, and prepare it for further processing or consumption.

[15] An *inlet hopper* is a funnel-shaped component used in various industrial and processing equipment to facilitate the controlled feeding of materials into a system. In the context of food processing, such as with mango puree or concentrate production, the inlet hopper serves as the entry point for raw materials, guiding them into machinery for further processing. The design helps ensure an even and consistent flow of ingredients, preventing blockages and ensuring efficient operation.

Additionally, positioned on the central shaft of the machine, just before the beaters, is a *toothed-blade breaker*[16]. This component's task is to superficially break the fruit, ensuring a more efficient subsequent pulp extraction by the beaters.

Some characteristics of this industrial equipment are as follows:

- Constructed entirely of stainless steel for durability and hygiene;
- Robust and bulky structure designed to handle large volumes of fruit;
- Rotor consisting of a central shaft, a toothed-blade breaker and four beaters made of steel with a rubber coating, all driven by an electric motor for efficient operation;
- Equipped with an internal washing system for thorough cleaning of the production plant and piping;
- Features easily removable inspection covers with safety switches, ensuring safe and easy maintenance access.

The resulting puree passes through sieve holes measuring 1/16 inch in size and falls into the outlet hopper, while the stones and peels are expelled from the back of the machine. The kernels are left perfectly clean, free from any residual pulp. These clean kernels are subsequently recycled to produce natural products, such as pellets that serve as fuel for boilers, highlighting the company's commitment to sustainable practices.

At this stage, the filtered puree is directed into an evaporator for sterilization. This rapid process, which lasts about 30 seconds, is conducted at a temperature of 100 °C and under low pressure. It effectively softens the puree and eliminates bacterial microorganisms, ensuring the product's safety and extending its shelf life during transport and storage.

A specialized tank is used to condense and cool the steam produced by the evaporator. This process allows for the recovery of water, which is then utilized in the subsequent step to cool the puree. This method not only conserves water but also enhances the efficiency of the cooling process.

Finally, the resulting mango product is poured into steel drums (Figure 9). These drums are then stored in the finished product warehouse located in Yanfolila, conveniently situated near the production line to facilitate efficient storage and handling.

[16] A *toothed-blade breaker* is a mechanical device used in food processing to break down solid materials into smaller pieces. It features blades with teeth that cut or shred the material, making it easier to process or handle. In food processing, toothed-blade breakers are often used to crush or reduce the size of fruits, vegetables, or other ingredients, facilitating their preparation for further processing, such as pureeing, cooking or extraction.

Montecarlofruit markets both mango puree and mango concentrate, packaged in steel drums weighing 235 kg and 245 kg respectively. This weight difference reflects the varying density and concentration of the two products.

The *Brix value*[17], which measures the percentage of solid substances dissolved in a solution, varies between mango puree and mango concentrate. Mango concentrate possesses three times the Brix value of puree. This means that the production of each barrel of concentrate requires three times the amount of mango compared to what is needed for a barrel of puree. This significant difference underscores the intensive processing required to produce mango concentrate, resulting in a highly concentrated and rich product.

Figure 9: Drum filling

1.6.4 Distribution

The drums, containing the semi-finished mango product, are prepared for sale by being packed on wooden pallets in groups of four. This packing method is strategically chosen to enhance stability and protection during transportation.

[17] The *Brix value* in mango puree and concentrate indicates the concentration of soluble solids, primarily sugars, and is a key quality parameter. It helps determine the sweetness, flavor intensity and potential applications of the product. A higher Brix value typically reflects a richer and more intense mango flavor, making the puree or concentrate suitable for various culinary and industrial uses, such as in beverages, desserts and processed foods.

This decision is based on the necessity of transporting the product from Yanfolila to the port of Dakar, a journey of 1565 km by truck. These trucks often traverse rural and unpaved roads, making it crucial to ensure the cargo's stability and safety during transit.
Traveling on potholed roads with heavy, scattered loads inside the container could damage the product before it even reaches its destination. Such damage could result in the customer rejecting the goods and the drums becoming dented, leading to additional costs for the company. By grouping the drums, the risk of damage is minimized, ensuring the product remains intact and presentable upon arrival.
Grouping the drums on pallets enhances transport efficiency by reducing the risk of collisions between individual drums and creating a more compact and stable load. This method significantly diminishes the impact of road bumps, ensuring the integrity of the product during the long and challenging journey.
Each container is capable of holding 20 pallets, accommodating a total of 80 drums. This results in a total weight of 18.8 tonnes for mango puree (80 drums x 235 kg each = 18800 kg) and 19.6 tonnes for mango concentrate (80 drums x 245 kg each = 19600 kg). This strategic packing maximizes the use of container space while maintaining the safety and quality of the product throughout the transportation process.
Upon arrival in Dakar, the drums are carefully loaded onto container ships, ready for international shipping to destinations all over the world. This global distribution network ensures that Montecarlofruit’s products reach customers in a timely and efficient manner.
At this stage, it is essential to distinguish the destinations of the goods into two primary categories:

1. *Make to Stock* (MTS): This category includes the quantity of product processed prior to receiving customer orders, based on demand forecasts. MTS also serves as a safety stock, accommodating any unexpected increases in demand throughout the year, beyond the initially forecasted and agreed quantities with customers. Initially, these products are stored in the finished goods warehouse in Yanfolila. Subsequently, they are shipped to Rotterdam and stored in the Vriesveem warehouse. Barring any unforeseen issues, the average transit time for a container from Yanfolila to Rotterdam is approximately two months. Occasionally, the lot might be sold while during the journey, in which case the logistics company (Vriesveem Vrieshuizen BV) will transport the goods either to their own warehouse or directly to the customer-designated warehouses as

per commercial agreements. This flexibility in logistics ensures timely fulfilment of orders and efficient inventory management.

2. *Make to Order* (MTO): This category comprises quantities of semi-finished goods produced based on contracts finalized with customers prior to the harvest season. For certain European customers, these goods follow a similar logistical flow as the MTS products, with Rotterdam and the Vriesveem warehouse serving as key distribution points. This approach ensures that customer-specific orders are efficiently processed and delivered in accordance with pre-arranged schedules and agreements. For other customers, located on other continents or with factories on European soil but further away from Rotterdam, direct delivery is made to the most strategic port agreed upon by the parties during the contractual period.

Montecarlofruit has a worldwide trade; the main trading ports are:

- Rotterdam;
- Montreal;
- Valencia;
- St. Cruz de Tenerife;
- Lisbon;
- Melbourne;
- New York;
- Adelaide;
- Brisbane;
- Tilbury.

1.6.5 Research and Development

In addition to its core activities related to the trade of mango puree and concentrate, Montecarlofruit is deeply committed to ongoing research and development initiatives each year. These R&D efforts are integral to the company's strategy for continuous improvement and innovation.

These R&D commitments necessitate significant investments in both human and financial resources, focusing on comprehensive scientific and territorial investigations. This multidisciplinary approach enables the company to explore new methodologies, improve existing processes, and identify opportunities for sustainable growth.

A central tenet of Montecarlofruit's mission is to replicate the successful CEDIAM project. This entails importing its proven business model into other marginalized regions, with the aim of leveraging local raw materials and significantly improving the socio-economic conditions of the local population. By doing so, Montecarlofruit not only enhances the value

of indigenous resources but also plays a pivotal role in combating local unemployment and fostering economic development.
On the other hand, the decision to expand business operations into countries like Mali necessitates careful consideration of the ongoing state of emergency and political instability that characterize these regions. Such conditions pose significant challenges but also present opportunities for impactful interventions.
Since 2012, Mali has faced a series of terrorism-related challenges and recurring coup attempts. These events often lead to potential customs issues, hindering the trade of goods and disrupting the local business economy. Such instability can pose significant risks to the continuity of operations and the smooth flow of the supply chain.
Despite these formidable challenges, Montecarlofruit remains steadfast in its commitment to developing an international supply chain. The company continually searches for optimal territories where it can replicate the success of the CEDIAM project, demonstrating resilience and a long-term vision for sustainable development.
In addition, Montecarlofruit is dedicated to financing scientific research aimed at diversifying its product offerings. This includes exploring the processing of other fruits beyond mangoes, thereby expanding its market reach and enhancing its portfolio. By investing in such R&D activities, the company not only innovates but also mitigates risks associated with relying on a single type of raw material.
In recent years, Montecarlofruit has not limited itself to investigating African territories, but has also approached Asian companies to create partnerships with them in order to combine their knowledge of fruit picking and processing with the logistics and management skills of the Monegasque company.
In order to improve the conditions of the workers and at the same time increase the quality of the raw material used, the company is engaged in a project to map crops in Mali in order to optimise the supply of the equipment needed for cultivation and harvesting. Furthermore, Montecarlofruit with CEDIAM is committed to training its farmers and updating them on new cultivation methods.
This type of research is flanked by continuous chemical and biological analysis of the product (Figure 10), in order to optimise the quality that characterises Montecarlofruit's output.

Figure 10: Analysis of a puree sample

1.6.6 Fruit for Peace

Fruit for Peace represents an exportable and scalable model of international cooperation and development. Originally conceived as a project aimed at economic activation and social progress, it is specifically designed to address the needs of marginal contexts characterized by persistent states of emergency. This innovative model seeks to empower local communities by creating sustainable economic opportunities.

Currently, Fruit for Peace is an active and evolving project, championed by Montecarlofruit. It involves a diverse coalition of stakeholders, including governmental institutions, designers and companies within the agricultural sector. This collaborative effort aims to leverage the expertise and resources of all parties involved to maximize the project's impact and sustainability.

Moreover, one of the core objectives of Fruit for Peace is to develop a comprehensive recycling system that ensures sustainability throughout the entire production chain at each selected site. By implementing advanced recycling technologies and practices, the project aims to minimize waste and promote a *circular economy*[18].

[18] A *circular economy* is an economic system focused on the sustainable management of resources. It aims to minimize waste and maximize the reuse, repair, refurbishment and recycling of products and materials. This approach encourages the design of goods with longer life cycles and promotes the regeneration of natural systems, ultimately reducing environmental impact and fostering sustainable growth.

Inspired by the successful CEDIAM project, Fruit for Peace has implemented a sophisticated recovery and processing system that revalues production waste, creating a robust recycling cycle. This approach not only reduces environmental impact but also generates additional economic value from by-products that would otherwise be discarded.

Following the processing of mangoes to obtain puree and concentrate, significant amounts of waste are generated, particularly during the stoning and stripping phases. Proper management and valorisation of this waste are crucial for achieving sustainability and reducing environmental impact.

The waste material primarily consists of the mango *stone*, which has an ovoid shape and occupies a substantial portion of the fruit, measuring approximately 7 centimetres in length. This by-product presents several opportunities for further processing and utilization. The stone can be processed using a hexane solvent, a hydrocarbon liquid, to extract mango butter oil. This oil is rich in fats and has various applications in the cosmetic and food industries.

In addition to oil extraction, the stone can be repurposed into non-food products such as fuel pellets and filaments for 3D printers. These innovative applications not only add value to the waste but also contribute to a circular economy.

The *seed* can be replanted to cultivate new mango trees, promoting agricultural sustainability. Additionally, it can be processed to produce a special biodegradable film. This film is created by combining sugars from maize and beets with fibers extracted from the mango seed, resulting in a fully natural and eco-friendly product.

This biodegradable film is completely natural and can serve as a fertilizer at the end of its lifecycle, thus integrating seamlessly into sustainable agricultural practices.

The *peel* is another valuable by-product, rich in fiber, essential minerals such as magnesium and potassium, and antioxidants. This nutrient-rich waste can be utilized in various ways to maximize its benefits. Because of these chemical properties, it is widely used in the cosmetics industry, as its antioxidants slow down cellular ageing and are good for the skin.

From the peel it is also possible to make special sprays that are required for mulching, an agricultural operation that consists of sprinkling dry leaves, manure or suitable sprays over the soil to protect crops from excessive sunlight or the danger of frost (Figure 11).

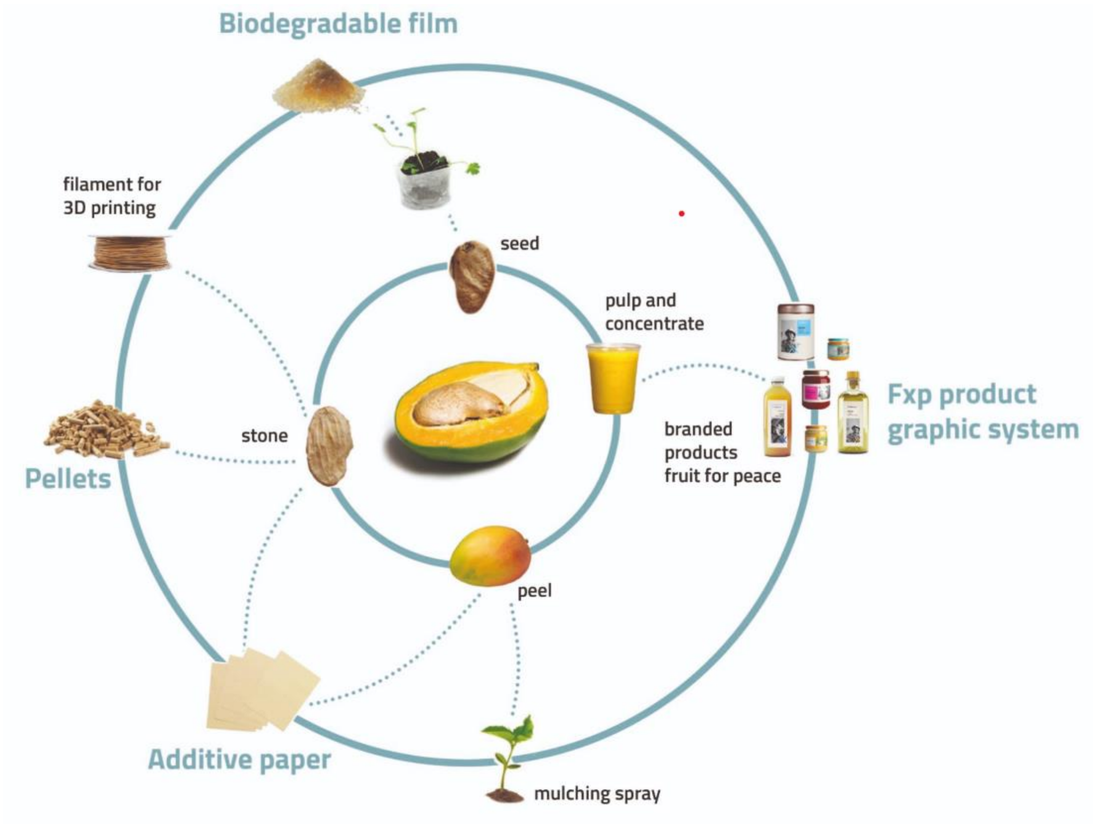

Figure 11: Mango waste recycling

In addition to individual waste valorisation, certain agri-food factory by-products can be synergistically combined in specific production processes to create innovative and valuable products.

For instance, combining mango peel and kernel in papermaking operations results in environmentally friendly paper reels, reducing the need for cellulose from plants by up to 15%. This approach not only conserves natural resources but also provides a sustainable alternative to traditional papermaking processes.

The resulting sheets of paper exhibit a darker, more opaque hue compared to the classic white sheets we are accustomed to. This colour variation is attributed to the natural pigments present in the mango waste, adding a unique aesthetic and reducing the need for chemical bleaching.

The Fruit for Peace model integrates a comprehensive production system that includes products derived from mango processing. These products are marketed through dedicated packaging that highlights the identity and mission of the system (Figure 12). This approach not only promotes brand recognition but also underscores the sustainable and ethical values of the initiative.

The primary packaging labelling is developed using an intercultural design approach, incorporating methodologies of thinking and listening design. This ensures that the packaging reflects and honours the diverse cultural backgrounds of the regions where the product originates. By doing so, the design not only enhances the aesthetic appeal but also fosters a deeper connection with consumers, who can appreciate the story and heritage behind the product.

Figure 12: Fruit for Peace distinctive packaging

Chapter 2

2. Internship

This section outlines the diverse range of activities undertaken by the candidate during his internship, showcasing a blend of administrative, analytical and organizational tasks. From the outset, the intern was integrated into the company's operations, gaining insights into its core functions and processes.

Throughout the internship, he was involved in tasks that required meticulous attention to detail and analytical thinking. These activities provided the intern with practical experience and an opportunity to apply theoretical knowledge in a real-world setting.

In fact, the trainee had the opportunity to actively participate in the functioning of a supply chain on an international scale involving various actors from local farmers to customers, usually represented by multinationals.

The tasks performed by the trainee that contributed to the organisation's objectives will be analysed below.

2.1 Data and documentation organisation

The departure from the Yanfolila plant, for each container, involves the preparation of a set of documents to identify the batch.

For each booking, whether directly related to a customer order or for a load destined for the warehouse in Rotterdam, the trainee's task was to create a folder with all the documentation related to that booking.

Each dossier contains:

- packing lists;
- certificate of origin and analysis;
- phytosanitary certificate;
- waybill;
- certificate of inspection, only for the organic variant of the product;
- cargo insurance;

- invoice.

The packing lists (Figure 13) are files containing all the information specific to that load: date of issue, container number, number of drums inside, weight of each drum and total weight, booking number, quality of the type of mango processed and number of pallets.

Each drum is identified by means of a batch code, i.e. an alphanumeric code that communicates all the data relating to the product contained in that specific drum.

The batch code consists of two initial numbers referring respectively to the year of harvest and a boolean variable with a value of 0 if the product is organic, 9 if it is not organic.

Next is an abbreviation that differentiates puree from concentrate and the various types of mango.

The puree is displayed as MP, the concentrate as MC and the different mango categories are characterised by a number: 1 for amelie, 2 for amber and 3 for golden.

In addition, for those bookings that contain organic mango qualities and are Naturland-certified, they have a distinctive 'N' in the batch code.

Finally, there are other numbers that list that particular drum within the entire production, distinguishing one from the other.

C.E.D.I.A.M. SA BAMAKO, MALI

REF. BOOKING N° 015 - 24 1/1 conteneur

PACKING LIST		
DATE 02/07/2024	B015. 1/1CT	CONTAINER NO : TTNU 113873-3
PRODUCT : ORGANIC AMBER MANGO PUREE		No of Drums 80
Total Net Weight		80 Drums x 235 kg = 18 800 kg
Weight of packing Materials (Drums, Aseptic bag and Polythene Bag)		80 x 11 kg = 880 kg
Weight of Pallets		20 pallets x 30 kg = 600 kg
Total Gross Weight		20 280 Kg
Container Tare		2 100 kg
VGM		22 380 kg
Container Type 20" Dry		SEAL N° H4538321

Code Summary	40MP2052229081D TO 40MP2052229160D		
PALLET NO	TRACEABILITY DATA	PALLET NO	TRACEABILITY DATA
1	40MP2052229081 D	11	40MP2052229121 D
	40MP2052229082 D		40MP2052229122 D
	40MP2052229083 D		40MP2052229123 D
	40MP2052229084 D		40MP2052229124 D
2	40MP2052229085 D	12	40MP2052229125 D
	40MP2052229086 D		40MP2052229126 D
	40MP2052229087 D		40MP2052229127 D
	40MP2052229088 D		40MP2052229128 D
3	40MP2052229089 D	13	40MP2052229129 D
	40MP2052229090 D		40MP2052229130 D
	40MP2052229091 D		40MP2052229131 D
	40MP2052229092 D		40MP2052229132 D
4	40MP2052229093 D	14	40MP2052229133 D
	40MP2052229094 D		40MP2052229134 D
	40MP2052229095 D		40MP2052229135 D
	40MP2052229096 D		40MP2052229136 D
5	40MP2052229097 D	15	40MP2052229137 D
	40MP2052229098 D		40MP2052229138 D
	40MP2052229099 D		40MP2052229139 D
	40MP2052229100 D		40MP2052229140 D
6	40MP2052229101 D	16	40MP2052229141 D
	40MP2052229102 D		40MP2052229142 D
	40MP2052229103 D		40MP2052229143 D
	40MP2052229104 D		40MP2052229144 D
7	40MP2052229105 D	17	40MP2052229145 D
	40MP2052229106 D		40MP2052229146 D

Figure 13: Packing list

Most of the other documents in the file are certifications required for the import of foodstuffs.

Finally, there is the waybill, a document issued by the carrier, responsible for transporting the goods, which provides all the information necessary for transit: identification of the shipper and consignee, starting point of the shipment, destination and the route that will be taken.

2.2 "Bon d'entrée" preparation

After creating a dossier for each booking, the trainee is instructed to develop, using Excel, the *bon d'entrée* (Figure 14), i.e. an internal company document that records the entry of goods into the control system.

These documents transport the information contained in the packing lists onto Excel spreadsheets and are then converted into 'text Unicode' files.

The data are the same as in the packing list; in addition, each batch code is associated with a characteristic product code, subsequently recognised by the management software, which depends on the quality of the mango that was processed, whether it is an organic product and whether it is puree or concentrate.

	A	B	C	D	E	F	G	H	I	J	K	L
1	Document -	Document -	Code dépôt	Document - Dépô	Ligne - Code article	Ligne - Quan	Ligne - Série/lot	Ligne - Q	Ligne - V	Ligne - Booking	Ligne - Rele	Ligne - Co
2	BE150	02/07/2024	2009c3fa-9824-468b-bf39-e983b5ae5f1a	TRANSIT BREDA	240MP2-235	235	40MP2052229081D	235		15		TTNU 113
3	BE150	02/07/2024	2009c3fa-9824-468b-bf39-e983b5ae5f1a	TRANSIT BREDA	240MP2-235	235	40MP2052229082D	235		15		TTNU 113
4	BE150	02/07/2024	2009c3fa-9824-468b-bf39-e983b5ae5f1a	TRANSIT BREDA	240MP2-235	235	40MP2052229083D	235		15		TTNU 113
5	BE150	02/07/2024	2009c3fa-9824-468b-bf39-e983b5ae5f1a	TRANSIT BREDA	240MP2-235	235	40MP2052229084D	235		15		TTNU 113
6	BE150	02/07/2024	2009c3fa-9824-468b-bf39-e983b5ae5f1a	TRANSIT BREDA	240MP2-235	235	40MP2052229085D	235		15		TTNU 113
7	BE150	02/07/2024	2009c3fa-9824-468b-bf39-e983b5ae5f1a	TRANSIT BREDA	240MP2-235	235	40MP2052229086D	235		15		TTNU 113
8	BE150	02/07/2024	2009c3fa-9824-468b-bf39-e983b5ae5f1a	TRANSIT BREDA	240MP2-235	235	40MP2052229087D	235		15		TTNU 113
9	BE150	02/07/2024	2009c3fa-9824-468b-bf39-e983b5ae5f1a	TRANSIT BREDA	240MP2-235	235	40MP2052229088D	235		15		TTNU 113
10	BE150	02/07/2024	2009c3fa-9824-468b-bf39-e983b5ae5f1a	TRANSIT BREDA	240MP2-235	235	40MP2052229089D	235		15		TTNU 113
11	BE150	02/07/2024	2009c3fa-9824-468b-bf39-e983b5ae5f1a	TRANSIT BREDA	240MP2-235	235	40MP2052229090D	235		15		TTNU 113
12	BE150	02/07/2024	2009c3fa-9824-468b-bf39-e983b5ae5f1a	TRANSIT BREDA	240MP2-235	235	40MP2052229091D	235		15		TTNU 113
13	BE150	02/07/2024	2009c3fa-9824-468b-bf39-e983b5ae5f1a	TRANSIT BREDA	240MP2-235	235	40MP2052229092D	235		15		TTNU 113
14	BE150	02/07/2024	2009c3fa-9824-468b-bf39-e983b5ae5f1a	TRANSIT BREDA	240MP2-235	235	40MP2052229093D	235		15		TTNU 113
15	BE150	02/07/2024	2009c3fa-9824-468b-bf39-e983b5ae5f1a	TRANSIT BREDA	240MP2-235	235	40MP2052229094D	235		15		TTNU 113
16	BE150	02/07/2024	2009c3fa-9824-468b-bf39-e983b5ae5f1a	TRANSIT BREDA	240MP2-235	235	40MP2052229095D	235		15		TTNU 113
17	BE150	02/07/2024	2009c3fa-9824-468b-bf39-e983b5ae5f1a	TRANSIT BREDA	240MP2-235	235	40MP2052229096D	235		15		TTNU 113
18	BE150	02/07/2024	2009c3fa-9824-468b-bf39-e983b5ae5f1a	TRANSIT BREDA	240MP2-235	235	40MP2052229097D	235		15		TTNU 113
19	BE150	02/07/2024	2009c3fa-9824-468b-bf39-e983b5ae5f1a	TRANSIT BREDA	240MP2-235	235	40MP2052229098D	235		15		TTNU 113
20	BE150	02/07/2024	2009c3fa-9824-468b-bf39-e983b5ae5f1a	TRANSIT BREDA	240MP2-235	235	40MP2052229099D	235		15		TTNU 113
21	BE150	02/07/2024	2009c3fa-9824-468b-bf39-e983b5ae5f1a	TRANSIT BREDA	240MP2-235	235	40MP2052229100D	235		15		TTNU 113
22	BE150	02/07/2024	2009c3fa-9824-468b-bf39-e983b5ae5f1a	TRANSIT BREDA	240MP2-235	235	40MP2052229101D	235		15		TTNU 113
23	BE150	02/07/2024	2009c3fa-9824-468b-bf39-e983b5ae5f1a	TRANSIT BREDA	240MP2-235	235	40MP2052229102D	235		15		TTNU 113
24	BE150	02/07/2024	2009c3fa-9824-468b-bf39-e983b5ae5f1a	TRANSIT BREDA	240MP2-235	235	40MP2052229103D	235		15		TTNU 113

Figure 14: Bon d'entrée on Excel sheet

Once the excel file has been converted into text unicode, it is possible to enter the bon d'entrée into a special management software called EBP (Figure 15), which allows all commercial and logistical aspects of the company to be managed, optimising cash management.

EBP represents a business operating model of the *Saas* (software as a service) type, in that the software is not installed on the user's physical computer, but on remote servers, which the user can access. In fact, Montecarlofruit paid the company offering the service and also pays an annual subscription to obtain continuous maintenance and support from the French technical company.

Within EBP, various articles are distinguished on the basis of whether they are puree or concentrate and on the basis of mango quality and harvest year.

For each article class, there is a product code that exactly matches the code associated with the batch codes when the bon d'entrée is created.

In this way, when a bon d'entrée is added, the system recognises the product and updates the relevant quantities for that article.

EBP also allows the codes to be differentiated by the presence of several virtual warehouses: Montecarlofruit distinguishes goods destined to end up in stock in the

Netherlands from those which already have a customer and are characterised by direct transit. Bookings destined for Rotterdam are labelled by the trainee as *'Transit Breda'*. When they arrive at the warehouse and the intake document is received from the organisation responsible for managing the warehouse, an employee of the Montecarlofruit team is responsible for converting the status of the booking from *Transit Breda* to *Breda*. In this way it is possible to have real time management of the quantities actually in the warehouse and those in transit. For an import-export company, confusing the quantities in stock with those in transit can pose serious risks. Firstly, it can lead to ineffective inventory management, causing shortages or surpluses of products. This can result in delivery delays to customers and loss of sales. In addition, a surplus of product in the warehouse would require a longer process to dispose of this quantity; being an agri-food product, specific technologies are needed to store the product for long periods and this would increase storage costs.

The management software allows cash flow control: delivery notes and invoices can be created using the software.

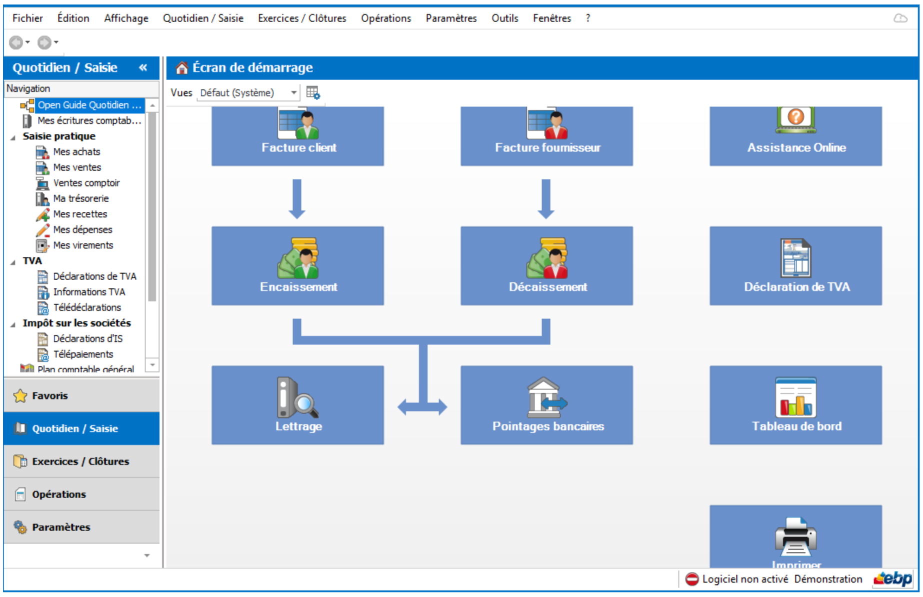

Figure 15: EBP interface

2.3 Batch code analysis

Some customers, especially larger ones, consisting of several factories located in various countries, such as Nestlé, require samples of puree and concentrate to carry out further chemical analysis for the production of baby food.

Following the chemical analyses, the managers of the various customers notify Montecarlofruit of the results.

For each of its processing plants, the customer provides tables containing its entire production, where it indicates for each batch code whether it has been accepted, rejected or accepted with reservations.

In addition, Nestlé identifies certain drums for Kosher Passover certification.

This certification distinguishes these selected drums from the rest of the production because the Passover declaration identifies products that are not contaminated with wheat and its derivatives and are therefore highly suitable for coeliac consumers. Furthermore, Kosher certification identifies all those foods that are suitable for feeding consumers observant of the Jewish faith.

Nestlé enters into a contract with Montecarlofruit at the beginning of the business year for the total quantity that will be purchased during the current crop. The quantities exchanged are very large and are not sent to a single factory, but in several tranches to different factories according to the results of chemical analyses, which in turn depend on the requirements of the final product to be developed. For this reason, it is essential to carefully manage the quantities delivered to various plants, ensuring that each plant receives the necessary amount of the right product at the right time, avoiding shortages or excesses that could create problems for the customer and worsen the working relationship with Montecarlofruit. Therefore, the company uses internal management files.

The trainee was instructed to develop an excel file by creating a sheet for each batch code. Each sheet was created with a specific structure (Figure 16), representing on some columns the characteristics of the batch code, then some characteristics of the reservation to which those specific drums were assigned and finally some columns representing the different Nestlé factories.

The intern's task was to fill in each cell between drum and factory in order to enter the chemical evaluation carried out with reference to that specific sample. In this way, the

Montecarlofruit team knows, for each batch code, the evaluations from each plant, can decide how to allocate the various drums to the factories and can keep track by updating the tables with each delivery.

Two different files were created: one referring to puree batch codes and one for concentrate batch codes.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	BATCH CODE	Drum counter	Release no.	Booking no.	Container no.	Arches	Rzeszow	PASSOVER	Zuegg	Sevares	Turku	Fruselva	
2	BATCH CODE	1											
3	BATCH CODE	2											
4	BATCH CODE	3											
5	BATCH CODE	4											
6	BATCH CODE	5											
7	BATCH CODE	6											
8	BATCH CODE	7											
9	BATCH CODE	8											
10	BATCH CODE	9											
11	BATCH CODE	10											
12	BATCH CODE	11											
13	BATCH CODE	12											
14	BATCH CODE	13											
15	BATCH CODE	14											
16	BATCH CODE	15											
17	BATCH CODE	16											
18	BATCH CODE	17											
19	BATCH CODE	18											
20	BATCH CODE	19											
21	BATCH CODE	20											
22	BATCH CODE	21											
23	BATCH CODE	22											
24	BATCH CODE	23											
25	BATCH CODE	24											
26	BATCH CODE	25											
27	BATCH CODE	26											
28	BATCH CODE	27											
29	BATCH CODE	28											
30	BATCH CODE	29											

Figure 16: Structure of each sheet

2.4 Monthly transport invoicing

To manage transport invoicing, Montecarlofruit uses special Excel tables which it updates monthly taking into account all the containers that leave the Yanfolila plant.

During the internship experience, the writer carried out the task of drawing up the transport invoicing control tables for the months of April, May and June.

To perform this task, the trainee used time filters on EBP on the bookings that left the African plant. In this way, it was possible to trace back for each month which orders had been dispatched.

Then, by continuing a reverse search, it was possible to trace the destination port and the number of containers that made up the booking. The reverse search was performed by tracing the information in the email launching the booking or in the dossier previously created by the trainee.

In addition to differentiating bookings according to the port of destination, Montecarlofruit differentiates them according to the logistics carrier handling the transport; it is important to differentiate orders correctly because distributors have different tariffs. The company relies on two different carriers:

- *Bolloré Logistics*: a French company that deals with multimodal transport and customs compliance. As far as its relationship with Montecarlofruit is concerned, it is currently dedicated to the transfer of containers destined for all destinations where the Monaco-based company trades, excluding Montreal, New York, Valencia, Lisboa, Melbourne and Brisbane, which are mainly served by the other logistics operator.
- *Sodimax Logistic Services*: an international freight forwarder based in Genoa that operates in all major import-export markets. The Italian logistics group handles container transports with final destinations in Montreal, New York, Valencia, Lisboa, Melbourne and Brisbane and occasionally some direct to Rotterdam.

These tables have a twofold function: on the one hand, they have a financial value because they serve to account for the transport costs of each month and, on the other hand, they have an important internal significance for the company, as they provide a clear view of the containers that have been marketed each period. The trainee was instructed to develop separate tables per month and port of destination comparing the data from 2023 with those of the current year 2024. This data enables the company to carry out performance analyses: it allows to quantify its performance, to visualise peaks and troughs in demand in a market characterised by the seasonality of the fruit and to optimise strategic and budget planning for the coming periods.

2.5 Procedures manual creation

Finally, one of the tasks that lasted the longest during the internship was the drafting of a procedure manual.

In fact, Montecarlofruit's objective is to standardize its management and operational processes to optimize efficiency and minimize the time required. Moreover, well-defined procedures reduce the margin of error, as employees follow a pre-established and tested path, and could also be useful in the future for a double reason: both because new resources can be trained more quickly and effectively and because it becomes easier for Montecarlofruit to expand by scaling its business by relying on standardised routines.

For this purpose, the intern was tasked with developing a procedure manual explaining in the simplest possible way the company routines to complete a specific task.

In this assignment, the intern was able to delve deeper into the activities he had come into contact with and mentioned the other activities carried out by the company using explanatory procedures developed by other team members.

The activities described in the manual covered all the various steps that represent Montecarlofruit's contribution in the mango supply chain, starting from the negotiation of the order with the agent representing the client to the management of the quantities in the warehouse to meet the customer's requirements and the consequent issuing of the invoice and delivery of the goods.

Finally, this detailed description of the routines carried out by the company allows a careful analysis of them in order to highlight the critical points that do not add value to the service offered and the possibility of finding ways to optimise them.

In fact, the central object of the candidate's research in this paper was the analysis of this supply chain and its optimisation, as will be discussed in the following sections.

Chapter 3

3. Supply chain analysis

The supply chain is a network of all organisations involved in the creation and distribution of a product with the objectives of improving customer value, reducing costs and ensuring overall efficiency (Chopra & Meindl, 2019) [19].

The mango supply chain is a sophisticated system that goes through several stages, from cultivation in producing countries to distribution in global markets.

This chapter analyses the various aspects of this supply chain, highlighting the unique challenges and opportunities associated with managing a highly perishable product such as mangoes.

Effective management of the mango supply chain is essential to ensure product quality, minimise costs and reduce logistical inefficiencies, while addressing risks related to climatic factors and demand fluctuations.

Through the analysis of evaluation methodologies, bottlenecks, quality issues and associated costs, the chapter will provide an in-depth insight by identifying those critical points that need optimisation to improve performance and meet global market demands.

[19] "Chopra, S., & Meindl, P. (2019). *Supply chain management: Strategy, planning, and operation* (7th ed.). Pearson." offers a comprehensive overview of supply chain management, exploring the design and optimisation of logistics networks, supply and demand planning, and inventory management. It also analyses the role of information technology, global management challenges, and strategies to ensure environmental and social sustainability. Through case studies and analytical tools, the text provides both the theoretical foundations and practical applications for improving efficiency and competitiveness in the supply chain.

3.1 Introduction to the supply chain

The mango supply chain is an example of logistical complexity that requires meticulous management to ensure that the product reaches the end consumer in the best possible quality (Alam, 2018)[20].

It is possible to subdivide the supply chain into different stages, each characterised by different activities, carried out by different actors with different responsibilities who must, however, work together.

The first steps that start the value chain are *cultivation* and *harvesting* of the fruit.

The operators and managers of these initial phases in Mali are small farmers operating within cooperatives representing them.

Mangoes thrive in a hot and dry climate, with ideal temperatures between 25 and 35°C. Mangoes prefer well-drained and fertile soils. In Mali, small farmers often work on clay or sandy soils, which may require improvement to optimise growth. Indeed, irrigation plays a crucial role, especially during the dry season. Smallholder farmers may use drip irrigation systems[21] or traditional irrigation canals [22] to supply water to the plants.

In addition, mangoes require regular fertilisation to ensure healthy growth and abundant production. Organic fertilisers are commonly used by small farmers.

From this process it can be deduced that it is necessary to have trained, competent and continuously updated people to work with this fruit. The role of cooperatives in training and protecting the rights of small farmers is crucial in this task.

[20] "Alam, M. M. (2018). Mango supply chain and value chain analysis from farm to market. *International Journal of Supply Chain Management, 7*(4), 7-18." examines the mango supply chain in detail, covering all stages from production to marketing. It analyses value-adding dynamics, logistical challenges and optimisation opportunities along the supply chain, providing a comprehensive overview of current practices and possible improvement strategies.

[21] *Drip irrigation systems* are a water-efficient method of irrigation that delivers water directly to the root zone of plants through a network of tubes, pipes, and emitters. This system minimizes water wastage by providing a slow, consistent flow of water exactly where it is needed, reducing evaporation and runoff. Drip irrigation is particularly beneficial for precision farming, optimizing water use, and enhancing crop yield while conserving resources.

[22] *Traditional irrigation canals* are man-made channels used to distribute water from a source, such as a river or reservoir, to agricultural fields. These canals have been used for centuries to support farming by providing a steady and controlled flow of water to crops. They are typically designed to channel water across large areas, often involving a network of main and secondary canals. While effective, traditional canals can be less efficient compared to modern irrigation methods due to issues such as water loss through evaporation and seepage.

Then *harvesting* takes place: a critical stage that affects the quality and shelf life of the fruit; this activity is also generally carried out by small farmers and cooperatives following traditional methods.

Mangoes are harvested when partially ripe, as they ripen further during transport and processing.

Harvesting is done manually to reduce the risk of breakage or bruising, and finally they are collected in plastic baskets on trucks to avoid damage during handling and transport to the processing centre.

The fruit is then processed to obtain the puree or concentrate. The reader is referred to section *1.6.3 Processing* where this procedure is described in detail.

These activities are mainly carried out by the supplying company, which is thus responsible for selection, preparation, processing, packaging and storage.

In this specific supply chain, those responsible for these steps are CEDIAM with the collaboration of the Agrifood team.

Once the puree or concentrate is ready, it is marketed through a *distribution company* that deals with import-export; this activity is carried out by Montecarlofruit.

The company has to manage customs practices, ensuring that all customs and health regulations are respected, negotiate with international buyers to sell mango puree and concentrate, manage customer relations, plan and coordinate activities between producers, processors and logistics companies.

At this point, the *logistics companies* come into action. Their main task is to organise and carry out the transport of the product. For this purpose, they must track the products along the entire route, manage any delays or transport problems and guarantee the freshness and quality of the products during the trip.

Finally, the mango semi-finished product reaches the customer who are *multinationals* or *large companies*. Their function is to process the puree into the final product, i.e. mango derivatives such as juice or baby food, which is destined for the end consumer.

It is their job to ensure the quality of the finished product and to supply consumers through various channels:

- Distribution to retailers: selling the product to supermarkets, grocery and speciality shops by entering into long-term supply contracts to ensure the continued presence of the products on the shelves.

- Online sales: use own corporate website with an online shop where consumers can buy the product directly or use food-specific e-commerce platforms.
- Distribution in *Horeca channels*[23]: supplying fruit juices and other mango-based products to restaurants and bars, hotels and catering services.

Table 3 provides an overview of the main steps in this chain in relation to the related actors and their responsibilities.

[23] *Horeca channels* refer to the distribution networks that supply products to the hospitality industry, encompassing hotels, restaurants, cafés and catering services. This term is commonly used to describe the segment of the food and beverage industry that caters to these establishments, providing a range of products including fresh produce, beverages and other food items. The Horeca sector is crucial for food producers and suppliers, as it represents a significant portion of the market demand for high-quality and diverse food products.

Activity \ Actor	Small farmers	Cooperatives	CEDIAM	Agrifood team	Montecarlofruit	Logistics carriers	Customers
Cultivation	Soil preparation, planting and care of plants	Training and protection of farmers					
Harvesting	Manual fruit picking, selection and initial cleaning of mangoes	Training and protection of farmers					
Processing			Grinding and processing of mangoes, packaging and preservation of the processed product	Design and management of engineering operations			
Distribution					Negotiation, trade, sales and export planning and control	Transport, traceability and storage of goods en route	
Final processing							Final processing and sale to the consumer

Table 3: Supply chain overview

In addition to the main actors operating in the mango supply chain, it is possible to identify *secondary actors* who do not act directly on the product but whose decisions and actions influence the work of others.

First and foremost, *policy makers* play an important role: they develop and implement regulations and standards for the cultivation, processing and export of mangoes, ensuring that agricultural practices and food safety standards are in line with national and international guidelines. They also offer financial support, subsidies and incentives to farmers and companies in the supply chain through specific calls for tenders.

In the Malian context, their importance is even more important, as in a country with a turbulent political past, it is crucial for a company to operate in a stable environment with the support of the local government in order to do business efficiently.

Another important figure is the *certification bodies*; they have to assess and certify mango processors for compliance with various standards in order to issue authoritative certificates for the import-export of an agri-food product.

These controls take place through regular audits and inspections and allow the company receiving the certification to validate its product in front of customers, so as to extract as much value as possible from it by guaranteeing a high quality product.

Finally, in order to make sure that the supply chain functions properly, the role played by *storage infrastructure managers* is crucial.

In fact, an agri-food product such as mango puree requires specialised infrastructure with the appropriate technology to enable the conservation of the goods without spoilage. It is therefore necessary to rely on professionals, also considering the strategic position the warehouse may have in relation to the location of customers and the manufacturing company. In this specific case study, Montecarlofruit rely on a Dutch group based in Breda, taking advantage of the nearby port of Rotterdam, which is an excellent trading point.

The supply chain can be affected not only by the primary and secondary actors operating in it, but also by the choices of the end consumers.

Consumers' preferences and purchasing habits directly shape the demand for products. For example, a growing preference for organic products can drive producers and suppliers to adopt more sustainable practices. Therefore, the increased demand for certain types of mango products may lead companies to diversify their product offerings. For this reason, companies have to pay close attention to the flexible needs of consumers by introducing new products, modifying existing ones or proposing new innovative solutions either as final goods or through revolutionary new processes.

3.2 Analysis methodologies

After understanding the functioning and the various steps that characterise this supply chain, it is possible to use certain analytical methodologies in order to understand at a deeper level of analysis the relationships between the various actors and the processes that transform inputs into final outputs (Breisinger et al., 2023)[24].

The analyses carried out in this section will not focus on a specific actor, but will have as their subject the supply chain as a whole (Figure 17). This holistic view allows a more complete overview of the dynamics influencing the entire system that might not be detected if focusing on a single component. It also avoids falling into the error of neglecting possible independencies and synergies that are created between the different actors.

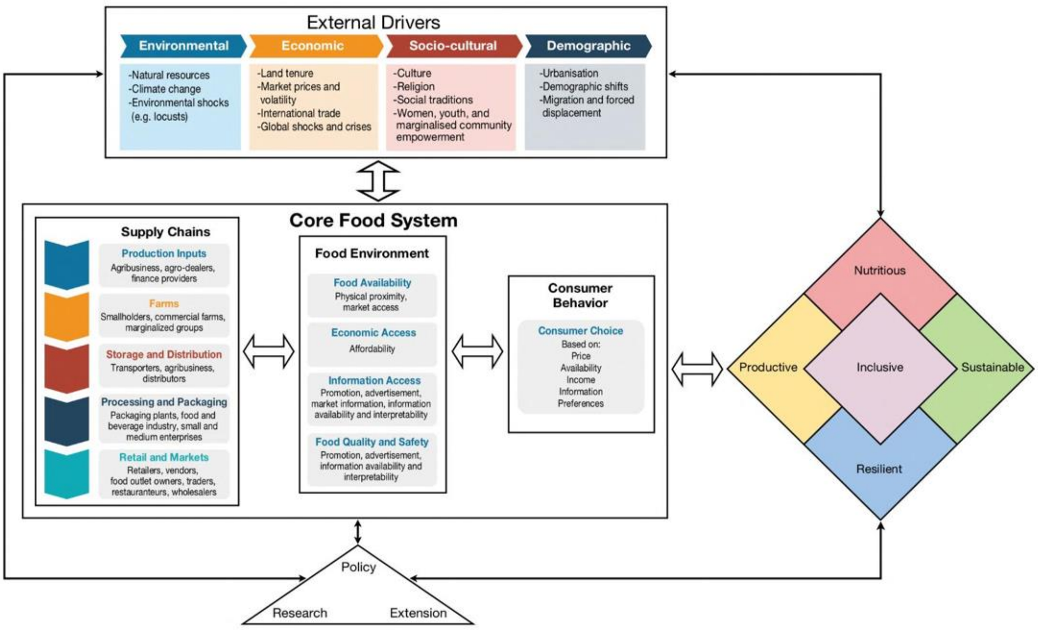

Figure 17: The agrifood system

[24] "Breisinger, Clemens, Michael Keenan, Juneweenex Mbuthia, and Jemimah Njuki (eds). (2023). *Food Systems Transformation in Kenya: Lessons from the Past and Policy Options for the Future.* Washington, DC: International Food Policy Research Institute." analyses models for analysing agri-food systems in detail, with a particular focus on the dynamics of sustainable transformation. The authors provide an analysis model for assessing and improving the sustainability and efficiency of the agri-food supply chain, highlighting challenges and opportunities that can be applied in different contexts, focusing on the Kenyan context but easily adaptable to similar realities, such as Mali.

3.2.1 PEST analysis

It is important to start by understanding the scenario in which the supply chain takes place and what external forces may affect it: a *PEST analysis* can be used for this purpose (Harrison & John, 2013)[25].

PEST is an acronym that stands for Political, Economic, Social and Technological; these are in fact the macro-categories into which the forces potentially influencing the supply chain are classified.

For the purpose of the research, a PEST was carried out on this supply chain:

- *Political*:
  - Malian laws and regulations: the Food Safety Law establishes food safety and hygiene requirements for food production and marketing. This law is essential to ensure that mango products meet both local and international standards, guaranteeing their safety and quality. In addition, agricultural regulations, including those specific to mango cultivation regulate the use of pesticides, imposing limits on the chemicals used. These regulations are essential to protect plants and maintain high standards of product quality. In Mali, there is an agency that deals with quality standardisation and promotion for trade called AMANORM[26].
  - Trade policies: export tariffs imposed by Malian law can include both tariffs and incentives for mango exports, thus affecting price competitiveness in international markets. These costs or concessions can have a significant impact on the ability of Malian producers to compete globally. However, the *Cotonou Agreement*[27] with the European Union offers a crucial advantage by allowing preferential access to the European market for products from ACP countries, including Mali. This agreement

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[25] "Harrison, J. S., & John, C. H. (2013). *Foundations in strategic management* (6th ed.). South-Western College Pub." describes the basics of strategic management and describes PEST analysis as a fundamental tool for analysing the macro-environmental context.

[26] *AMANORM* is the Malian agency responsible for setting and overseeing national standards and regulations. Its mission includes developing and implementing standards for various sectors, including agriculture, industry, and trade, to ensure quality and safety. AMANORM plays a crucial role in facilitating trade, enhancing product quality, and supporting the development of national and regional standards in Mali.

[27] *The Cotonou Agreement* is a framework established in 2000 between the European Union (EU) and 79 African, Caribbean, and Pacific (ACP) countries. The agreement aims to foster political and economic cooperation and development assistance, with a focus on trade, economic integration, and sustainable development. It replaces the Lomé Convention and includes provisions for enhancing trade relations, supporting regional integration, and addressing issues such as poverty reduction and governance.

reduces duties and tariffs for mangoes, further improving the competitiveness of Malian products in European markets.

- *Economic:*
    - Production costs: in Mali, agricultural labour costs are very low compared to other countries, which positively influences production costs by lowering them. However, there are other non-negligible costs involved in the cultivation of the fruit that significantly increase production costs, such as irrigation costs, fertilisers, pesticides and the maintenance of agricultural and farm machinery for the subsequent processing of the harvest. Finally, the final resale price is affected by another very important component: transport and storage costs, which are crucial for the supply chain.
    - Global economic conditions: operating in a global supply chain, therefore using different currencies, the system is also affected by the fluctuations in exchange rates and inflation of the different countries involved, mainly Mali.
    - Demand cycles: demand for mango products depends on its seasonality, increasing in summer. This increase can influence price, production planning and stock management.
- *Social*:
    - Quality and safety standards: the supply chain is influenced by socio-cultural norms that affect product quality. One of them is ISO 22000: an international standard for food safety management that requires a management system to ensure product safety from production to consumption. It is essential to access global markets. Another element of fundamental importance recognised on a global scale is the BRCGS[28] certificate: it represents a necessary standard for operating in the agri-food sector, guaranteeing the food safety of suppliers and their operational processes.
    - Consumer preferences and trends: globally, there is a growing consumer focus on natural, organic and minimally processed foods (Figure 18). This trend can certainly

[28] *BRCGS* is a certification scheme that was developed in 1998 by the British Retail Consortium, a UK trade association representing retailers. Originally known as BRC, the name was changed to BRCGS to reflect the expansion of the scheme globally. The standard is regularly improved, involving international players in the supply chain. Today, it is considered a necessary requirement for operating in the sector and also represents a great opportunity to demonstrate the company's ongoing commitment to safety, quality and compliance with the regulations governing the agri-food industry.

be beneficial for products such as puree and concentrate derived from mangoes as they are the basis for healthy, natural foods and drinks.

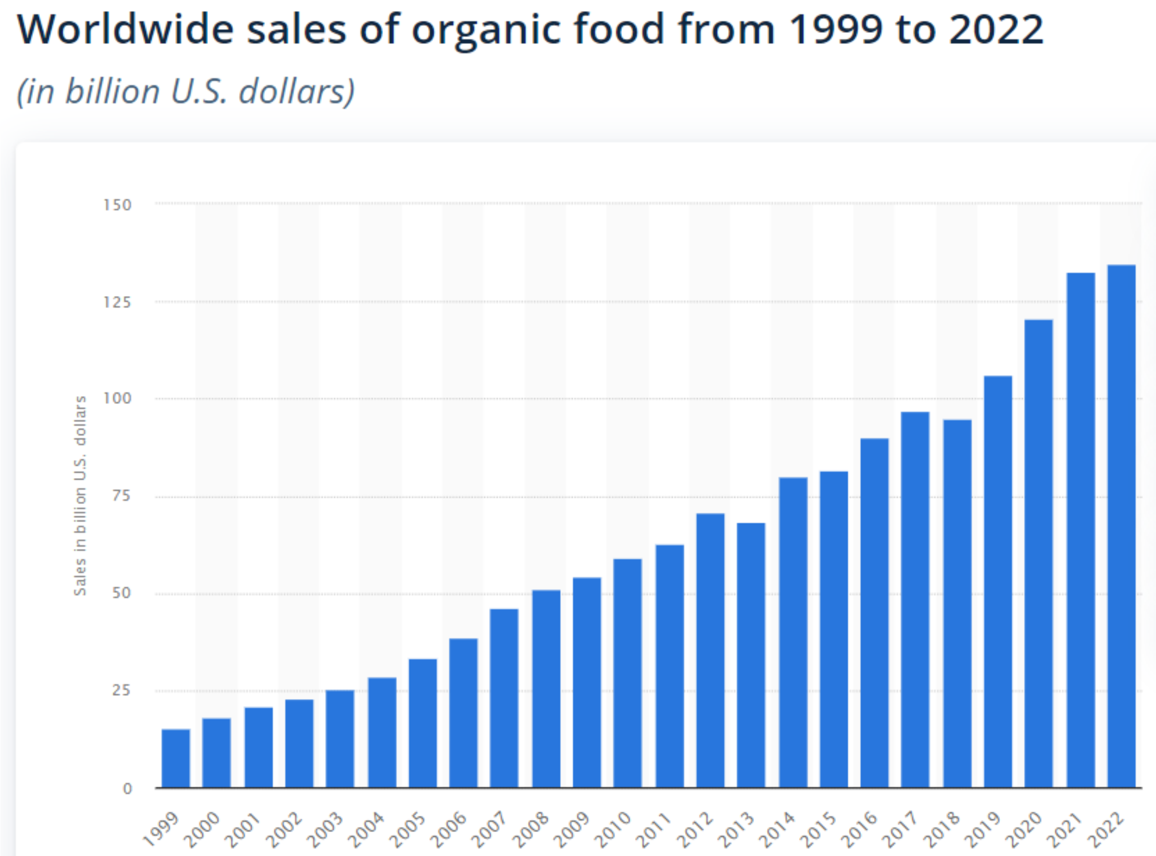

Figure 18: Worldwide sales of organic food[29]

- Sustainability and social responsibility: the supply chain operates largely in an emerging territory, Mali, enabling strong economic growth in the fight against local poverty and unemployment. Furthermore, in many markets, particularly in Europe, there is a strong preference for certified fair trade products. The combination of these movements can lead to the predisposition of consumers to pay a premium for products that improve the living conditions of workers and local communities. Reinforcing this consumer predisposition are the presence of specific certifications

[29] Source: https://www.statista.com/statistics/273090/worldwide-sales-of-organic-foods-since-1999/

to verify social and environmental sustainability: *Fair Trade*[30] and *Rainforest Alliance*[31].

- Evolution of purchasing behaviour: a final, non-negligible factor in the supply chain is the digital evolution that is sweeping the purchasing method of a large proportion of consumers worldwide. there is in fact an increase in online purchasing and distribution via e-commerce platforms. This push will have to be considered by the final retailers in the chain who will have to adapt to the new dynamics, where online shopping is preferred to buying in physical shops.

- *Technological*:
  - Innovations in cultivation and production: new irrigation technologies could improve mango cultivation as it requires a lot of water and Mali is very arid. Innovations in water utilisation would increase crop yields and mango quality, and decrease costs. Innovations could also concern post-harvest treatments to maintain quality during transport and storage before processing, that could be improved by new cooling technologies.
  - Conservation technologies and logistics: the supply chain could be improved by new technologies for product preservation, either through new vacuum application methods or innovations in the pasteurisation process. In parallel, the distribution process can also be improved by new methods of tracking goods to optimise the logistics network.

The PEST analysis provided a clear picture of the political, economic, social and technological forces influencing the market for mango puree and concentrate. The analysis highlights the importance of constantly monitoring not only the direct stakeholders, but

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[30] A *Fair Trade* certificate is a designation given to products that meet specific social, economic, and environmental standards set by Fair Trade organizations. These standards focus on fair wages for producers, safe working conditions, environmental sustainability, and community development. The certification aims to promote equitable trading relationships and improve the livelihoods of small-scale farmers and workers in developing countries. Products bearing the Fair Trade label have been independently audited to ensure compliance with these rigorous criteria.

[31] The *Rainforest Alliance* is an international non-profit organization that works to conserve biodiversity and ensure sustainable livelihoods by transforming land-use practices, business practices, and consumer behaviour. Products bearing the Rainforest Alliance Certified seal have been produced according to rigorous environmental, social, and economic criteria designed to protect ecosystems and the people and wildlife that depend on them. The certification covers a wide range of products, promoting sustainable agriculture and forestry practices.

also the external environment to ensure effective and sustainable management in the supply chain.

3.2.2 SWOT analysis

After analysing the external factors that may affect the supply chain, the analysis proceeds deeper to have a complete assessment of it both internally, analysing strengths and weaknesses, and externally, analysing opportunities and threats.

A strategic planning tool called *SWOT analysis* was used for this purpose (Heizer, Render, & Munson, 2020)[32].

This analysis plays a key supporting role in helping to identify areas in need of improvement and to focus on resources and capabilities that can be exploited to take advantage of opportunities or mitigate threats.

Starting with the internal strengths, the first distinguishing feature of this product is its quality. Indeed, mangoes cultivated in Mali can be of excellent quality due to the favourable climate, guaranteeing a high quality raw material for the puree and concentrate. This supply chain that originates on Malian soil differs from its main competitors who are the mango producers in Central America and India that focus more on marketing large quantities, exploiting economies of scale, rather than aiming for excellent quality.

Another strong point related to the geography of cultivation and processing is labour costs. In fact, labour costs in Africa are much lower than the European and US averages (Table 4). These data take into account a national average considering both unskilled workers and more experienced and technically trained professionals.

[32] "Heizer, J., Render, B., & Munson, C. (2020). *Operations Management: Sustainability and Supply Chain Management* (13th ed.). Pearson." provides a comprehensive treatment of strategic planning techniques, including SWOT analysis, and explains their importance in the optimisation and management of operational processes and supply chains, with a focus on sustainability.

Country	Average Monthly Salary (USD)
Mali	100-400*
Senegal	250-450
Ivory Coast	200-500
Ghana	300-700
Nigeria	200-600
South Africa	1000-2000
France	3000-4000
United States	3000-5000

Table 4: Comparison of average salaries

It is evident that Mali is not only significantly inferior to European countries and the USA, but it is also inferior to other West African nations with a more comparable situation. The extremely low labour costs allow for economical production, enabling competition both in terms of quality and price.

Another strength that characterizes this supply chain is its sustainability. In fact, the promotion of sustainable agriculture can enhance the product's reputation and attract sustainability-conscious customers who are willing to pay a premium. Furthermore, companies operating within this system receive support from local and international governments through initiatives aimed at agricultural development and food processing in Africa, which can provide incentives and financial assistance.

On the other hand, the supply chain presents numerous weaknesses that limit the growth and business of many companies.

Operating in Mali offers certain distinctive strengths; however, it also results in the system's principal weakness, which is the presence of inadequate infrastructure.

Many roads, especially rural ones where mango crops are located, are in poor condition or inadequately paved. This can lead to delays in overland transportation, both from the farms to the processing plant and from the plant to the port of Dakar for worldwide shipping. Even worse, it can result in accidents such as truck overturns, which, in addition to posing safety risks to personnel, can lead to material loss and, consequently, financial losses. Another challenge for trucks is the size of the roads, which are often inadequate for accommodating such large vehicles. Additionally, both rail and river transport are underdeveloped and not usable on a large scale, leaving the use of trucks on unsuitable roads as the only alternative.

A weakness in the supply chain is related to the dependence of agricultural production on climatic conditions. This variability can lead to negative impacts on the continuity of raw material supply.

In fact, Mali is characterised by extreme climatic variability, with short and intense rainy seasons followed by long periods of drought. Seasonal variability is high, with years characterised by extremely low rainfall that severely affect agricultural yields.

This arid situation has been worsened by rising temperatures. According to a study on future climate situations in Mali (World Bank & GFDRR, 2011)[33], temperatures are projected to continue rising, with increases that could exceed 5°C by the end of the century, exacerbating the already precarious situation of water resources.

In addition to the danger of extreme temperatures and drought, another threat is crop epidemics, which can make plants sick and compromise an entire year's harvest (Figure 19).

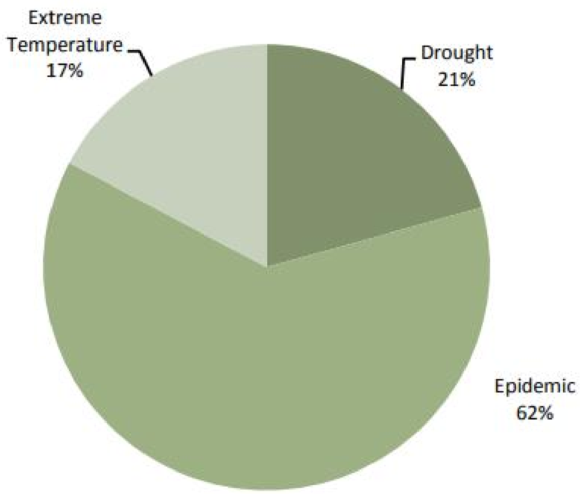

Figure 19: Average annual distribution of reported disasters[34]

[33] "World Bank, & Global Facility for Disaster Reduction and Recovery (GFDRR). (2011). *Climate Risk and Adaptation Country Profile: Mali*. World Bank." offers a detailed analysis of climate risks and adaptation strategies for Mali. It examines the impact of climate change on agriculture, water resources and public health, and proposes specific measures to improve the country's resilience to increasingly extreme weather conditions.

[34] Source: EM-DAT: The OFDA/CRED International Disaster Database, Université catholique de Louvain, Brussels, Bel." Version: v11.08.

A final major weakness of this supply chain is the political instability in Mali. Indeed, it has a history of political instability characterised by coups, internal conflicts and ethnic tensions. Since 2012, the country has faced a series of political and military crises that have affected the entire economic and social system.

This issue has significant implications on various aspects of product processing and distribution. Instability can undermine security in agricultural regions: access to agricultural areas could be restricted due to armed conflicts, which in turn can also damage or destroy infrastructure such as bridges, roads and irrigation systems. In addition, this chaotic political situation leads to sudden shutdowns of production facilities and creates logistical damage, as visas are not issued to enter Mali and checkpoints are set up that cause delays or block trade out of the country, causing economic losses to companies.

After highlighting the main internal strengths and weaknesses of the supply chain, and knowing the external forces that may influence it thanks to the previous PEST analysis, it is possible to analyse the opportunities and threats related to this system.

The first big opportunity in this area is the growth in global demand for mango products.

These products are increasing worldwide, particularly in the western world, as they offer consumers the convenience of enjoying the delicious taste and nutritional benefits of the mango beyond its natural season.

In addition, increased awareness of the health benefits of mango products, rich in vitamins, minerals and antioxidants, has accelerated the adoption of these products by health-conscious consumers, who are looking for healthier snacking options, attractive to busy lifestyles and urbanisation trends.

The market has also been helped by the improvements that have been made in recent years to improve the distribution of products to end consumers, through a dense network of supermarkets and e-shops. Innovations in processing and preservation techniques to extend product shelf life are also supporting market growth.

Table 5 shows market growth forecasts taking these factors into account.

Report Attribute	Key Statistics
Base Year	2023
Forecast Years	2024-2032
Historical Years	2018-2023
Market Size in 2023	US$ 21.0 Billion
Market Forecast in 2032	US$ 34.4 Billion
Market Growth Rate (2024-2032)	5.61%

Table 5: Mango products market growth[35]

The high growth rate of this market presents another opportunity: attracting foreign investment into this supply chain.

With a globally expanding market, profitability, and low production costs, this sector offers attractive features for investors, particularly with regards to sustainability and social responsibility. Such investments can help improve infrastructure, expand production capacity and adopt new technologies.

For companies within the supply chain, another opportunity is *vertical integration*[36] (Porter, 1985)[37]. By doing so, companies would directly control all stages of the production process, from mango cultivation to processing and distribution. This direct control helps ensure that quality standards are consistent and that issues are identified and resolved promptly, thereby enhancing the overall quality of the product and reducing defects. Additionally, this approach would facilitate more efficient cost management within the supply chain, allowing

[35] Source: https://www.imarcgroup.com/processed-mango-products-market

[36] *Vertical integration* is a business strategy where a company expands its operations into different stages of production or supply chain processes that are typically handled by separate businesses. This can involve acquiring or merging with suppliers (backward integration) or distributors and retailers (forward integration). The goal of vertical integration is to gain greater control over the supply chain, reduce costs, improve efficiency, and enhance market position by consolidating various functions within a single organization.

[37] "Porter, M. E. (1985). *Competitive advantage: Creating and sustaining superior performance*. Free Press." describes the concept of competitive advantage as a key element for achieving success. The book delves into various typical strategy and organization topics, emphasizing the importance of the value chain and its analysis to understand which strategies to implement in order to obtain and sustain a competitive advantage.

the company to increase the value captured, which can be reflected both in higher profits and in improved benefits for employees.

The supply chain is also subject to certain external threats, foremost among them being international competition.

Asian and Central-South American countries are major mango producers with well-developed supply chains and facilitated access to global markets (Table 6).

Their ability to produce at competitive costs and meet the growing global demand poses a significant threat. These supply chains, having access to larger quantities of mangoes compared to those in Mali, can leverage economies of scale, thereby challenging the African supply chain.

Country	Production (Tons)
India	24,968,000
China	3,961,662
Indonesia	3,561,867.46
Pakistan	2,677,017
Mexico	2,441,495.85
Brazil	2,057,765
Malawi	1,696,121.46
Thailand	1,635,233.37
Bangladesh	1,458,554
Vietnam	1,439,272.8
Egypt	1,327,865
Nigeria	927,146.7
Mali	887,008

Table 6: Mango producers[38]

Another threat to the supply chain is the fluctuation in raw material prices.

In addition to the direct costs of mangoes, there are other expenses such as energy, fuel for transportation, and the cost of equipment needed for transport, such as barrels and pallets, which can impact the profitability of the business.

[38] Sources: https://worldpopulationreview.com/country-rankings/mango-production-by-country
https://www.atlasbig.com/en-us/countries-mango-guava-production

Finally, another threat is related to potential trade restrictions and customs barriers. After being produced in Mali, the product must pass through various intermediaries and, crucially, through multiple customs checkpoints before reaching the final consumer. Possible increases in customs duties or specific restrictions could negatively impact the success of the business, compromising the entire supply chain.

In conclusion, the SWOT analysis of the mango purée and concentrate supply chain has highlighted the unique complexities and opportunities of the sector, from cultivation in Mali to global distribution.

It is now essential to examine deeper into the critical areas of the system that can enhance the entire chain.

3.3 Analysis of critical points

After a detailed analysis of the external forces that can influence the supply chain, its internal strengths and weaknesses and its opportunities and threats, the critical points of the system are analysed in greater detail.

Critical points represent steps or processes with flaws that negatively affect the efficiency, reliability, quality or profitability of the entire supply chain.

In order to optimise the chain, it is crucial to fully understand these aspects in order to know what the root problems are and look for solutions to improve them.

These critical points if not managed properly can lead to operational disruptions, waste, additional costs, or loss of competitiveness.

3.3.1 Quality and monitoring issues

The supply chain originating in Mali differs from its global competitors in its quality, as it is not able to compete on marketed volumes.

Precisely for this reason, quality control at every step is crucial, representing a critical point that could lead to major difficulties for the entire network. In fact, if the Malian product were to lose its distinctive quality, it would no longer be competitive on the market and

would be outclassed by products from Central America and Asia, which are able to keep prices lower thanks to their large production.
The quality of the final product depends on so many factors, it would therefore be ideal to try to optimise each individual variable in order to decrease the variance relative to quality. As described in the SWOT analysis, the final product depends on external factors such as climate, crop adversity and political and economic difficulties.
One has no control over these external factors and it is often difficult to predict them, so it is necessary to focus one's attention on those factors that can be governed and to have a stable system that is able to be affected as little as possible by alterations from external forces.
The Malian supply chain has a raw material, the mango, of the highest quality for each of its varieties; consequently, in order to ensure that quality is maintained throughout all steps and reaches the final product, it is necessary to constantly monitor the processes. It is precisely in this quality maintenance activity that problems occur.
Following a chronological order of activities, the first critical situation concerns the selection of the mangoes: once the mangoes arrive at the production plant, they are screened in order to get rid of any defective ones, which may have an ugly colour, an unsuitable shape or size, or be too unripe or too ripe (Mitra, 2005)[39].
This selection is problematic because it is done manually by employees.
It depends on the skill and experience of the workers, which can lead to great variability in the quality of the selected mango.
Workers may have difficulty in uniformly identifying fruits with the best parameters of ripeness, size and absence of defects. This can result in the mixing of fruits of different quality, compromising the quality of the final product.
Furthermore, this process being carried out manually is subject to a higher rate of human error, making it more laborious, less efficient and unsuitable for recognising defects within the fruit that are not visible from the outside.

[39] "Mitra, S. (2005). *Postharvest physiology and storage of tropical and subtropical fruits*. CAB International." provides a detailed analysis of the post-harvest physiology and storage techniques of tropical and subtropical fruits, including mangoes. The book not only addresses the challenges of transportation and storage, but also discusses the selection of mangoes to ensure optimal quality and shelf life during distribution.

Finally, it is subject to restrictions related to the availability of labour and the seasonality of the fruit, which can create a bottleneck during periods of high demand or abundant harvests.

Continuing along the supply chain, a quality-related issue pertains to product control throughout the various stages of production.

Currently, to monitor the puree at each step of the supply chain, tests are conducted that include physical, chemical and microbiological analyses. Various indicators are checked to ensure and define the quality of the product:

- *BRIX value*: represents the concentration of total soluble solids, usually sugars but can also include acids, vitamins, or minerals.
- *Titratable acidity*: indicates the total amount of organic acids present in the puree. This parameter is important for flavour (balance between sweetness and acidity) and for the stability of the product over time. It is indicated as anhydrous citric acid %.
- *pH*: is a measure of the acidity or basicity of a solution, expressed on a scale from 0 to 14. When checking the puree, it is a key parameter for visualising microbiological stability, taste profile and shelf life.

In addition, other values are identified during the analysis, such as viscosity and moisture content, which, if they are out of the ordinary, can be an alarm bell regarding the quality of the product.

These tests are carried out in laboratories and require the destruction of the samples on which they are carried out as the process can lead to irreversible changes in the properties of the sample, compromising its quality and making the product unsuitable for further processing. Destructive testing also represents an economic inefficiency, as a part of production is inevitably sacrificed.

In order to cope with destructive testing, *sampling inspections*[40] are employed; however, they reveal significant problems: firstly, this control methodology only identifies issues intermittently, which means that some defects might go unnoticed until the next sampling,

[40] *Sampling inspections* involve selecting a representative subset of items from a larger batch or production lot to assess the overall quality and compliance of the entire batch. This method is used to identify defects, ensure adherence to quality standards, and make decisions about product acceptance or rejection. Sampling inspections are often employed in manufacturing and food safety to manage quality control efficiently while reducing the need for inspecting every single item.

while a certain quantity of product may already have been produced with defects (Montgomery, D. C., 2020)[41].

Furthermore, a sampling inspection, as opposed to continuous inspection, can increase the variability of results because the sample selection, being a random process, might not accurately represent the entire batch of product.

Obviously, the use of sample checks is more uncertain and imprecise as only part of the batch is examined and the data obtained may depend on the size of the batch and the natural variability of the process.

Although the cost of sampling inspection may appear more economical compared to continuous inspection, as not the entire batch is inspected, this is only partially true.

From a broader perspective, the lower accuracy in detecting defects can be linked to indirect costs associated with defective production, such as product recall, customer refunds, and replacements. In addition to these quantifiable damages, there are intangible harms, such as damage to the company's reputation, which can lead to the loss of customers in the future.

To gain an understanding of how significant these costs can be for a company, it is possible to make an estimation: a batch may consist of 240 drums (N), with a sampling inspection analysing only about 10% of them, or 24 drums (n). Assuming, based on company historical data, a defect probability of 0.03 (p) and that the batch is not accepted if more than 2 drums contain defective product (c), it is possible to compute the probability of accepting or rejecting the lot.

Usually, when considering a single sampling plan without replacement as in this case, the best distribution to use to represent the model is the hypergeometric distribution (Maisano, 2023). Since the ratio between n and N is equal to or less than 0.1, it is possible to approximate the hypergeometric distribution with a binomial distribution, thereby using Bernoulli's formula (Figure 20) to calculate the probabilities.

[41] "Montgomery, D. C. (2020). *Introduction to Statistical Quality Control* (8th ed.). Wiley." is a fundamental resource in the field of statistical quality control and production process analysis. It provides an in-depth discussion of quality control techniques, including control charts, variability analysis, and methodologies for continuous process improvement.

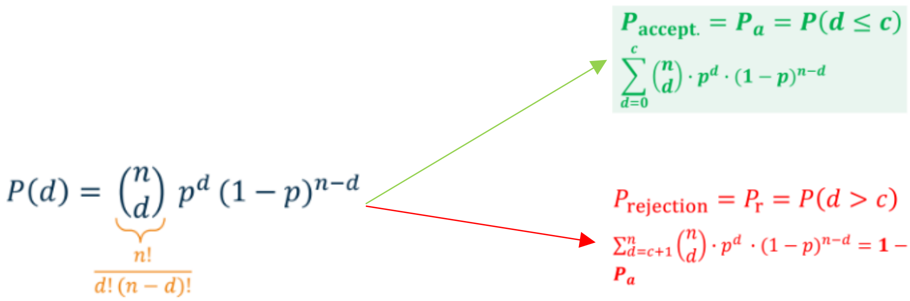

Figure 20: Bernoulli's formula

$$p = 0{,}03$$
$$N = 240$$
$$n = 24$$
$$c = 2$$
$$P_a = \frac{24!}{0!\,(24)!}(0{,}03)^0(0{,}97)^{24} + \frac{24!}{1!\,(23)!}(0{,}03)^1(0{,}97)^{23} + \frac{24!}{2!\,(22)!}(0{,}03)^2(0{,}97)^{22} = 0{,}9659$$
$$P_r = 1 - 0{,}9659 = 0{,}0341$$

The probability that the entire batch will be rejected is therefore 3.41%.

For precision, this represents the risk for the company acting as a supplier that a batch of good quality may be rejected by the company acting as the customer. The defect rate used, p, corresponds to the AQL (*Acceptable Quality Level*), which is a relatively low reference value for defectiveness which is set by the supplier and agreed by the customer.

For this case study, we are considering the distribution company as the supplier and the companies involved in the final processing before delivery to the consumer as the customer.

To proceed with an economic estimate a batch of this size can have a commercial value of:

$$Price\ for\ tons = 1060\,\frac{\$}{tons}$$
$$Quantity = 240 * 235\ kg = 56400\ kg$$
$$Commercial\ Value = 56{,}4\ tons * 1060\,\frac{\$}{tons} = 59784\$$$

When conducting a sampling inspection, it may happen that a batch, after a first sample inspection in Mali post-processing, is found to meet quality standards.

However, after shipment and delivery to the Rotterdam warehouse or the customer, a second sample inspection reveals irregularities that were not present in the initial sampling, leading to the rejection of the batch. This issue is inherent to sampling inspection, as the inspection performed may not accurately represent the entire population and the quality may vary within the batch itself.

Therefore in addition to this lost commercial value, there would be costs associated with recalling defective goods, which can vary depending on logistical distance, ranging from 2.000 to 3.000 dollars up to several tens of thousands of dollars per container.

In this case study, with 3 containers (each container contains 80 drums, so 240/80=3), the costs could reach up to \$30.000. Additionally, there would be costs for their disposal, as well as issuing a credit note to the customer.

Using a sample control method, there is another type of risk that does not burden the supplier actor, but the customer.

To calculate an estimate of this risk, the same assumptions as before are used, but with a defect index of 0.2.

$$p = 0{,}2$$

$$N = 240$$

$$n = 24$$

$$c = 2$$

$$P_a = \frac{24!}{0!(24)!}(0{,}2)^0(0{,}8)^{24} + \frac{24!}{1!(23)!}(0{,}2)^1(0{,}8)^{23} + \frac{24!}{2!(22)!}(0{,}2)^2(0{,}8)^{22} = 0{,}1145$$

This 11.45% represents the risk for the customer of accepting a bad-quality lot.

In this case, p represents the LTPD (*Lot Tolerance Percent Defective*), which is the minimum quality ratio that the customer is willing to accept. Again, the lost commercial value would be equivalent to the previous one.

In this case study, the relationship that can occur between the company handling import-export and the client companies reselling the final product has been analysed. However, this reasoning can be applied at every step and to all the various actors within the supply chain, from the arrival of the mango at the production facility to the final processing to obtain the end product, adapting it to different situations with the correct data.

This underlines the need to find an alternative inspection solution to sample checks in order to minimise the risks for both actors, despite the advantages it can bring, such as reduced direct inspection costs and less time required.

3.3.2 Logistical inefficiencies

This supply chain operates on a global scale, involving various actors, ranging from Mali to distant parts of the world such as Canada or Australia.

For this reason, logistics plays a crucial role and must be preserved to minimize inefficiencies that could compromise product quality, increase costs, and delay delivery times.

A careful analysis of its inefficiencies is therefore necessary to understand them and propose new solutions that can benefit the ecosystem.

The first point to analyse is related to the transportation and preservation of the product. As it is a perishable agricultural product sensitive to temperature, it requires specific technical measures for preservation. The most common ones are (Siddiq & Brecht, 2017)[42]:

- *Modified atmosphere packaging* (MAP): this technique involves replacing the air inside the packaging with a gas mixture that optimises product preservation. The gases usually used are nitrogen to reduce oxidation, carbon dioxide to inhibit microbial growth and slow ripening, and sometimes a reduction of oxygen to prevent oxidative spoilage. This procedure requires the use of controlled atmosphere containers to regulate the composition of the internal atmosphere to maintain optimal gas levels and the use of sensors and monitoring systems to continuously monitor all gas level, temperature and humidity parameters.
- *Freezing technique*: this approach uses very low temperatures to preserve the quality and safety of food products. In fact, rapid cooling of the puree or concentrate inhibits

[42] "Siddiq, M., & Brecht, J. K. (Eds.). (2017). *Handbook of mango fruit: Production, postharvest science, processing technology and nutrition*. John Wiley & Sons." offers a detailed overview of mango production, storage and processing. It includes specific chapters on preservation technologies, postharvest handling and packaging techniques, which are essential to maintain the quality and freshness of mangoes during storage and transport. It is a valuable resource for professionals and researchers in agriculture and food science.

the growth of microorganisms and the degradation of enzymes, allowing the flavour, colour and nutrients of the mango to be preserved. The temperature required to freeze the product is around -18°C or lower, so hermetically sealed packaging in which to store the product and refrigerated containers capable of holding the low temperatures are required.

- *Pasteurisation*: this technique uses heat to prolong the preservation of the puree, which is heated to eliminate pathogenic microorganisms such as moulds, bacteria and yeasts. Pasteurisation can take place either at a lower temperature (63°C) for a longer duration (30 minutes), or at a temperature above 100°C for a few minutes. The two techniques produce similar results, but the former is suggested for products ready for domestic use, and the latter for longer-term storage along the supply chain. Pasteurisation is one of the safest methods as it significantly reduces the risk of food borne diseases caused by bacteria, but compared to the other techniques it may slightly change the taste and colour of the puree.
- *Drying:* this process reduces the moisture content, preventing the growth of microorganisms and slowing down chemical and enzymatic processes that can cause spoilage. Drying can take place in different ways (sunlight, air, in an oven, cold or hot) that differ in the process, but achieve the same result with minor differences that may lead certain processes to be more suitable for certain sectors. For mango puree, the most commonly used processes are by heat, i.e. in an oven or by convection. During heat drying, there is a risk of partial loss of certain nutrients, such as vitamins, which may be sensitive to heat. This technique requires humidity-controlled containers and packaging with moisture-resistant walls.
- *Vacuum preservation:* this technique, unlike drying which removes moisture, involves removing the air from the product packaging. The absence of air slows down the degradation of the product and prevents the growth of bacteria and moulds. To carry out this procedure, specific machines are required to remove the air using a pump, along with special airtight packaging designed to maintain the vacuum around the puree.

In the supply chain being studied, the techniques used to enhance efficiency are pasteurization following processing, and then the puree is sealed in aseptic bags before being placed into drums and subsequently loaded into containers.

Precisely in relation to these procedures, certain inefficiencies can be identified that both increase costs within the system and alter the puree.

The first issue is cost-related, as both the pasteurization and aseptic bag filling processes are expensive.

The pasteurization process requires heating the product and maintaining the temperature for a period of time, which entails high energy costs.

Working at high temperatures, pasteurisation can lead to the loss of some nutrients in the mango puree as well as a slight change in flavour. Adding to this problem is the fact that small temperature variations can occur during this procedure, which can lead to changes in quality that adversely affect the final product.

Just like pasteurization, aseptic filling also incurs significant expenses: in addition to the costs at the start of the season for purchasing the necessary packaging materials (aseptic bags and drums) and the initial investment in industrial aseptic filling machine (Figure 21), there are ongoing maintenance costs, which can amount to around $5.000, and require qualified personnel.

Figure 21: Industrial aseptic filling machine

Another problem related to logistics is the time needed to transport the puree from the plant in Yanfolila to the warehouse in Rotterdam.

This duration is a critical issue as it is the longest transport period within the supply chain, around 60 days, slowing down the supply much. In particular, looking at the Dakar-

Rotterdam shipping route (Figure 22), it can be seen that the average transport time is 20/25 days, which suggests that the real problem lies between Yanfolila and Dakar.

Figure 22: Dakar-Rotterdam shipping route[43]

In fact, this leads back to the results of the SWOT analysis, which highlighted as one of the main weaknesses of the supply chain the lack of adequate infrastructure for truck transport in Africa, as well as organisational problems in customs between Mali and Senegal and at the port of Dakar that lead to goods experiencing delays and interruptions.
Although Mali has experienced economic growth of around 5.3% per year in recent years, its potential is limited by the absence of a sea outlet and inadequate road, rail and river infrastructure.
This infrastructural problem is not only significant in the post-production phase, from the exit of the puree from the production facility to its delivery to the Dutch warehouse or to the client companies that process it further, but is also relevant in the initial phase of mango supply, from the plantations to the production facility.
To quantify this problem, it is possible to examine data (Table 7) comparing various indicators related to the road infrastructure situation in Mali with that of low- and middle-income African countries (Briceño-Garmendia, Dominguez, & Pusha, 2011)[44].

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[43] Source: https://www.searates.com/it/distance-time
[44] "Briceño-Garmendia, C. M., Dominguez, C., & Pusha, N. (2011). *Mali's infrastructure: A continental perspective*. The World Bank, Africa Region, Sustainable Development Department." offers an analysis of the state of infrastructure in Mali, examining in detail the challenges and opportunities related to roads, energy and other infrastructure sectors. The paper contextualises Mali's infrastructure issues within a broader regional perspective and proposes recommendations to improve the situation.

	Unit	Low-income countries	**Mali**	Middle-income countries
Classified road density	km/1000 km² of arable land	132.1	**38.3**	318.4
Classified road density	km/1000 km² of land	88.2	**27.9**	278.4
Rural accessibility Index-HH Survey	% of rural population within 2km of all-season road	34.1	**14.0**	62.7
GIS rural accessibility	% of rural population within 2km of all-season road	23.1	**16.7**	31.5
Paved road traffic	Average annual daily traffic	1341.1	**547.5**	3797.7
Unpaved road traffic	Average annual daily traffic	38.5	**21.5**	74.7
Paved network condition	% in good or fair condition	86.2	**64.8**	82.0
Unpaved network condition	% in good or fair condition	55.8	—	57.6
Perceived transport quality	% firms identifying roads as major business constraint	27.6	**20.1**	18.2
Overengineering	% of main road network paved relatively to low traffic	29.6	**47.7**	18.4

Table 7: Mali's road indicators benchmarked against Africa's low- and middle-income countries

It is readily apparent that Mali is positioned critically below the average values of other countries. Specifically, focusing on the first two indicators, about *classified road density*, highlights the accessibility and efficiency of road infrastructure in agricultural areas. This situation underscores the challenges faced by trucks loaded with mango crates in reaching the processing facility, as well as the difficulties encountered by farmers in accessing their plantations. This issue concerning farmers is also highlighted by *rural accessibility indicators*, which reveal that only a minimal percentage, around 15%, has convenient access within 2 kilometres to passable roads throughout all seasons.

Finally, a last noteworthy indicator is the *paved network condition*, which analyses the percentage of paved roads in good or acceptable condition, thus assessing the maintenance and quality of roads. This indicator is also significantly below comparative values, reflecting the lack of intervention by the local government due to political instability and the absence of necessary road maintenance.

Although these logistical inefficiencies related to delays or high costs might seem like isolated problems for the actors facing them, this is a misconception. In such a supply chain, there is constant collaboration among all parties, and thus, an inefficiency in the initial stages can cause disruptions throughout the entire system. This can lead to inconveniences for the end consumer, such as increased prices or an inability to supply the good when needed, resulting in a loss of appeal for the product. It is therefore necessary to develop a strategy to mitigate these issues.

3.3.3 High costs

Starting from the cultivation and harvesting of the fruit to its distribution to final retailers, it is possible to highlight for each step of the supply chain a series of costs that influence the profit of each actor and the final price to the consumer.

For this reason, it is important to identify those excessively high costs that negatively affect the ecosystem and need improvement.

Contrary to what has just been mentioned, some costs represent a strength of the supply chain and do not require further analysis or modifications. Among these are the labour costs for cultivation, harvesting, and processing, due to low wages. Another positive aspect is the collaborative relationship between the producer, CEDIAM, and the distributor, Montecarlofruit, which allows for a purchase price that is not excessively high for the latter but still profitable for the supplier, benefiting both parties and preventing a significant price increase for the subsequent actors in the chain.

After listing these non-critical costs, we can begin to analyse a key cost that can be improved: the maintenance cost of machinery.

This aspect has already been briefly addressed in the section on *Logistical inefficiencies* concerning the machinery required for aseptic filling of packaging. This discussion can now be extended to all industrial machinery present in the facility. Given the production of nearly 4.000 tons per year, the maintenance of machinery cannot be overlooked due to the large number of machines involved. A production facility similar to the one in Mali, in order to produce that annual quantity, requires 10-15 industrial machines, each needing maintenance with an estimated cost of $5.000. This amounts to tens of thousands of dollars, which could potentially be reduced through more efficient maintenance management.

However, the real problem with poorly organized maintenance is the risk of machine failure. Beyond causing damage to the entire supply chain by halting or reducing the output flow from the production facility, it would also be economically detrimental. This is because repairing a machine in such cases can be much more costly than routine maintenance, and even worse, the replacement of the machine might be necessary, leading to significantly higher expenses.

Furthermore, poor maintenance, beyond the risks of incurring high costs, can negatively affect product quality. A machine that is not properly maintained may not operate efficiently, leading to potential defects or inconsistencies in the product (Mobley, 2008)[45]. Finally, an additional issue related to maintenance for these machines is the geographic location of the facility in Mali. Finding the right spare parts in this region can be challenging, highlighting the need for planned maintenance, taking into account the procurement of the component.

Another cost-related problem, also linked to and previously mentioned in the *Logistical inefficiencies*, is the high cost of pasteurization, which requires significant energy consumption. This is due to the fact that Mali is one of the African countries with the highest energy costs per kWh (Figure 23).

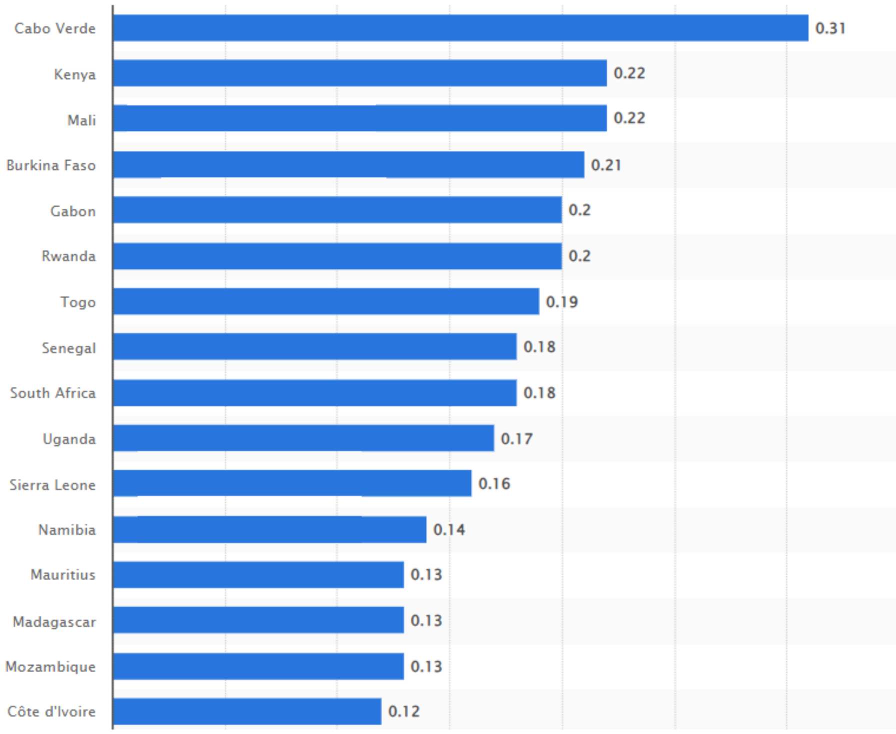

Figure 23: Energy prices in Africa as of September 2023, by country (in $/kWh)[46]

With this more comprehensive view, it becomes evident that a high-energy-consuming pasteurization process may not be the best preservation technique for puree in a country

[45] "Mobley, K. (2008). *Maintenance engineering handbook* (6th ed.). McGraw-Hill Education." is an authoritative resource in the field of industrial maintenance, providing detailed insights into maintenance management, failure prevention techniques and optimisation of operations.
[46] Source : https://www.statista.com/statistics/1277594/household-electricity-prices-in-africa-by-country/

with such high energy costs. It might be worth considering innovations in this process or even making a more drastic change by adopting a different preservation method.

A key challenge that incurs significant costs in the supply chain is related to transportation expenses from Africa to Europe, particularly for containers shipped from the production facility to the warehouse in Breda or directly to the agreed destination port with the customer.

Each year, the production facility ships just under 4.000 tons of puree or concentrate, equivalent to approximately 200 containers[47]. Each container must be transported 1.500 km to Dakar, with an average trucking cost of about $2.500 per container, and then shipped to Rotterdam or another European port, with an average cost of $1.100 per container. Considering these unit costs, the supply chain, particularly the distributing company, incurs an annual cost of $720.000 [48]related to product importation.

In addition to these costs, there may be penalties, service credits or other unforeseen expenses. These can arise from delays, damages, or additional charges that could further increase the overall expenditure. Given the high costs involved, it is crucial to optimize the transportation and exportation processes to minimize additional expenses and enhance cost efficiency.

3.3.4 Risk management

Risk represents the possibility that an uncertain event or condition may adversely affect the objectives of an organisation, project or activity (Hopkin, 2012)[49].

As highlighted in the *SWOT analysis*, the system is subject to numerous risks that render it highly vulnerable. The main risks are agricultural, political, and logistical in nature.

The major issue in this supply chain is the lack of a detailed study and plan to address the potential risks that may arise. This lack of planning can lead to severe consequences such

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[47] A container of concentrate weighs 19,6 tonnes, but for ease of calculation we assume a container weighing 20 tonnes: 4000/20=200 CTs

[48] (2500$+1100$)*200=720.000$

[49] "Hopkin, P. (2012). *Fundamentals of risk management: Understanding, evaluating and implementing effective risk management*. Kogan Page." provides a comprehensive overview of risk management principles and practices, including risk definition, risk analysis and mitigation strategies. It is a useful resource for understanding how to identify, assess and manage risks in business and project contexts.

as supply chain disruptions, additional costs, waste, damage to reputation and a lack of resilience.
There are various approaches to responding to risk, which can be classified according to the likelihood of the adverse event occurring and the damage it can potentially do (Figure 24).

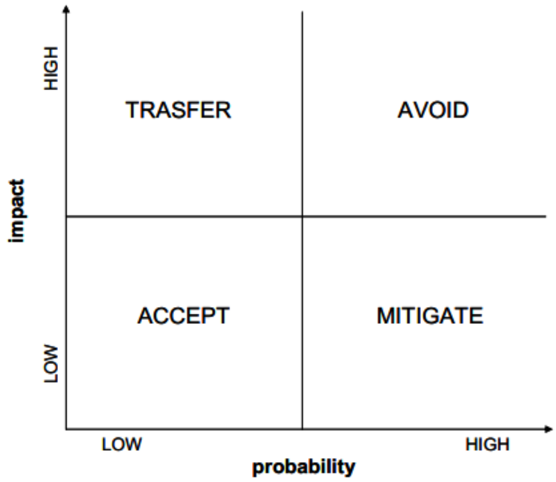

Figure 24: Main types of risk control strategies

It is quite clear that the less probable and less damaging a risk is, the easier it is for a company to manage and thus accept. Nevertheless, this is the least desirable option, as it is always advisable to maintain control over the situation and have a "plan B" in case the unexpected occurs. If a company chooses to accept the risk and therefore does not prepare any mitigation plans, it would be sufficient to implement monitoring systems to keep the risk under observation.
Conversely, for risks with high probability and low impact, planning actions to mitigate the risk would be a prudent approach. These actions would be aimed at preventing or managing the risk effectively.
On the other hand, for risks with high potential impact but low probability, it may be appropriate to transfer the risk to other stakeholders, such as through the use of insurance policies for protection. In this type of response, the risk is not mitigated but rather shifted onto third parties, that could operate outside the supply chain.
Finally, in the most drastic situations with risks of high probability and impact, it may be necessary to avoid the situation altogether by seeking alternative solutions that achieve the same results while circumventing the risk.

Certain types of risks originating from external forces, such as natural disasters affecting the harvest or political instability, although high in both impact and probability in Mali, are not always avoidable.

For this reason, it is essential to develop mitigation plans to manage these risks effectively.

Chapter 4

4. Supply chain optimisation

After providing a detailed description of the supply chain and identifying its weaknesses that require improvement, this section will discuss solutions and methodologies for optimizing it, employing a systematic and engineering-based approach.

In particular, typical principles of Quality Engineering will be used, a field dedicated to ensuring products and processes meet specific standards and perform reliably through design, control and continuous improvement.

The chapter will begin with an introduction to the world of Quality Engineering and its applications, followed by a detailed discussion of the proposed solutions, which will address the critical points in the same order as outlined in the previous chapter.

4.1 Introduction to supply chain quality

Quality of a product/service/entity refers to the degree to which the product/service/entity is able to satisfy (stated or implied) needs – ISO 9000:2015, Quality management systems, Fundamentals and vocabulary.

This is the definition of quality in engineering and represents in a very clear way its main purpose: to ensure that each stage of the supply chain, from design to final distribution, meets high quality standards.

In such a complex and globalized system, it is essential not to limit the focus solely to adherence to final product standards but to maintain a holistic perspective that takes into account all stakeholders involved and their interconnections, also considering the product at the semi-elaborated stage.

When discussing adherence to standards, reference is made to *specifications*, which are defined as a range of values. If the measured value falls within this range, the product is deemed compliant; otherwise, if the value falls outside the range, the product is considered non-compliant (Maisano, 2023). Within the range, it is possible to distinguish the Target (T) or Nominal Value (NV), which represents the ideal measurement, the Upper Specification

Limits (USL), referring to the largest allowable value to be conforming, and the Lower Specification Limits (LSL), indicating the smallest allowable value to be conforming. These specifications are not determined by the process itself, but rather by external entities or factors that establish them in order to regulate and standardize the market. In contrast, the process itself introduces an intrinsic characteristic, namely *natural variability*, which can be defined as its tendency, under regular conditions, to produce products with quality characteristics that deviate from the Target values. Natural variability refers to the variation in a process when it is governed solely by random sources of variability, with no trends, cycles, or anomalies present. It represents an important aspect to consider for understanding and managing quality control in a production process, using Statistical Process Control methods.

Quality management of the supply chain thus moves in two directions: both towards the product and towards the processes. In this context, specific quality management tools and methodologies emerge, such as control charts, Lean production theory and FMECA, which enable continuous monitoring and improvement of production and logistics processes.

Additionally, this optimization-focused approach involves adopting strategies for the prevention of potential risks and defects, rather than simply resorting to ex-post problem-solving after issues have occurred.

Approaching problems with an engineering quality perspective involves not only checking whether the product or process conforms to certain specifications but also a continuous pursuit of system improvement. In this context, correlations between quality and innovation become evident.

Innovation occurs when a quality gap is created between the expected quality (Q_e), which is the subjective assessment anticipated by customers before using the product, and the offered quality (Q_o), which is the technical and objective quality provided by the organization.

$$Quality\ gap: \Delta = Q_e - Q_o$$

The creation of this gap can lead to two different situations (Figure 25):

- $\Delta > 0 \rightarrow Q_e > Q_o$: in this case, the continuous evolution of customer needs has led to a situation where their expectations exceed the current market offering by the supply chain. This gap creates a need for technical improvement of the product, necessitating enhancements in production and logistics processes or the addition of new product attributes. This results in technological innovation, which can be either incremental, with gradual improvement, or disruptive, with radical change.

- $\Delta < 0 \rightarrow Q_e < Q_o$: conversely, this situation occurs when the market is not yet mature for a new product or an improvement of a previous version. This could lead to a loss of some features in the new offering, necessitating a marketing push from the supply chain to create new customer needs that align with the new product attributes. Thus, the innovation is of a marketing nature.

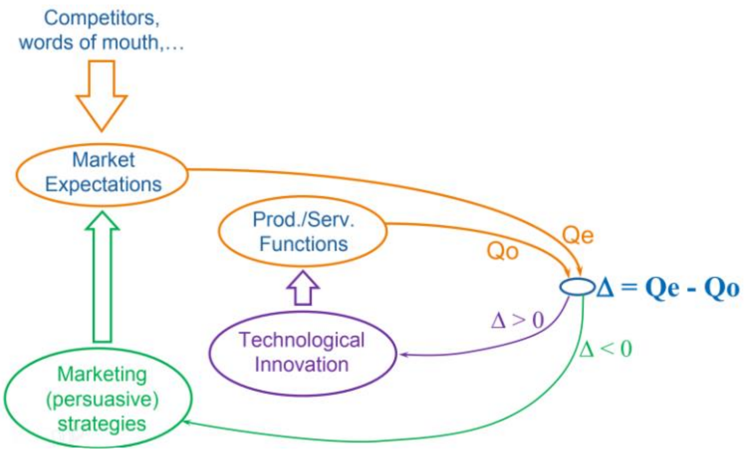

Figure 25: Quality forces driving innovation

4.2 Solution proposals and application of quality engineering principles

The issues highlighted in the previous chapter require resolution. This section will propose solutions to address these problems.

In addition to examining the application of Quality Engineering principles within this specific case study in the agri-food sector, mathematical models and recent scientific studies will be utilized, employing an analytical approach to optimize the entire supply chain, rather than focusing on a single actor or process within the system.

4.2.1 Advances in quality control and monitoring techniques

The first issue encountered along the supply chain concerns the preservation of the quality of the raw material, particularly its monitoring.

To proceed in an orderly fashion, the initial problem is linked to the screening of mangoes once they arrive at the production facility in Mali. This inspection is currently performed manually, which leads to a multitude of complications.

To address this issue, *Near-Infrared Spectroscopy* (NIRS) machines could be utilized: an analytical technique used to identify and quantify the chemical components of a sample by measuring the absorption of radiation in the near-infrared region, typically in the wavelength range between 780 nm and 2500 nm. The wavelengths of NIR are just beyond visible light and shorter than mid-infrared. When NIR light is irradiated onto a sample, it can be absorbed, reflected, or transmitted depending on the material's properties: the absorptions are caused by molecular vibrations, particularly in bonds between atoms like C-H, O-H, and N-H, which are common in organic compounds. By measuring the intensity of the light that is not absorbed, an absorption spectrum can be generated (Figure 26). Finally, through specific software utilizing *multivariate calibration*[50] techniques, the spectrum is converted into data describing the chemical properties of the analysed product.

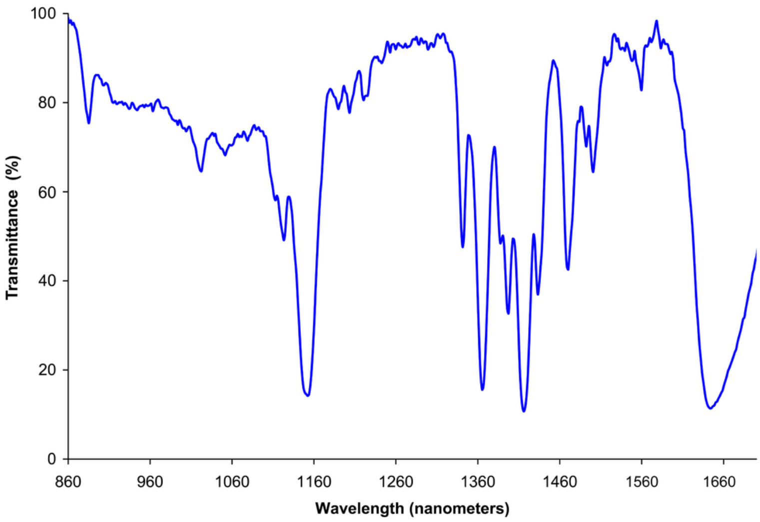

Figure 26: Example of absorption spectrum obtained from NIRS

[50] *Multivariate calibration* is a statistical method used in spectroscopic analysis to correlate the complex spectra of a sample with known concentrations of one or more analytes. This approach allows quantitative information to be extracted from overlapping spectra using techniques such as multiple linear regression (MLR) or the partial least squares (PLS) method.

This technology performs tests very quickly, making it easy to implement on the production line for continuous testing.
The NIRS can provide detailed analyses of internal characteristics of mango fruit, such as acidity or sugar concentration. However, it has limitations in detecting external features, such as bruises. To optimize the screening of incoming fruits, the optimal solution would be to combine NIRS with artificial vision techniques. This approach would use cameras to continuously monitor the line, measuring the shape and size of the fruits.
The production line could be further improved by adding dividers that automatically separate defective mangoes from those deemed good after evaluation by the NIRS system. The good mangoes would then proceed to the next stage of processing.
This approach would optimize the screening step by significantly reducing the manual effort and consequently minimizing human error, as personnel would only need to monitor the machinery and ensure that the rollers are functioning smoothly.
Additionally, during peak demand periods or excessive harvests, it would prevent bottlenecks caused by a shortage of labour, since the NIRS scanner can perform inspections faster than humans.
Additionally, the monitoring activity conducted using NIRS enables non-destructive testing. This aspect is crucial: this technology could be used not only to inspect incoming fruits but also to monitor the puree or concentrate exiting the production facility.
By implementing continuous monitoring on the production line thanks to non-destructive tests, issues related to sampling inspection, such as uncertainty, variability, sample size, and the representativeness of the sample, would be eliminated, as the puree would be consistently checked throughout the production process.
The application of NIRS machines for analysing mangoes, as well as liquid compounds like puree, has already been tested with excellent results.
The use of this technology in the agri-food sector for quality evaluation has been extensively verified in Japan on peaches, oranges, and other soluble solids and liquids, such as milk. Subsequently, it was applied to mangoes, achieving high accuracy with a correlation

coefficient of 0.92 (Jha et al., 2010)[51]. The correlation coefficient measures how closely the values predicted by the NIRS model match the actual values measured using reference methods. A correlation coefficient of 1.0 indicates a perfect correlation, while 0 indicates no correlation. In the food industry, where data is complex, variables are numerous, and non-destructive testing is required, a value of 0.92 is considered highly reliable.

Performing continuous checks on the obtained data requires monitoring the evolution of the production process, as every process has a certain amount of natural variability. A process that is influenced only by random causes of variation and not by *assignable causes*[52] is said to be in statistical control.

To verify if a process is in control, *control charts* can be used. Indeed, according to basic criteria of Quality Engineering, a process is considered to be in control if it meets two criteria:

- The process operates within predefined control limits: the values of the process measurements should consistently fall within the established upper and lower control limits on the control charts, indicating that the process variation is due to common causes rather than special or assignable causes.
- There are no patterns or trends indicating assignable causes: the data points on the control charts should not show any systematic patterns or trends that suggest the presence of assignable causes of variation, such as shifts or cycles in the process.

To establish statistical process control, an $\bar{x}$-R control chart can be used, where $\bar{x}$ represents the sample average, an estimator of the central tendency, and R represents the sample range, an estimator of the variability within samples.

To effectively create a control chart for this case study, the *BRIX* level of the puree will be used as a quality and food safety parameter. It is measured in °BRIX and represents the percentage of Total Soluble Solids (TSS) at 20°C. In particular, the quality of mango analysed is *organic Amelie*.

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[51] "Jha, S. N., Narsaiah, K., Sharma, A. D., Singh, M., Bansal, S., & Kumar, R. (2010). *Quality parameters of mango and potential of non-destructive techniques for their measurement – a review*. *Journal of Food Science and Technology*, 47(1), 1–14." is a scientific article that explores mango quality parameters and discusses non-destructive techniques for their measurement, such as near-infrared spectroscopy (NIRS) and nuclear magnetic resonance (NMR). The importance of factors such as total soluble solids (TSS), acidity, colour and firmness is analysed, and the use of these technologies to improve the monitoring of fruit quality without destroying it.

[52] *Assignable causes* refer to sources that can cause a process to be out of control. These sources can include failures due to improperly adjusted or controlled machines, operator errors, and defective raw materials.

Control charts are developed by selecting *m* samples of *n* units each. In this case study, 25 samples, each consisting of 4 units, were selected.

The strategic choice of these data is significant: a sample of 4 units (i.e., 4 drums) corresponds to one pallet, which simplifies traceability. Additionally, the selection of 25 samples allows for the construction of reliable control limits due to the number of data points considered.

It is crucial to ensure that the samples are independent and that the variables analysed are normally distributed: the distribution of R is approximated normal (strong hypothesis); whereas that of $\bar{x}$ is normal due to *Central Limit Theorem*[53].

The data are reported in Table 8.

Sample	Drum 1	Drum 2	Drum 3	Drum 4	$\bar{x}_i$	R_i
1	14,9	16,1	15,7	16,8	15,9	1,90
2	15,5	14,9	14,3	16,3	15,3	2,00
3	16,0	15,9	15,6	14,8	15,6	1,20
4	14,3	16,3	16,7	15,1	15,6	2,40
5	16,5	15,5	14,2	15,4	15,4	2,30
6	16,0	14,7	16,9	16,5	16,0	2,20
7	14,9	15,0	14,6	14,4	14,7	0,60
8	15,8	16,6	16,0	14,9	15,8	1,70
9	16,2	15,1	15,2	14,8	15,3	1,40
10	15,1	14,7	16,0	16,6	15,6	1,90
11	14,5	15,7	16,3	15,2	15,4	1,80
12	15,4	16,4	15,0	15,9	15,7	1,40
13	16,7	15,2	14,8	15,5	15,6	1,90
14	14,8	16,2	15,6	14,4	15,3	1,80
15	15,0	16,8	14,2	15,1	15,3	2,60

[53] The *Central Limit Theorem* (CLT) states that, for a sufficiently large number of observations, the distribution of the sample mean of an independent, identically distributed random variable (i.i.d.) tends to be normally distributed, regardless of the original distribution of the variable. Convergence towards a normal distribution occurs more quickly if the sample size is larger and if the original distribution of the data is less skewed or more distributed. This principle underlies many statistical methods, including hypothesis tests and confidence intervals.

16	16,6	15,8	15,6	14,3	15,6	2,30
17	15,0	16,0	16,9	14,7	15,7	2,20
18	16,1	14,9	15,2	15,4	15,4	1,20
19	15,3	15,6	14,4	16,1	15,4	1,70
20	14,7	16,3	16,7	14,8	15,6	2,00
21	15,3	15,9	15,1	16,2	15,6	1,10
22	16,5	14,5	16,1	14,9	15,5	2,00
23	14,9	16,1	15,4	15,6	15,5	1,20
24	15,8	14,9	16,3	16,7	15,9	1,80
25	16,1	15,5	14,8	15,0	15,4	1,30

Table 8: Data for Control Charts

Computing $\bar{x}_i$ and R in this way:

$$\bar{x}_i = \frac{\sum_{j=1}^{n} x_{ij}}{n}$$

$$R_i = \max(x_{ij}) - min(x_{ij}) \quad \forall j$$

Where *i* indicates the row therefore the sample number and *j* indicates the column therefore the drum number.

Now, the two control charts can be constructed.

Each control chart will consist of a central value, called the Central Line (CL), which represents the expected value of the process under normal operating conditions. It will also include the Upper Control Limit (UCL), which indicates the upper threshold beyond which the data signal a significant deviation, and the Lower Control Limit (LCL), which indicates the lower threshold.

$$UCL = \mu + L * \sigma$$

$$CL = \mu$$

$$LCL = \mu - L * \sigma$$

L represents the distance of the control limits from the centre line expressed in standard deviation units. The interval does not necessarily have to be symmetrical. Due to the assumption of normality of our variables, we will use a value L = 3.

Starting with the construction of the *R* control chart and knowing that $\mu_R = \bar{R}$ and $\sigma_R = \frac{d_3(n)}{d_2(n)} * \bar{R}$:

$$UCL_R = \mu_R + 3 * \frac{d_3(n)}{d_2(n)} * \bar{R} = \left(1 + 3 * \frac{d_3(n)}{d_2(n)}\right) * \bar{R} = D_4 * \bar{R}$$

$$CL_R = \mu_R = \bar{R}$$

$$LCL_R = \mu_R - 3 * \frac{d_3(n)}{d_2(n)} * \bar{R} = \left(1 - 3 * \frac{d_3(n)}{d_2(n)}\right) * \bar{R} = D_3 * \bar{R}$$

Where d_2, d_3, D_4 and D_3 are coefficients that depend on the sample size *n*.

To be rigorous LCL_R must be greater than or equal to 0.

Substituting numerical values and representing them graphically (Figure 27):

$$UCL_R = 2{,}282 * 1{,}76 = 4{,}01$$

$$CL_R = \bar{R} = \frac{\sum_{i=1}^{m} \bar{R}_i}{m} = 1{,}76$$

$$LCL_R = 0 * 1{,}76 = 0$$

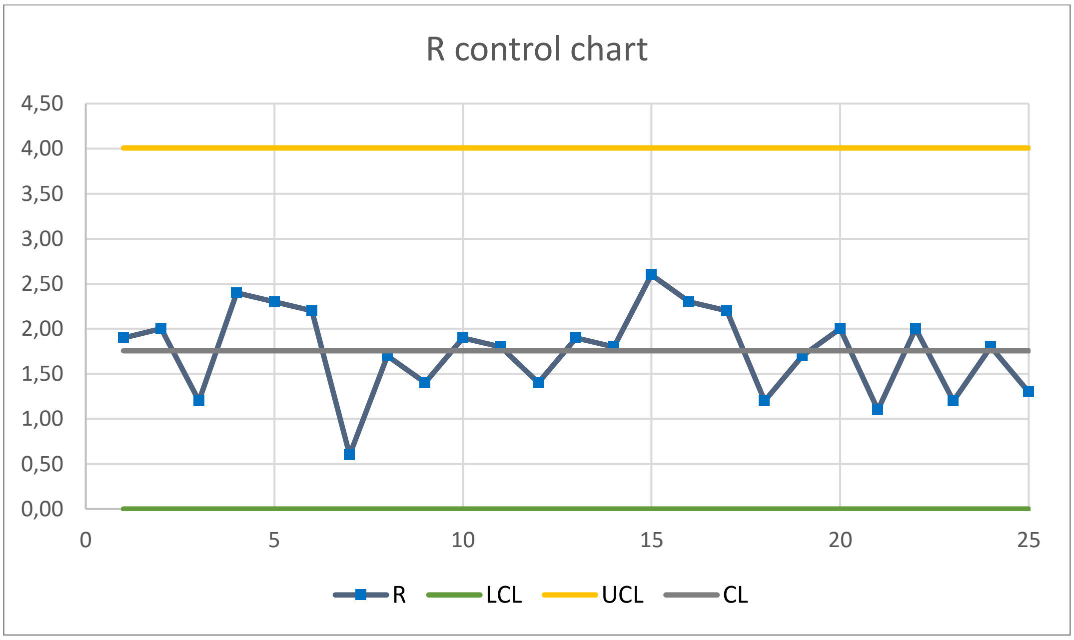

Figure 27: R control chart

Similarly, the $\bar{x}$ control chart can be created knowing that $\mu_{\bar{x}} = \bar{\bar{x}}$ and $\sigma_{\bar{x}} = \frac{\bar{R}}{d_2} * \frac{1}{\sqrt{n}}$:

$$UCL_{\bar{x}} = \mu_{\bar{x}} + 3 * \frac{\bar{R}}{d_2} * \frac{1}{\sqrt{n}} = \bar{\bar{x}} + A_2 * \bar{R}$$

$$CL_{\bar{x}} = \mu_{\bar{x}} = \bar{\bar{x}}$$

$$LCL_{\bar{x}} = \mu_{\bar{x}} - 3 * \frac{\bar{R}}{d_2} * \frac{1}{\sqrt{n}} = \bar{\bar{x}} - A_2 * \bar{R}$$

Where d_2 and A_2 are coefficients that depend on the sample size *n*.

Substituting numerical values and representing them graphically (Figure 28):

$$UCL_{\bar{x}} = 15{,}5 + 0{,}729 * 1{,}76 = 16{,}8$$

$$CL_{\bar{x}} = \bar{\bar{x}} = \frac{\sum_{i=1}^{m} \bar{x}_i}{m} = 15{,}5$$

$$LCL_{\bar{x}} = 15{,}5 - 0{,}729 * 1{,}76 = 14{,}2$$

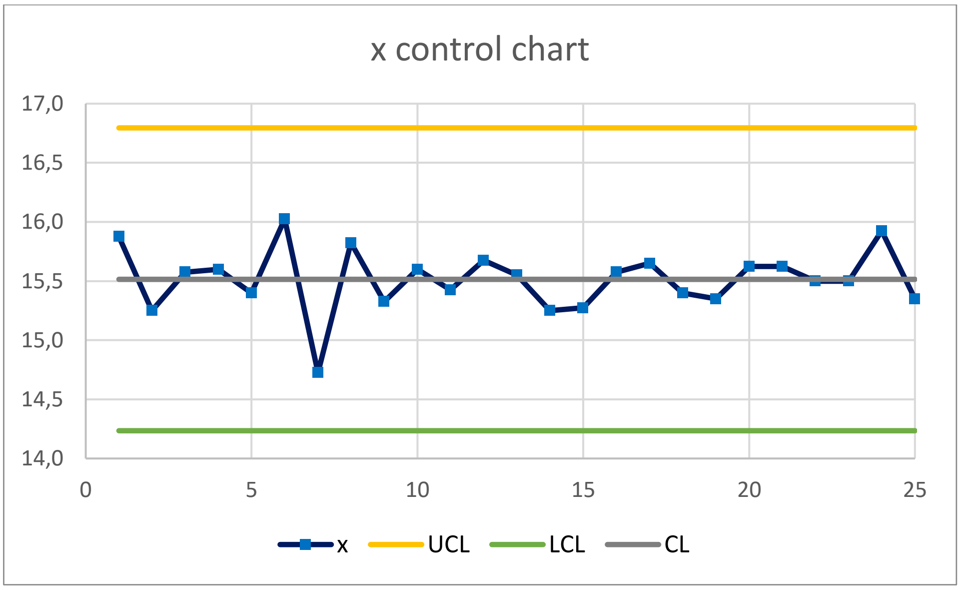

Figure 28: x control chart

The results of the control charts need to be analysed to determine if they are appropriate for monitoring the future evolution of the process. This requires checking the two basic criteria mentioned earlier.

From the graphs, it can be observed that there are no outliers and that all measurements fall within the control limits for both control charts, indicating that the first criterion, which requires the process to operate within the control limits, is satisfied.
The next step is to verify if the patterns do not exhibit any trends but rather have a random distribution. For this purpose, *Kendall's turning point test* can be employed. This test assumes the null hypothesis that the sequence is random, calculates the number of turning points (T_p), and assumes this variable follows a normal distribution.
It is then necessary to check if T_p falls within the 95% confidence interval. If this condition is met, the null hypothesis cannot be rejected, and the sequence can be considered random.
Starting by analysing the *R* control chart:

$$T_p = No.of\ local\ minima + No.of\ local\ maxima$$

$$T_p = 8 + 8 = 16$$

$$95\%\ C.I.: \left[\mu_{T_p} - 2 * \sigma_{T_p}\ ;\ \mu_{T_p} + 2 * \sigma_{T_p}\right]$$

$$\mu_{T_p} = \frac{2}{3} * (m - 2) = 15{,}33$$

$$\sigma_{T_p}^2 = \frac{16 * m - 29}{90} = 4{,}12$$

$$95\%\ C.I.: [11{,}27\ ;19{,}39\ ]$$

For the *R* control chart, the null hypothesis is verified. Let us now analyse the x control chart:

$$T_p = 8 + 8 = 16$$

$$\mu_{T_p} = \frac{2}{3} * (m - 2) = 15{,}33$$

$$\sigma_{T_p}^2 = \frac{16 * m - 29}{90} = 4{,}12$$

$$95\%\ C.I.: [11{,}27\ ;19{,}39\ ]$$

The null hypothesis was also verified for the $\bar{x}$ control chart.

It is now possible to state that the process is in statistical control, so the created control charts can be used as models to monitor both the quality and variability of the process over time. Control charts are not permanent and must be updated whenever changes occur within the process, such as machine replacements, material variations or operator changes. Furthermore, they are only valid for this specific type of mango. For instance, if the production process for organic Kent mango puree were analysed, the BRIX values would be higher due to their greater average sugar content.

In this case study, $\bar{x}$-*S* control charts could have also been utilized. However, the choice to use *R* chart is strategic, as it simplifies the calculations. If the size of the samples had been variable or the size greater than or equal to 10, it would have been better to use $\bar{x}$-*S* control charts.

It is important to remember that the results obtained through control charts do not provide any information regarding whether the analysed parameter adheres to the specifications imposed by external bodies. They only serve as a statistical tool to analyse the process variability. If one wanted to calculate the probability of sample adherence to the specifications, it would be necessary to study its distribution in relation to the standard values provided. Let's suppose that the standards require the BRIX value for Amélie organic puree to be between 14 and 19,5 °BRIX and that the quality characteristic is normally distributed (Figure 29).

$$LSL = 14$$

$$USL = 19{,}5$$

$$x \sim N(\mu\,,\,\sigma^2)$$

$$\mu = \bar{\bar{x}} = 15{,}5$$

$$\sigma \cong \hat{\sigma} = \frac{\bar{R}}{d_2} = \frac{1{,}76}{2{,}059} = 0{,}855$$

$$P_r = P(x < LSL) + P(x > USL) = P\left(x < \frac{LSL-\mu}{\hat{\sigma}}\right) + P\left(x > \frac{USL-\mu}{\hat{\sigma}}\right)$$

$$P\left(x < \frac{LSL-\mu}{\hat{\sigma}}\right) = P\left(x < \frac{14-15{,}5}{0{,}855}\right) = P(x < -1{,}75) = 0{,}040$$

$$P\left(x > \frac{USL-\mu}{\hat{\sigma}}\right) = P\left(x > \frac{19{,}5-15{,}5}{0{,}855}\right) = P(x > 4{,}68) \cong 0$$

$$P_r = P(x < LSL) + P(x > USL) = 0{,}04 + 0 = 0{,}040$$

Thus, this process has a percentage of 4% of the product that does not conform to the specifications set by regulatory bodies.

To analyse the process variability in relation to the specifications of this product, and thus assess the process's ability to produce puree that complies with specifications, process capability ratios (PCRs) can be utilized.

The first-generation PCR (C_p), in particular, considers the ratio between the specification range and the natural tolerance range of the quality characteristic being examined.

To proceed, it is necessary to calculate the limits of the natural tolerance interval of the variable, which is the interval covering 99.73% of the probability range that includes the values assumed by the BRIX variable. It is important to recall that a normal distribution has been assumed (Figure 29).

$$x \sim N(15{,}5\ ;\ 0{,}855^2)$$

$$UNTL = \mu + 3 * \sigma = 15{,}5 + 3 * 0{,}855 = 18{,}065$$

$$LNTL = \mu - 3 * \sigma = 15{,}5 - 3 * 0{,}855 = 12{,}935$$

$$NT = 6 * \sigma = 5{,}13$$

$$S = USL - LSL = 19{,}5 - 14 = 5{,}5$$

$$C_p = \frac{S}{NT} = \frac{5{,}5}{5{,}13} = 1{,}07$$

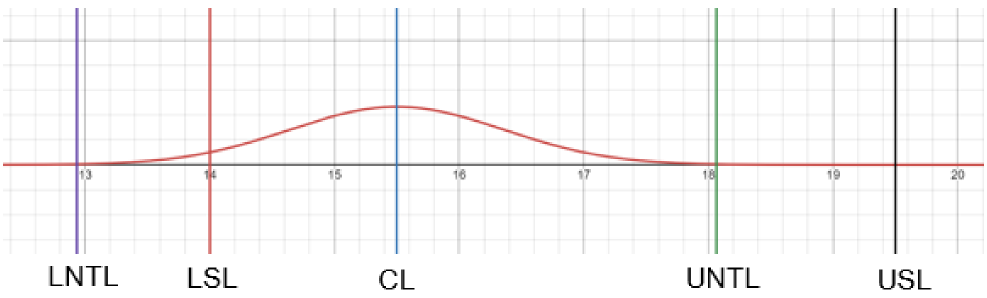

Figure 29: Normal distribution of quality characteristic

This value is satisfactory, as it is greater than 1 and approaches the ideal value of $\frac{4}{3}$, which is established by quality engineering standards. A value higher than 1 indicates that the

natural tolerance range is narrower than the specifications, suggesting that the process is capable of producing a large portion of output that meets the standards.
However, this indicator does not take into account the position of the mean relative to the specifications. Therefore, the second-generation PCR (C_{pk}) can be calculated:

$$C_{pk} = \min\left(C_{pu}, C_{pl}\right)$$
$$C_{pu} = \frac{USL - \mu}{3 * \sigma} = \frac{19{,}5 - 15{,}5}{3 * 0{,}855} = 1{,}56$$
$$C_{pl} = \frac{\mu - LSL}{3 * \sigma} = \frac{15{,}5 - 14}{3 * 0{,}855} = 0{,}59$$
$$C_{pk} = C_{pl} = 0{,}59$$

This indicator demonstrates the process's capability to centering. The value is above 0, which confirms that the mean is within the specification limits, and it is slightly smaller than its ideal value, which equals Cp: where the mean would be at the midpoint of the specification range. Since the value is slightly smaller than Cp, it can be inferred, and verified from the graph, that the mean is shifted towards the lower limit of the specifications.
Finally, it is possible to evaluate whether adopting this new control method makes economic sense compared to using sample checks.
Considering a batch of 240, the economic loss would therefore be approximately:

$$Quantity = 240 * 235\ kg = 56{,}4\ tons$$
$$Total\ value = 56{,}4\ tons * 1060 \frac{\$}{tons} = 59784\ \$$$
$$Lost\ value = 59784\ \$ * 4\ \% = 2391{,}4\ \$$$

This value justifies an investment in this type of equipment, capable of providing real-time control of the process and its output. In fact, the economic loss is lower than the risk-related cost of performing sample checks, which can amount to tens of thousands of euros, as analysed in section *3.3.1 Quality and monitoring issues*.
Therefore, although the initial purchase and integration costs may be high, these new control methods will lead to long-term cost savings, while also ensuring a much higher level of quality through both product and process monitoring.

4.2.2 Innovative solutions for logistics optimisation

Along the supply chain, the role of logistics is crucial; therefore, it must be preserved and subjected to a continuous improvement process.

The first logistical challenge encountered in this ecosystem pertains to the technique used for product preservation, namely the pasteurization of the puree followed by packaging in aseptic containers.

Indeed, this process, operating at high temperatures, can compromise the flavour and result in the loss of certain nutrients characteristic of mango-derived products. Such losses may lead to alterations in key indices, potentially compromising an entire batch.

As highlighted in the previous chapter, pasteurization also has another issue related to costs due to high energy consumption and the cost of energy in Mali.

To optimize this situation, it is essential to find a solution that addresses the issues caused by pasteurization while still providing the same benefits that this procedure offers.

To achieve this, it is necessary to expand the perspective beyond the traditional techniques previously described, as these methods may mitigate the issues associated with pasteurization but come with their own set of disadvantages.

Instead, an excellent solution may be found by exploring natural products.

An excellent alternative to the pasteurization process could be the use of plant extracts whose properties ensure the preservation of puree quality and its food safety. Among the various possible alternatives, the one that best meets the requirements for mango puree is the use of essential oil extracted from the fresh leaves of *Mentha piperita L* (Adjou, René, Dahouenon-Ahoussi, & Soumanou, 2017)[54].

This oil possesses antimicrobial properties, particularly antifungal activity against fungi such as *Aspergillus parasiticus, A. versicolor* and *Mucor spp.*, inhibiting their growth as they represent the microflora capable of causing the deterioration of the puree.

[54] "Adjou, E. S., René, D., Dahouenon-Ahoussi, E., & Soumanou, M. M. (2017). Chemical composition and biological activity of essential oil from *Mentha Piperita* L. leaves on the quality of mango puree during storage. *Journal of Microbiology, Biotechnology and Food Sciences, 7*(2), 97-100." is a scientific study investigating the effectiveness of Mentha piperita essential oil in the preservation of mango puree during storage. The study provides details on the chemical composition of the oil, its antimicrobial properties and the results of microbiological analyses performed on stored mango puree.

The oil has been chemically analysed using *gas chromatography*[55] and *gas chromatography-mass spectrometry*[56], identifying 15 components that account for 94.2% of the total composition (Table 9).

Components	Kovats Index (KI)	Percentage (%)
α-Pinene	939	0.8
β-Pinene	979	1.2
Limonene	1028	2.8
1,8-Cineole	1031	6.5
Terpinene	1060	0.3
Menthone	1153	7.4
menthofurane	1164	1.6
iso-menthone	1166	4.8
Menthol	1174	46.7
iso-menthol	1183	0.8
neo-menthol	1188	8.28
pulegone	1238	3.6
piperitone	1254	1.7
menthyl-acétate	1294	6.7
Trans β- caryophyllene	1408	2.1
Total		**94.2**

Table 9: Chemical composition of the essential oil of Mentha piperita L.

The oil is extracted directly from fresh Mentha piperita leaves using a hydro-distillation method: the leaves are immersed in water, and the mixture is heated until it generates steam that carries the plant's volatile compounds. The steam is then condensed, resulting in the oil in liquid form. After extraction, the oil is dried over anhydrous sodium sulphate and stored at 4°C until use.

[55] *Gas chromatography* (GC) is an analytical technique used to separate and analyse volatile compounds in a mixture. The mixture is vaporised and passed through a column filled with a stationary material. The different components of the mixture separate according to their interactions with the stationary phase and are detected at the end of the column.

[56] *Gas chromatography-mass spectrometry* (GC-MS) is a combined technique that combines the separation of compounds by gas chromatography with their identification by mass spectrometry. After separation, compounds enter a mass spectrometer, where they are ionised and fragmented, allowing them to be identified according to their mass-to-charge (m/z) ratio.

To test the effectiveness of the essential oil and determine the optimal concentration to use, five mango puree samples were prepared with different concentrations of the oil: 0.50, 1.00, 1.50, 2.00 and 2.50 µL/mL. Additionally, a negative control was prepared, consisting of mango puree without any oil. The puree used in the tests was derived from a type of mango from Benin. However, it has characteristics very similar to those from Mali, as both grow in tropical regions and, most importantly, belong to the same species, *Mangifera indica,* sharing the same botanical traits.

The samples were stored at 25°C for 15 days, after which key characteristics essential for the food safety of the puree were observed. These included the pH level, measured using a digital pH meter, as well as nutritional values such as the percentage of carbohydrates, carotenoids in mg/100g, and vitamin C in mg/100g.

The microbiological (Table 10) and physicochemical (Table 11) analyses yielded the following results:

Parameters	Concentrations of essential oil *(µl/ml)*					
	0	***0.50***	***1.00***	***1.50***	***2.00***	***2.50***
Total bacterial count	$3.0\text{x}10^{7a*}$	$2.0 \text{ x } 10^{5b*}$	10^{2c*}	10^{d*}	00^{e*}	00^{e*}
Fungi count	$1.0\text{x}10^{5a*}$	$1.0 \text{ x } 10^{2a*}$	$1.2 \text{ x}10^{1b*}$	10^{c*}	00^{d*}	00^{d*}

Table 10: Microbiological quality of mango puree analysed after 15 days of conservation (ufc/ml)

Physicochemical parameters	**Mango puree 's characteristics at the beginning of the conservation tests**	**Characteristics of the mango puree after 15 days of conservation** *Concentrations of essential oil (µl/ml)*					
		0	***0.50***	***1.00***	***1.50***	***2.00***	***2.50***
pH	$6.80±0.10^{a*}$	$2.40±0.10^{b*}$	$4.90±0.40^{b*}$	$5.40±0.60^{b*}$	$5.70±0.20^{c*}$	$6.20±0.30^{a*}$	$6.40±0.70^{a*}$
Carbohydrates (%)	$9.50±0.40^{a*}$	$1.80±0.20^{b*}$	$5.70±0.30^{c*}$	$6.20±0.10^{c*}$	$8.10±0.60^{d*}$	$9.40±0.10^{a*}$	$9.10±0.30^{a*}$
Carotenoids (mg/100g)	$20.05±0.03^{a*}$	$4.51±0.07^{b*}$	$9.06±0.04^{c*}$	$11.53±0.02^{d*}$	$14.03±0.06^{e*}$	$18.03±0.05^{a*}$	$19.02±0.07^{a*}$
Vitamin C (mg/100g)	$21.03±0.05^{a*}$	$1.06±0.03^{b*}$	$4.07±0.09^{c*}$	$10.01±0.04^{d*}$	$12.08±0.07^{d*}$	$20.04±0.07^{a*}$	$21.01±0.03^{a*}$

Table 11: Physicochemical quality of investigated mango puree after 15 days of conservation

Both tests demonstrate the effectiveness of Mentha piperita essential oil in preserving mango puree. The preservation quality is directly proportional to the concentration of the oil, confirming its validity as a repellent against fungal growth. The microbiological analysis showed that at lower concentrations of oil, some bacteria and fungi still developed, whereas at concentrations of 2.00 and 2.50 µL/mL, no growth was observed. Similar results were obtained from the physicochemical test, which revealed significant changes in the

analysed values after 15 days at lower oil concentrations, while higher concentrations exhibited minimal variations.
Thus, it is feasible to use the addition of peppermint essential oil before storing the puree in aseptic packaging as a substitute for the traditional pasteurization technique and avoiding the use of synthetic substances.
Additionally, another advantage of this solution is related to the political drivers analysed in the PEST analysis: regulatory bodies are increasingly inclined to favour the use of natural products and discourage synthetic ones. Mentha piperita essential oil has been recognized as a safe substance in food products by both the European Commission and the United States Food and Drug Administration (FDA).
During the analysis of logistical inefficiencies, another critical factor that emerged is related to the transportation of drums from the factory in Yanfolila to Rotterdam, particularly the land route between Yanfolila and Dakar. The timing for this segment is extremely lengthy relative to the distance travelled due to customs delays and waiting times at the port before loading, as well as the hazardous conditions of the roads, which often result in accidents. The road conditions also pose a challenge for farmers, who struggle to reach the plantations, and for the trucks transporting the harvested fruit from the plantations.
Finding a solution that completely resolves these issues is impossible, as they are beyond the control of the actors within the supply chain. However, it is possible to address these challenges by mitigating them through a holistic approach aimed at creating a *Lean and Integrated System* (*LIS*).
LIS is an innovative approach that is applied in a company as opposed to the traditional vertical structure. Its aim is to optimise operational efficiency and minimise waste using *Concurrent Engineering*[57] and *Lean Production*[58] approaches.
The traditional vertical structure of companies is characterised by a great separation between functions, very strict hierarchies between them and only high-level iterations. A typical characteristic of this structure is to follow a *waterfall* method of working, where

[57] *Concurrent Engineering* is an approach that simultaneously integrates design and production, promoting collaboration between different disciplines to reduce development time, improve quality and optimise costs.
[58] *Lean Production* is an approach to production management that aims to optimise efficiency and reduce waste in all business processes. Based on the principles of the *Toyota Production System*, it focuses on practices such as eliminating waste, creating a continuous workflow and production based on real demand.

divisions are isolated, communication is only vertical, tasks are carried out in succession and communication and cooperation are not encouraged.

A LIS approach, on the contrary, provides for less bureaucracy, few hierarchical levels (*flat hierarchy*), collaboration and interaction between functions thanks to cross-functional teams and finally proposes a concurrent engineering working method where tasks are not carried out sequentially, but in parallel, overlapping some of them.

If one wants to apply this approach not to an individual company, but to the entire supply chain, one has to make some clarifications: in this case, the internal functions of the company are represented by the actors in the supply chain, the company hierarchy is represented by the relationships between the different actors, and the project tasks are the processes that take place during the chain.

Following the principles of Lean Production aimed at the elimination of waste and non-value-added actions, as emerged from the criticality analysis, transport between Yanfolila and Dakar must be optimised.

By transforming the supply chain into a Lean and Integrated System, it is possible to mitigate this problem by strengthening the relationship between the actors involved and overlapping certain tasks.

In this case, the actors involved are the production firm, the logistics carrier whose trucks handle the transport, Montecarlofruit, which buys the puree from the producing company to export it from Africa and resell it, and the government agencies that handle customs and the port of Dakar.

Increased collaboration aims to improve operational efficiency along the critical path by promoting continuous dialogue to anticipate problems, plan logistics operations and ensure that transport times and customs formalities are well coordinated.

To enhance the coordination of bookings and minimize waiting times at customs and ports, the tasks performed by the distribution company related to the preparation of the necessary import-export documentation can be conducted concurrently with other operations, such as the drums storage, without having to wait for the truck to leave the factory. To do this, it is necessary for the distribution and manufacturing companies to exchange information promptly and continuously. This approach allows the anticipation of bureaucratic requirements, reducing idle times and expediting shipping processes.

Greater collaboration between actors can also help small farmers, who, because of the bad roads, may have problems reaching the plantations or obtaining the necessary equipment for efficient cultivation.

The role of cooperatives and their relationship with companies is crucial here (Mumararungu, Gisaro, Bisetsa, & Burny, 2024)[59]. Indeed, cooperatives manage to offer various benefits to their members (Table 12).

Category	Cooperative Members	Non-Members
Mutual Support	Benefit from mutual support, enhancing resilience.	Lack organized support, rely on own resources.
Knowledge Sharing	Direct access to latest techniques, enhancing efficiency.	Learn from members, improve practices through observation.
Timely Access to Resources	Access to quality seeds on time, maximizing yields.	May face delays in accessing quality seeds.
Aid and Support	Access food and financial aid, ensuring resilience.	Vulnerable to food insecurity and financial instability.
Access to Information	Better access to price info for informed decisions.	Rely on less reliable or delayed information sources.
Financial Management	Maintain operating accounts for effective decisions.	May lack effective financial management practices.
Credit Access	Better access to credit within the cooperative.	Reliance on external credit sources.
Awareness and Open-mindedness	Exposed to new ideas and perspectives.	Miss out on opportunities for personal growth.

Table 12: Benefits of cooperative members

Among the various benefits, one of fundamental importance to the functioning of the supply chain is the preparation and continuous training they provide to farmers to optimise the agricultural performance of the land.

Since the mangoes do not come from a specific plantation, but from the entire region within a radius of 450 km, it could be advantageous for the whole system to complete a *mapping project of the plantations* in order to collect data and digitise them. In this way, the producer

[59] "Mumararungu, I., Gisaro, M., Bisetsa, E., & Burny, P. (2024). Agricultural cooperative and members' resilience in Kita and Yanfolila cercles of Mali. *African Journal of Food, Agriculture, Nutrition and Development*, 24(4), 26007-26023." analyses the contribution of agricultural cooperatives in strengthening the resilience of farmers in the Kita and Yanfolila regions of Mali. The cooperatives not only provide training and resources such as irrigation systems and food aid, but also promote social cohesion, resolving conflicts and supporting the community during crises such as the COVID-19 pandemic.

could more accurately predict the volumes of mangoes produced, optimise logistical routes to ensure that the mangoes arrive as fresh as possible, and have complete traceability, which could be useful in quality control or to identify possible problems, such as pests, related to a particular plantation.

Comprehensive, digital mapping can also be favourable for farmers who can receive technical support to improve production or in case of problems.

For these reasons, it is beneficial for both farmers and companies to continue improving the role played by cooperatives that link rural realities with developed companies.

Therefore, by applying some Quality Engineering principles and transforming the supply chain into a Lean and Integrated System, reducing wastage of resources and time and increasing the exchange of information and planning between actors, it would be possible to mitigate some of the critical logistics issues that weaken the ecosystem.

4.2.3 Cost reduction in the supply chain

In order to offer a final product at a competitive price in a market characterised by global competition and at the same time allow operating companies to generate profit margins, it is essential to have control over costs along the supply chain.

In order to govern costs, it is necessary to limit all types of expenses that can negatively affect business. As emerged in the criticality analysis, one of them is related to indirect expenses due to the maintenance of industrial machines.

Current preventive maintenance programmes are time or condition-based. The former performs periodic maintenance according to calendar time, lacking flexibility as the actual state of the machinery is neglected, leading to over- or under-maintenance that can lead to very costly failures and breakdowns. The latter use sensors to monitor certain key parameters of the machinery components to decide how much maintenance work to apply. Although this type of maintenance is more precise than the periodic one, it has limitations because the choice of whether or not to perform repair actions depends on pre-specified degradation thresholds, losing the ability to adapt them according to real-time data.

To remedy this problem, it is necessary to resort to the use of *predictive maintenance* policies (*PdM*), which make use of real-time predictions of component conditions in order to get maintenance work done just before potential failures occur. This approach can be seen as an intelligent evolution of its predecessors as it has no temporal rigidities and is able to update degradation benchmarks with each analysis, making forecasts flexible.

Predictive maintenance aims at automation by collecting data through monitoring sensors, they are saved on company clouds thanks to *IoT*[60] and then processed through the use of software with a computerised maintenance management system and artificial intelligence support. All the data collected serve the system's dynamism to continuously update the evaluation parameters and have no constraints as in preventive maintenance.

The purpose of processing the degradation data in real time is to estimate the Remaining Useful Life (RUL), i.e. the time interval from the current moment until the next failure of the component (Figure 30).

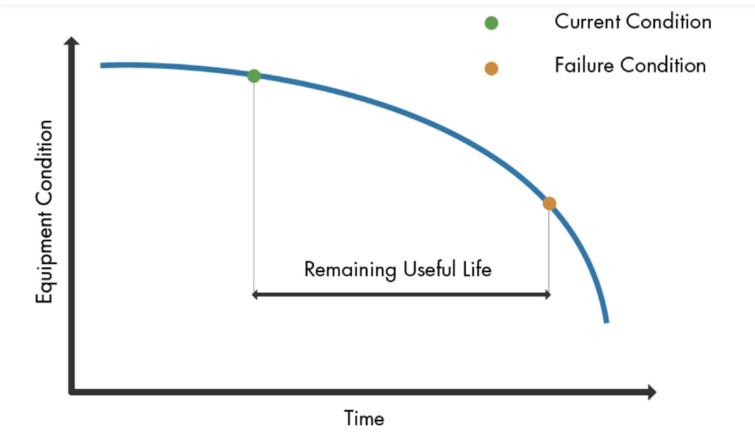

Figure 30: RUL of a component

Switching to a PdM policy can have considerable and quantifiable benefits[61]:

- 5% - 15% reduction in facility downtime, freeing up capacity;
- 5% - 20% increase in labour productivity;
- 10% - 30% reduction in inventory levels with 5% - 20% reduction in carrying costs;
- 3% - 5% reduction in new equipment costs.

The global predictive maintenance market is growing strongly with an estimated C.A.G.R. of 37.6% until 2025, reaching a value of 28.24 billion.

[60] The *Internet of Things* represents the network of physical devices connected to the Internet that are used to collect and exchange data. Any device that can communicate with others or connect to a centralised system is part of the IoT, such as sensors, household appliances or vehicles. In the business environment, IoT is used to optimise production processes and improve resource management, increasing operational efficiency and reducing costs.

[61] Source: Deloitte. (2022). *Predictive Maintenance.* Internal Deloitte analysis derived from work with clients.

This exponential growth in recent years has led to more research and an increase in the number of publications by experts.

A recent interesting study has proposed a method for optimising PdM policy (Yang L. et al., 2024)[62].

The innovative proposal is to dynamically combine *predictive group maintenance* (PGM) and *unscheduled opportunistic maintenance* (UOM). The former corresponds to classic predictive maintenance based on continuously updated data to predict the condition of components. In particular, in addition to the classic procedure, an interesting algorithm is proposed that allows the application of a dynamic component grouping strategy based on the predictive data of the RUL, the savings resulting from the grouping of those components, as setup and/or transport costs, and the potential penalty costs due to the postponement or anticipation of maintenance with respect to the optimal component time. This algorithm makes it possible to work always with real time data, as not all groups of components requiring maintenance are planned together, but always short-term forecasts of the next group requiring maintenance are made, and then the data are updated and moved on to the next group. In this way, the system is always up-to-date with the actual conditions and the computational complexity is significantly reduced.

The research proposal, however, does not stop at the identification of strategic component groups and the planning of their maintenance on a predictive basis, but combines this approach with UOM policy. The UOM policy comes into play in the event of a sudden component failure: in this case, the system would have to be stopped in order to remedy the failure, but the algorithm would at the same time identify components that could be maintained at the same time, in order to reduce costs related to machine downtime.

This new innovative approach to PdM is shown in detail in Figure 31.

[62] "Yang, L., Zhou, S., Ma, X., Chen, Y., Jia, H., & Dai, W. (2024). Group machinery intelligent maintenance: Adaptive health prediction and global dynamic maintenance decision-making. *Reliability Engineering and System Safety, 252*, 110426." is a scientific article that highlights the problems associated with the rigidities of time- or condition-based preventive maintenance policies and proposes an optimisation of predictive maintenance by combining several theories. The article's proposal is also tested and the results are subsequently analysed.

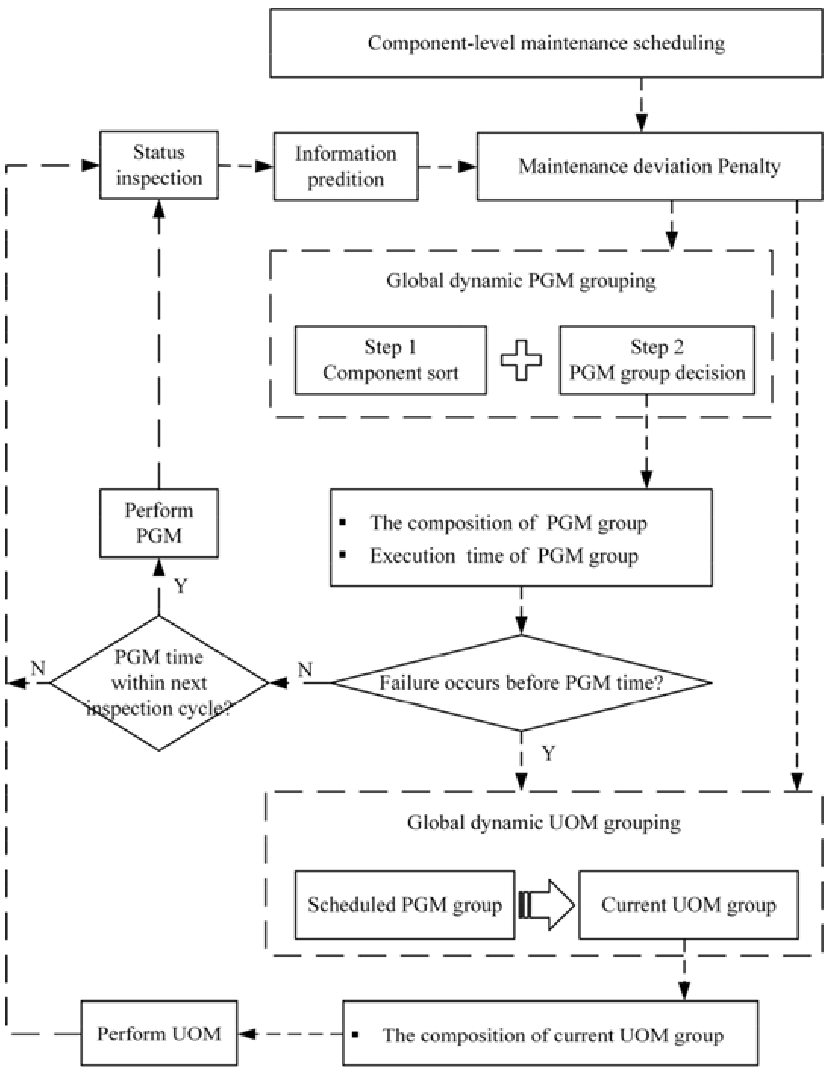

Figure 31: Flowchart of the maintenance policy

The algorithm was tested by running a simulation on a system of motorized railway carts, considering 10 components: 4 wheel treads, 2 gears, and 4 bearings. In the simulation, data collected over a period corresponding to 8 × 10^5 kilometres of railway service were used. This intelligent PdM approach was then applied to estimate the overall maintenance costs. The results were compared to the traditional periodic preventive maintenance strategy, leading to a 17,6 % savings.

In conclusion, it is possible to assert that adopting this type of maintenance can reduce costs, increase efficiency and quality, and prevent the need to deal with breakdowns or failures. This solution is ideal for a production facility located in a country with limited component availability, such as Mali, because the algorithm, during the formation of groups and maintenance planning, takes into account transportation costs for component procurement and setup costs.

During the critical cost analysis, attention was paid to logistics costs, which cover a large part of the expenses along the supply chain.

These high costs are due to land transport, sea transport and a risk component, due to unforeseen events during transport that often occur due to the poor condition of the transport infrastructure or due to customs detentions, which leads to delay penalties, credits or discounts for customers that negatively affect the economy of companies operating logistics tasks.

This risk can be seen as the probability that each container that is transported will suffer an unforeseen accident or stoppage. It is not possible to determine ex-ante the probability that each individual container will suffer a mishap, but it is possible to model it according to the number of containers transported: obviously, the greater the number, the greater the risk and thus the greater the additional costs. This model assumes an implicit dependency between the accident probabilities of the various containers as they share common resources, such as the same route, often many containers are transported on the same ship or truck and the same port terminal, this leads to cascading events, i.e. if a failure occurs in one of the common resources the whole shipment is affected and not just a single container.

A model was created in *MATLAB*[63] to depict this situation:

- Parameters: they represent the costs required to transport a single container from Yanfolila to Dakar and then from Dakar to Rotterdam.

$$Yanfolila \rightarrow Dakar: c_{A1} = 2500$$
$$Dakar \rightarrow Rotterdam: c_{A2} = 1100$$

  Another parameter concerns the penalty that is paid for each container in the event of a contingency occurring. This parameter has been assumed to have a constant value for computational purposes, but may vary depending on the problem encountered.

[63] *MATLAB* is software created by MathWorks in the C programming language that performs numerical calculation and statistical analysis to manipulate functions, matrices, data, algorithms or to interface with other programmes.

$$Penalty: p_{A1} = 2000$$

A parameter was included to represent the probability of an accident for each container. Since this risk increases as the number of containers transported increases, a directly proportional relationship was assumed to represent the probability as a function of the quantity transported on the route. A constant parameter was used to model the growth rate of the probability:

$$Probability\ of\ an\ accident\ for\ each\ container: \mathrm{P(y)} = \alpha_A * y_A$$
$$\alpha_A = 0{,}001$$

Finally, the total number of containers to be transported was considered:

$$y_A = 200$$

- Objective function: was calculated as the sum of transport costs and additional costs due to the risk of unforeseen events. The first term of the sum represents the part relating to transport, the second the one relating to the penalty. The latter contains the *min* function to limit the probability to the value 1:

$$cost = (c_{A1} + c_{A2}) * y_A + p_{A1} * y_{A1} * \min(\alpha_A * y_A\ ; 1)$$

Then the algorithm was run, Figure 32.

```
>> % Cost parameters per container on the Dakar route
cA1 = 2500;  % Cost per container from Yanfolila to Dakar (1500 km)
cA2 = 1100;  % Cost per container from Dakar to Rotterdam (5000 km)

% Fixed penalty for delay on each container
pA1 = 2000;

% Parameter for linear delay probability
alpha_A = 0.001;

% Total quantity in containers
y_A = 200;

% Calculation of the objective function (total cost)
cost = (cA1 + cA2) * y_A + pA1 * y_A * min(alpha_A * y_A, 1);

% Output
fprintf('Total cost to transport %d containers on Route A: %.2f\n', y_A, cost);
Total cost to transport 200 containers on Route A: 800000.00
```

Figure 32: Total transportation costs, one route

The result shows an estimated total expenditure of $800.000, knowing that $720.000 is the part due to transport, calculated in the section *3.3.3 High costs*, the expenditure due to risk is $80.000. The most costly component is the transport by truck from Yanfolila to Dakar. Unfortunately, it is the only alternative because Mali has no sea outlet and no facilities for river or rail transport. It is therefore logical to focus on the cost component related to the transport risk along this route.

Since there is no route that is better in everything than the one currently used, and therefore it is not possible to simply replace the route with another, to optimise this situation it is possible to start using another route in addition in order to diversify the risk by reducing the number of containers travelling each route.

Evaluating the distances from the production factory to the ports and the roads to reach them, the best option alongside the existing route is via the port of Conakry, Guinea's capital.

To verify this solution, the previously created programme was modified in MATLAB, adding the new path as an option and minimising the cost objective function to find the ideal quantities to be transported on each route:

- Parameters: the first parameters set are the unit costs per container according to the route travelled.

$$Yanfolila \rightarrow Dakar: c_{A1} = 2500$$

$$Dakar \rightarrow Rotterdam: c_{A2} = 1100$$
$$Yanfolila \rightarrow Conakry: c_{B1} = 2000$$
$$Conakry \rightarrow Rotterdam: c_{B2} = 1500$$

The same fixed penalty parameters per container were inserted:

$$Penalty\ via\ Dakar: p_{A1} = 2000$$
$$Penalty\ via\ Conakry: p_{B1} = 2000$$

The probabilities of unexpected events for each container were also formulated in the same way. To make the model as realistic as possible, a slightly higher proportionality coefficient was used for the Conakry route, as it is a smaller, less organized, and less advanced port compared to Dakar, and therefore more prone to unexpected events:

$$Probability\ of\ an\ accident\ for\ each\ container, via\ Dakar: P_A(y_1) = \alpha_A * y_1$$
$$\alpha_A = 0{,}001$$
$$Probability\ of\ an\ accident\ for\ each\ container, via\ Conakry: P_B(y_2) = \alpha_B * y_2$$
$$\alpha_B = 0{,}0015$$

The total amount of containers to be transported remained the same:

$$Demand = 200$$

- Variables: two variables were used concerning the number of containers transported on the Dakar route and the Conakry route:

$$Number\ of\ containers\ transported\ via\ Dakar: y_1$$
$$Number\ of\ containers\ transported\ via\ Conakry: y_2$$

- Constraints: the sum of containers transported via all routes must equal the total demand:

$$y_1 + y_2 = 200$$

The quantities transported on each route must be non-negative:

$$y_1 \geq 0$$
$$y_2 \geq 0$$

- Objective function: it was set considering both transport costs and additional costs related to the risk of unforeseen events for both routes. In contrast to the previous model, which was a simple calculation, in this simulation the function was optimised by minimising it and finding optimal values for the quantities:

$$fun\ (y_1\ , y_2) = (c_{A1} + c_{A2}) * y_1 + (c_{B1} + c_{B2}) * \ y_2 + p_{A1} * y_1 * \min(\alpha_A * y_1\ ; 1) + \ p_{B1} * y_2 * \min\ (\alpha_B * y_2\ ; 1)$$

Then the algorithm was run, Figure 33.

```
>> % Cost parameters per container on the two routes
cA1 = 2500;  % Cost per container from Yanfolila to Dakar (Route A)
cA2 = 1100;  % Cost per container from Dakar to Rotterdam (Route A)
cB1 = 2000;   % Cost per container from Yanfolila to Conakry (Route B)
cB2 = 1500;  % Cost per container from Conakry to Rotterdam (Route B)
% Fixed penalty for container delay
pA1 = 2000;   % Fixed penalty on Route A
pB1 = 2000;   % Fixed penalty on Route B
% Parameter for linear delay probability
alpha_A = 0.001;  % Probability of linear delay on Route A
alpha_B = 0.0015;  % Probability of linear delay on Route B
% Total quantity in containers
demand = 200;
% Objective function (to be minimised)
fun = @(y) (cA1 + cA2) * y(1) + (cB1 + cB2) * y(2) + pA1 * y(1) * min(alpha_A * y(1), 1) + pB1 * y(2) * min(alpha_B * y(2), 1);
% Equality constraint (sum quantity equals total demand)
Aeq = [1, 1];
beq = demand;
% Lower limits of variables (non-negative quantities)
lb = [0, 0];
% Troubleshooting using fmincon
options = optimoptions('fmincon', 'Display', 'iter', 'Algorithm', 'sqp');
y0 = [demand/2, demand/2];  % Initial estimate: half on Route A, half on Route B
[y, cost] = fmincon(fun, y0, [], [], Aeq, beq, lb, [], [], options);
% Output
fprintf('Containers transported on Route A (via Dakar): %.2f\n', y(1));
fprintf('Containers transported on Route B (via Conakry): %.2f\n', y(2));
fprintf('Total costs: %.2f\n', cost);
 Iter  Func-count            Fval   Feasibility   Step Length       Norm of   First-order
                                                                       step    optimality
    0           3    7.600000e+05    0.000e+00    1.000e+00    0.000e+00    4.100e+03
    1           9    7.597556e+05    0.000e+00    3.430e-01    2.425e+01    2.679e+03
    2          12    7.595000e+05    0.000e+00    1.000e+00    1.011e+01    1.245e-04

Local minimum found that satisfies the constraints.

Optimization completed because the objective function is non-decreasing in
feasible directions, to within the value of the optimality tolerance,
and constraints are satisfied to within the value of the constraint tolerance.

<stopping criteria details>
Containers transported on Route A (via Dakar): 110.00
Containers transported on Route B (via Conakry): 90.00
Total costs: 759500.00
```

Figure 33: Total transportation costs, two routes

The results obtained from this simulation confirm that there would be advantages in using two paths: the optimal solution is to transport 110 containers via Dakar and 90 containers via Conakry, with the total costs amounting to $759.500. In fact, by diversifying the quantities across the different routes, the risk would be diluted, leading to a reduction in additional costs related to unexpected events. Comparing the two simulations, a savings of over 5% was achieved. If this savings is considered with a future perspective, taking into account the continuous increase in demand, the savings will be even greater, allowing for an improvement of the entire ecosystem and in a reduction of contingencies.

Finally, another approach that can be pursued to achieve cost savings is through the creation of *routines*. In the supply chain, the company responsible for the import and export of puree initiated this procedure, in which the writer actively participated during the internship.

The objective is the creation of a procedure manual that provides a detailed description of a predefined sequence of actions or behaviours to be performed repetitively and regularly, in order to complete a task in a standardized and efficient manner.

Routines represent the knowledge possessed by the company and in this specific case they reduce the time needed to create and manage the documentation required for stock management and the transport of goods.

The time saved can be translated into cost savings, as the resource dedicated to completing that task is allocated for a shorter period of time.

This is known as the *learning effect*: the greater efficiency that leads to savings is linked to the greater skill of the resource due to the repetition of the same activities. It is important to note that this learning does not evolve as a function of time, but rather of the cumulative volume of production.

This effect can be represented with a mathematical model called the *Boeing-Crawford Experience Curve Model*: costs reductions evolve as a function of production volume following a straight and downward sloping line, if the two variables are plotted on logarithmic scales (Cantamessa & Montagna, 2023)[64]. The model is therefore:

[64] "Cantamessa, M., Montagna, F. (2023). *Management of Innovation and Product Development: Integrating Business and Technological Perspectives* (2th ed.). Springer London." offers a comprehensive view of what innovation is and its role in business and society. This book is both a practical and theoretical guide to the strategies to be applied in order to manage the various types of innovation. In addition, the processes that characterise product development are analysed in detail.

$$C(n) = C(1) * n^{-b}$$

$C(n)$ represents the cost of the n^{th} part that has been produced as a function of cumulated volume n, b is the learning rate with which costs decrease and $C(1)$ is the cost related to the first part.

The model has been applied to this case study to estimate the potential savings considering a time horizon of two years on a monthly basis.

The cost of preparing a document to enter a new order into the management system has been computed based on the time a specific resource spent on the task.

On average, it was estimated that an employee, between the various tasks he/she performs, works on the creation of approximately 400 documents in a year, each requiring an estimated average time of 2 hours; the seasonality of demand was not taken into account, but documents production was assumed to be uniformly distributed throughout the year. So, for an employee the monthly production of documents is equal to $docs. = \frac{400}{12} = 33{,}33$.

To estimate the learning rate, a 5% reduction was estimated for each doubling of production.

The model carried out on excel is shown below, Figure 34:

salary/month	$	3.000,00
salary/day	$	150,00
salary/hour	$	18,75

time/doc. (hours)		2
cost doc. = C(n)	$	37,50
first lot = n		33,3333
C(1)	$	45,01
savings = 1-α		5%
k		2
b		0,074

$$b = -\frac{\ln \alpha}{\ln k}$$

$$C(1) = \bar{C}(n) * (1-b) * n^b$$

$$\bar{C}(n_1, n_2) = \frac{C(1)}{n_2 - n_1} * \frac{n_2^{1-b} - n_1^{1-b}}{1-b}$$

time	docs.	cum. docs.	cost/doc.
0	33,333	33,333	$ 37,500
1	33,333	66,667	$ 33,750
2	33,333	100,000	$ 32,466
3	33,333	133,333	$ 31,659
4	33,333	166,667	$ 31,072
5	33,333	200,000	$ 30,613
6	33,333	233,333	$ 30,236
7	33,333	266,667	$ 29,917
8	33,333	300,000	$ 29,640
9	33,333	333,333	$ 29,397
10	33,333	366,667	$ 29,180
11	33,333	400,000	$ 28,984
12	33,333	433,333	$ 28,806
13	33,333	466,667	$ 28,642
14	33,333	500,000	$ 28,491
15	33,333	533,333	$ 28,351
16	33,333	566,667	$ 28,220
17	33,333	600,000	$ 28,097
18	33,333	633,333	$ 27,982
19	33,333	666,667	$ 27,873
20	33,333	700,000	$ 27,770
21	33,333	733,333	$ 27,672
22	33,333	766,667	$ 27,579
23	33,333	800,000	$ 27,491

Figure 34: Learning effect model

The average cost of the first batch produced, that is the production of the first month, is \$37,50. By applying the model that takes the experience effect into account, it is possible to determine how the average cost per document decreases as cumulative production increases (Figure 35). At the end of the analysis period, the average cost per document is \$27,49, with a unit savings of 26,69%.

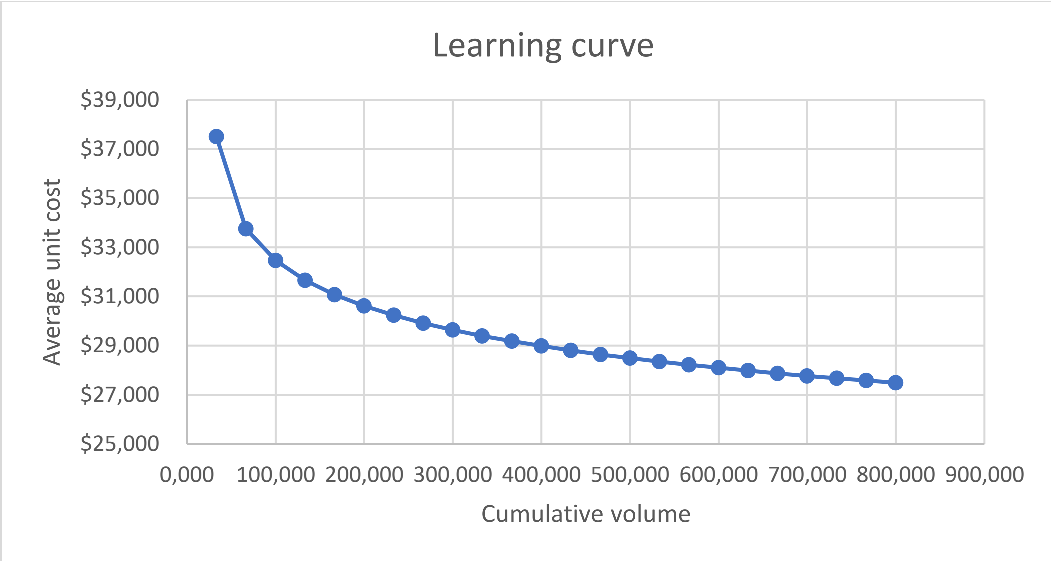

Figure 35: Learning curve

In addition to the financial savings, considering a fixed hourly wage of the resource, there was also a reduction in the time per document from 2 hours to 1 hour 28 minutes[65].

This model has demonstrated how the creation of routines to follow in order to complete a specific task leads to greater efficiency, which increases as more documents are produced, thanks to the resource's growing skilfulness.

4.2.4 Risk planning

Finding solutions to critical supply chain issues can be an excellent starting point for optimising the flow of goods, reducing costs and increasing quality, but it is not enough to limit risks as a well-organised plan is required.

For this purpose, specific tools from the Quality Engineering literature can be adapted and applied.

One of the first and main strategies used is *Failure Modes, Effects and Criticality Analysis*.

FMECA is a methodology used to identify, analyse and mitigate potential failures that may occur in a product, process or system. It is possible to recognise two parts:

- *"FMEA"* concerning the identification where a component, process or system may fail (failure modes) and the evaluation of the consequences of each failure (effects);

65 $\frac{27{,}491}{18{,}75} = 1{,}466\ h\ \rightarrow 1\ hour\ and\ 28\ minutes$

- *"C"* concerning the classification of failures modes identified according to their criticality.

There are different types of FMECA, which vary based on their purpose: Design FMECA is used to highlight and eliminate failures during equipment design, considering the entire life cycle of the equipment; Process FMECA is used to identify issues related to the manufacturing, operation, and maintenance of the equipment; finally, System FMECA takes a more general approach, identifying problems in large-scale processes. In this research a supply chain is to be analysed so a System FMECA must be used.

The analysis was carried out using a *top-down* approach, meaning a function-oriented method was applied at the highest possible level of system hierarchy, and in case a problem was identified, the analysis proceeded to the lower level.

At the highest level, the functions are represented, which correspond to the various steps of the supply chain. These functions may have different operational modes, referring to the different states of the system for that function. The lower level is represented by failure modes, which describe how the system fails, and are associated with one or more effects. These effects are assessed using a parameter called *severity* (*S*), ranging from 1 to 10, where 1 represents a minor failure and 10 represents a high-severity issue. Subsequently, the causes of the previously identified failure modes are determined. The causes are also classified using a parameter called *occurrence* (*O*), ranging from 1 to 10, with a negative connotation. Since some failure modes are more easily identifiable than others, the detection system is indicated. Its value is estimated using a parameter called *detectability* (*D*), which also has a negative connotation and ranges from 1 to 10. This parameter assesses the probability that a combination of failure mode and cause will be detected before the product reaches the final consumer.

To assess the risk of the various failure modes, the *Risk Priority Number* (*RPN*) was calculated:

$$RPN = S * O * D$$

Finally, depending on the previously proposed solutions and possible mitigation plans for the various risks, corrective actions were proposed.

The FMECA is shown below, Table 13.

Unique Ref.	Function	Operational Mode	Failure Mode	Effect	S	Failure Causes	O	Detection System	D	RPN	Corrective actions
1.1	Mango cultivation	Harvest	Plant diseases	Reduced yield and low-quality raw material	8	Lack of crop treatment	4	Diagnostic testing	3	96	Increasing the frequency of phytosanitary treatment programmes
1.2					8	Unpredictable climate change	3	Human perception	2	48	Improving irrigation systems and implementing temporary protective covers
2.1	Local transport	Road transport	Damage to mangoes	High raw material rejection rate	6	Inadequate local roads	9	Human perception	5	270	Identifying alternative routes and equipping vehicles with reinforced suspension
2.2					6	Poor packaging	7	Human perception	5	210	Using stronger materials and better load securing
2.3			Vehicle break-down	Delay in transport	3	Outdated and non-maintained vehicles	6	Human perception	3	54	Regular vehicle inspections with predictive maintenance
2.4					3	Adverse weather conditions	5	Human perception	2	30	Programming transport according to the weather forecast
3.1	Mango puree processing	Processing	Defective machinery	Low-quality puree	7	Worn-out components, poor maintenance	4	Diagnostic testing	6	168	Predictive maintenance
3.2			Machinery break-down	Delay in processing	3	Worn-out components, poor maintenance	4	Human perception	1	12	Predictive maintenance
3.3			Contami-nation during processing	Contamina-ted puree, food safety issues	9	Poor cleanliness of machinery	3	Diagnostic testing	6	162	Implement a more rigorous and frequent cleaning protocol
3.4					9	Improper handling of operators	5	Diagnostic testing	6	270	Better staff training through cooperatives
4.1	Storage in the plant	Preservation of the puree	Loss of puree quality	Loss of taste and nutrient values	9	High temperature pasteurisa-tion process	4	Diagnostic testing	8	288	Using innovative techniques for puree preservation, such as the use of essential oil of Mentha piperita
4.2				Deterioration of the puree	10	Poor processing of the filling machine	2	Diagnostic testing	4	80	Predictive maintenance
4.3					10	Hole in aseptic packaging	3	Human perception	2	60	Rely on quality suppliers and better monitoring of equipment before use
5.1	Transport to Dakar	Road transport	Road accident	Loss of load	10	Inadequate logistical infrastructu-re	9	Human perception	1	90	Consider alternative routes to diversify risk
5.2				Logistical delays	4	Inadequate logistical infrastructu-re	9	Human perception	1	54	Consider alternative routes to diversify risk
5.3			Customs stops	Logistical delays	4	Political instability	9	Human perception	1	36	Consider alternative routes to diversify risk

5.4					4	Incomplete customs documentation	7	Human perception	1	28	Preparing documentation in advance through increased collaboration between supply chain actors
6.1	Export from Dakar	Maritime transport	Customs stops	Logistical delays	4	Incomplete customs documentation	7	Human perception	1	28	Preparing documentation in advance through increased collaboration between supply chain actors
6.2					4	Overloaded port terminal	9	Human perception	1	36	Consider alternative routes to diversify risk
7.1	Final processing	Processing	Puree not conforming to standards	The customer detects the problem: return of goods from customers	6	Contaminated puree not identified in previous steps due to sample checks on an unrepresentative sample	4	Diagnostic testing	7	168	Replacing sample checks with continuous checks using non-destructive testing (NIRS) and control charts to control the process itself
7.2				The customer does not detect the problem: processes and delivers a low quality end product	10	Contaminated puree not identified due to sample checks on an unrepresentative sample	4	Diagnostic testing	7	280	Replacing sample checks with continuous checks using non-destructive testing (NIRS) and control charts to control the process itself

Table 13: FMECA

The results obtained from the FMECA must be evaluated to decide which mitigation plans to implement. Since it is not possible to carry out all the improvements at once due to economic, time and resource constraints, it is necessary to focus on the major risks.

Two tools can be used complementarily for this purpose:

- *Pareto chart*: a bar chart based on the RPN value for each unique reference to visualize all the data obtained and easily prioritize the highest risks. This technique suggests starting from the highest bar and working downwards (Figure 36).

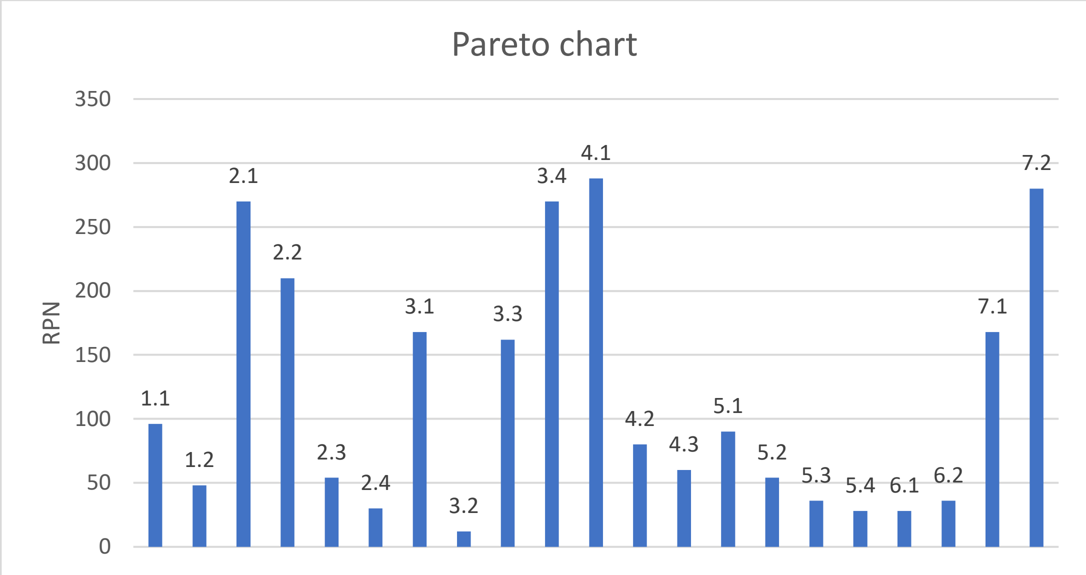

Figure 36: Pareto chart

The graph suggests starting from 4.1, 7.2, 2.1 and 3.4, which respectively represent the risks related to the loss of puree quality during storage, the failure of client companies to identify substandard puree, the possible damage suffered by the mangoes during transport to the production plant and the contamination of the puree during processing due to operator error. Solutions to these problems are described in the previous sections and can be found in the corrective actions column.

- *Risk matrix:* is a matrix expressing the risk associated with a failure mode as a function of its probability of occurrence *(occurrence)* and its potential effects *(severity).* The matrix is divided into three coloured areas: the red area represents unacceptable risks that require preventive measures, the yellow area represents acceptable risks that require further analysis and the use of *ALARP*[66] principles, and the green area represents acceptable risks that only require the application of *ALARP* actions. Since this matrix neglects the third dimension of risk, namely detectability, it is possible to represent the data with a bubble graph in order to represent all 3 parameters at the same time. The x-axis represents occurrence, the y-axis severity and the bubble dimension detectability (Figure 37).

[66] *ALARP* is an acronym representing a risk management tenet: 'As Low As Reasonably Practicable'. The principle involves considering risk reduction in relation to the costs, time and resources required to mitigate it.

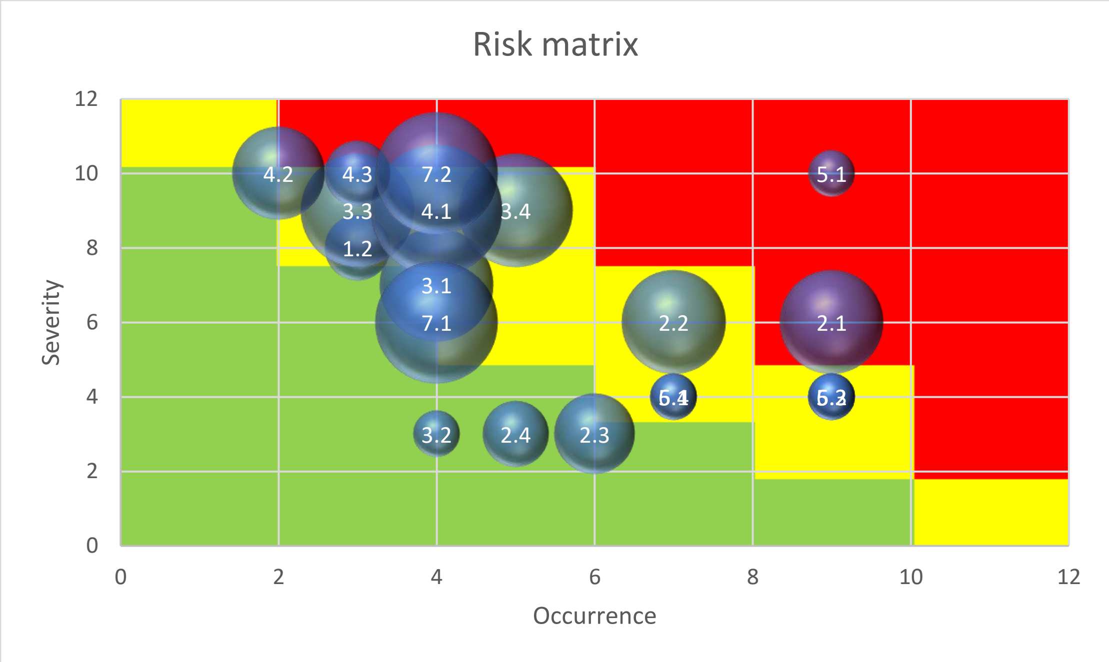

Figure 37: Risk matrix

The matrix confirms the need to take mitigation actions for the same references highlighted by the Pareto chart, and another previously unassessed risk emerges that requires a preventive plan due to its high severity and occurrence, i.e. 5.1: the risk related to accidents during transport by truck from Yanfolila to Dakar.

It can be concluded that, through the use of an analytical tool such as FMECA and the evaluation of its results, it was possible to assess the reliability of the supply chain and prepare a risk mitigation plan prioritising worst-case scenarios.

Chapter 5

5. Conclusions

The objective of this research was to analyse in detail the activities within the mango puree supply chain, its actors and their relationships, in order to identify criticalities and propose optimisation solutions.

After describing the research company and the activities carried out during the internship period, an examination of the entire system was carried out using two strategic tools: PEST and SWOT analysis.

The former was of fundamental help in framing the different external forces that can influence the supply chain, either positively favouring its growth or negatively weakening it. This analysis revealed: a political push towards the reduction of synthetic products, such as pesticides and chemical agents, and an increase in natural resources, the volatility of export tariffs, even though Mali can use an agreement with the European Union as an ACP country to its advantage, and economic advantages, such as cheap labour, but high logistical costs due to the location and infrastructure of the country of production. Demand characteristics have also emerged, marked by seasonal cycles with peaks in summer, and influenced by social factors, such as sociocultural norms that define standards related to product quality and food safety, including ISO 22000. Additionally, there is a growing consumer preference for organic, healthy products that ensure Fair Trade, i.e. sustainable and socially responsible trade towards workers and communities involved in the supply chain. In view of improvement and evolution, it has been emphasized to consider innovations and new technologies that can enhance production and logistics processes.

These results were used in the SWOT analysis to understand strengths, weaknesses, opportunities and threats within this system. The identified strengths include the quality of the raw material, namely mango, low labour costs, and sustainability. On the other hand, the weaknesses concern inadequate logistical infrastructure, which puts in danger transportation, climate instability that could damage crops, and political instability that could lead to the country being blocked both in terms of imports and exports. The analysis of opportunities has highlighted growth in the global market for mango-based products, which could lead to the expansion of the entire ecosystem and attract new investors. As for the threats, these are related to competition from companies in Asia and Central-South America, as they are the main producers of mango and therefore possess larger quantities, allowing them to leverage economies of scale. Additionally, the fluctuation in the prices of raw materials used in the supply chain, such as energy and fuel, poses another threat.

Having obtained these insights, the paper continues with a detailed analysis of the main critical points and then in the fourth chapter deals with solution proposals.

The first issue addressed concerns the actions related to the quality control of mangoes entering as input in the production plant and of the puree during the various steps of the supply chain. Specifically, critical issues were found as the initial inspection of the fruits is performed manually by employees, while for the puree, random sampling controls are used, which can lead to inconsistent results if the selected sample is not representative. These situations have been resolved by proposing the use of the NIRS technology, which allows for non-destructive testing on both the fruit and the puree. The use of non-destructive tests would allow for continuous monitoring rather than random sampling. For this purpose, an $\bar{x} - R$ control chart has been created to monitor the process variability, and the adherence of the produced puree to standards has been calculated by analysing a specific parameter indicative of quality and food safety, i.e. the BRIX degree. This solution would lead to higher product quality, but also to savings because it would reduce the risk of good batches not being accepted for the supplier and non-conforming batches being accepted for the customer companies.

Then the problems of logistical inefficiencies, related to the preservation of the puree during storage and the long transport time were addressed. The first issue is due to the technique used, i.e. pasteurisation, since, in addition to requiring a high use of energy which is an expensive resource in Mali, it can alter some nutritional values and key indices in the evaluation of the puree, as well as altering its taste. In opposition to this, a solution using natural resources, the essential oil of Menta piperita, was proposed. This alternative was tested on samples of mango puree with similar characteristics to the one from Mali for 15 days at 25°C, obtaining excellent results both in terms of bacterial and fungal growth, almost zero, and in terms of index changes, negligible with an essential oil concentration of 2.00-2.50 µL/mL. Instead, in order to remedy the long transport times, it was proposed to adapt the supply chain to a Lean and Integrated System, so as to increase the exchange of information between the various actors and to allow some activities to overlap. For an integrated system, it will be essential to continue improving the role of cooperatives, which serve as a key link between companies in the sector and farmers. An interesting project related to this is the digital mapping of crops across the entire region, which can bring benefits to the processing company in terms of traceability and production organization, as well as to farmers, in terms of equipment supply.

Another critical aspect that has been analysed concerns the high costs represented by indirect expenses related to maintenance, namely machine failures and breakdowns, and logistics. For the first issue, the transition from a time-based preventive maintenance policy to a predictive maintenance policy was proposed. Furthermore, a more detailed approach was taken to optimize by integrating predictive group maintenance with unscheduled opportunistic maintenance. Tests of this solution resulted in savings of around 15%-20% of total maintenance costs and a significant reduction in breakdowns. Logistics costs are high as they consist of three components: road, maritime, and a component related to risk in the event of unforeseen accidents that could negatively impact the economy of companies that manage transport. Given the impossibility of eliminating road and maritime transport, a way was found to reduce the costs associated with risk. To achieve this, a MATLAB model was developed to simulate the situation, and a new route was added to diversify transportation and dilute risk. This is because the probability of an unforeseen event for each container is directly proportional to the number of containers transported on that route. By adding the Conakry route to the existing Dakar route and transporting 90 containers and 110 containers respectively, a savings of over 5% was achieved. In order to decrease costs along the supply chain, during the research period the candidate actively participated in the creation of a procedures manual for the import-export company. This manual is aimed at the creation of company routines to improve the efficiency of the tasks related to the creation of bookings documents, through learning and increased skilfulness of the employees, resulting in cost and time savings per document. The cost of each document has been calculated on the basis of the time a resource is allocated to it. A mathematical model - Boeing-Crawford Experience Curve Model - was then used to represent the learning effect: over a time horizon of two years, savings of 26.69% per document were calculated.

As a final issue, the lack of a plan to deal with risks along the supply chain was addressed. A FMECA was proposed to identify and assess failures that may occur in the system. Each failure was evaluated by severity, occurrence and detectability, to obtain a risk priority number, and associated with possible corrective actions. These data were processed using a Pareto chart and a Risk matrix to prioritise the risks. The biggest ones turned out to be: the loss of puree quality during storage, the failure of client companies to identify substandard puree, the possible damage suffered by the mangoes during transport to the production plant, accidents during transport by truck from Yanfolila to Dakar and the contamination of the puree during processing due to operator error.

Although a holistic view has been maintained throughout the paper, research has been limited by the last step in the supply chain, i.e. the final processing performed by the customer and the subsequent distribution to the end consumer. This limitation was due to the fact that it was not possible to access precise data of these companies and the processes they carried out in this specific industry.

However, the results obtained are still considered significant and highly beneficial for optimizing the entire system. This study could serve as a starting point for further research, not only due to the proposed solutions, but also thanks to the detailed analysis that was conducted.

The work could be enhanced by conducting an analysis of the process used by the reseller companies for the puree and by establishing statistical quality controls to monitor this step as well. As future developments, beyond the proposed optimizations, the work initiated within the company on the creation of the procedure manual could be continued, involving other stakeholders in undertaking this process to establish standardized and efficient routines across all steps of the supply chain. These should always be accompanied by mitigation plans, as routines are efficient only under consistent conditions. In the event of changes, dynamism is required, which would be supported by appropriate risk planning.

In conclusion, the research has made it possible to understand, analyse, evaluate and improve certain processes that allow the connection of rural areas to international markets, promoting a sustainable ecosystem.

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