POLITECNICO DI TORINO

Engineering department
Master's Degree
in Management Engineering

Master's Degree Thesis

Development of a calculation model for materials management using DDMRP (Demand Driven MRP)

Company: Syd Laboratorio Cosmetico SAS

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Acknowledgments

I am grateful to my family, who have always believed in me, giving me an example of self-improvement, humility and sacrifice; teaching me to value everything I have. This thesis is dedicated to all of them because they instilled in me the desire to excel and triumph in life, which has contributed to my success. I hope I can always count on their valuable and unconditional support.

I am very thankful to the Politecnico di Torino University and my supervisor for the training and knowledge that enabled me to complete this achievement to the best of my ability. Thanks to Syd Laboratorio Cosmetico SAS for allowing the realization of this initiative in their installments.

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Motivation

There is currently a major movement in companies to develop and implement process optimization and continuous improvement. As in any business, this effort is difficult without the application of methodologies that provide the necessary foundations and tools to achieve the scopes and the goals set within the organization.

MRP was designed in the 1950s, the associated software was developed in the 1960s, and has since become the dominant planning principle in manufacturing around the world. Today, MRP calculations can be found in any ERP system available on the market.

Over the years since the inception of MRP, the business context has fundamentally changed from local to global procurement, with increasingly demanding customers, significantly shortened product life cycles, and a shift from an overdemand to an oversupply environment. All of the above create new challenges that make MRP simply not fit for today's business needs. As a consequence, many companies operate in reactive mode. With MRP, products are manufactured against an uncertain forecast, which inevitably leads to a combination of shortages (stock-outs = lost sales) and overstocks (financial cost overruns). Promotions and price cuts are used to eliminate excess inventories. As a result, sales and customer loyalty suffer, and profit margins are squeezed.

The DDMRP methodology was developed in response to the context described, as an extension to the obsolete MRP, but designed to deal with today's reality. It will support the transition to a proactive state in which companies position inventory buffers to reduce lead times and ultimately become truly demand-driven and with a Pull Approach.

Several problems have been identified with the current materials management system at Syd Laboratorio Cosmetico SAS. The current system would benefit from a reduction in inventory levels but above all will have high visibility and usability of the system that shows exactly what they need to do during the day, focusing their attention first on the most critical items.

Introduction

The cosmetics industry is one of the economy's fastest growing sectors. The improvement of physical appearance to achieve certain stereotypes creates a need for consumption, leading these companies to sales figures unattainable in many other industries. The growing trend towards product customization has caused more and more FMCG (fast-moving consumer goods) companies to diversify their products. This results in a large number of SKUs (stock keeping units) that must be managed precisely to avoid product overstocks or shortages and increase company costs.

This thesis looks at the case of a company whose inventory planning is insufficient for future growth and could be greatly improved. At the same time, it has inventory management issues, resulting in excessive inventory costs. Consequently, management must conduct a detailed review of current logistics processes and methodologies to determine which methodology can be applied to the current tools and resources to reduce excess inventories and avoid the risk of demand losses.

To begin, the conceptual framework introduces the reader to the fundamental concepts of planning and supply chain, allowing them to focus on the execution scenario of the Demand Driven methodology. At the same time, the benefits of implementing the Demand Driven methodology in organizations will be presented.

Subsequently, the principles of the methodology and the main characteristics of its execution will be explained; the basic rules, the steps for its execution and the results expected with its implementation. Likewise, various opinions of authors will be presented, as well as cases or theories developed.

After providing the reader with enough tools to understand the methodology, real measurements will be recorded to model the production process of the case study. In time samples and data collection, we will seek to expose the current situation of the company. With this, the step by step of the applied methodology will be developed for the case study company, justifying and explaining theoretically the different steps for the reader's understanding, in such a way that it can be applicable to other operations.

Then the simulation will be performed under the Demand Driven MRP methodology model. It will be compared relevant metrics as the stock level and unsatisfied demand according to the product selected for the study. Moreover, it will be necessary to calculate the buffer levels, the net flow equation and seek to expose the associated inventory costs or demand losses that affect directly the company's profits.

Lastly, results applicable to the specific company will be delivered to facilitate the decision making of the planning manager that will allow the company to have a flexible structure to the continuous demands of consumers in order to be more profitable and compete in the market with price and quality.

Thesis purpose

Develop a Demand driven MRP model for the production planning of the Hair dye line in the company Syd Laboratorio Cosmetico SAS.

Objectives

The objectives of the thesis are described in the following table.

Objectives	**Method/Tool**
Perform a diagnosis of the production planning program of the hair dye line of SyD Laboratorio Cosmetico SAS, in order to identify the critical variables to be included in the DDMRP model.	● Five Ws method - Interviews ● Techniques of work measurement
Design and develop the DDMRP model to define the production and inventory plan for the hair dye line. Apply and develop the Demand Driven Inventory Management methodology to determine the aspects that expose its benefits.	● Engineering and operations analysis ● The five components of DDMRP ● Mathematical modeling
Perform real measurements in pilot categories of the historical stock level of different SKUs and compare it with the theoretical stock level proposed by the Demand Driven methodology, in order to analyze results, costs and associated benefits.	● Quantitative data analysis - Excel ● Statistical tools - Minitab software

Develop a Monte Carlo simulation model to evaluate the results of DDMRP in the hair dye production line of the company SyD Laboratorio Cosmetico SAS.	● Monte Carlo simulation model - Anylogic software
Perform a cost-benefit analysis of the use of the DDMRP model in the production line of hair care products. Expose the variation of inventory costs (storage - risk - opportunity) when using the Demand Driven methodology with respect to the conventional methodology. Expose and analyze the cost associated with the loss of service level with both methodologies and the cost associated with inventory obsolescence.	● Cost-benefit analysis
Develop for the pilot company the step-by-step of the applied methodology, justifying and explaining theoretically the different steps for the reader's understanding, so that it can be applicable to other operations and to provide the management of the organizations with another possible tool in the decision-making process related to inventory management.	● Synthesis and data analysis

Research plan

The following is the Gantt chart with the plan/to-do of the thesis in object. The time was distributed between October 2021 and September 2022.

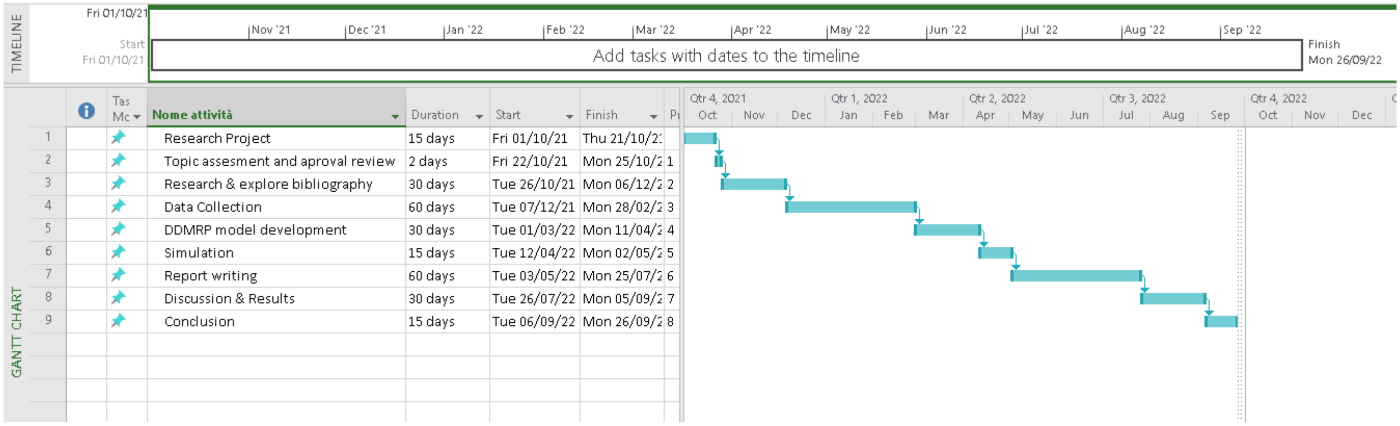

Figure 1. Gantt chart in Microsoft project.

The planning of the work is distributed in a sequence of activities that depends on the completion of the previous activity. it is based on the 8 main activities carried out for the development and completion of the thesis.

Literature Review

Several authors have proposed different approaches to reduce inventory levels and increase customer service levels. These approaches consist of implementing different inventory policies, designing heuristics, and optimization models. In the first instance, the different inventory policies were analyzed. These should establish how often the inventory should be reviewed, when to order and how much to order, either independent or dependent demand items. The policy estimation methodology to answer these questions can vary significantly due to two aspects: the type of product (finished product or raw material) and the production environment.

Ketzenberg et al. develop a heuristic model for the common production and inventory problem. The problem consists of products with stationary and stochastic demands, many sales, and different constraints throughout production. Here they attempt to answer three common questions that arise in these environments: when to start producing more than immediate needs in anticipation of high demand seasons; how to schedule inventory build-up for products; what to produce when current capacity constraints may result in immediate shortages. The authors conclude that the use of heuristics is fundamental in calculating optimal policies for real systems, as they argue that it is impossible to do so exactly. (Ketzember,Metters & Semple, 2006)

In the work developed by Kapuscinski et al., a management system is designed for the decision making of inventories in the supply chain of Dell Computers. This company does not handle finished product inventories and recognizes that it must focus its efforts on the control of components. For this purpose, an inventory control model is developed, which, through the application of forecasting techniques for the management of independent demand and by analyzing the replenishment times between the nodes of the chain, defines the safety inventory levels of the components. An Excel tool is also created for the implementation of control methods (Kapuscinski, Zhang, Carbonneau, Moore, Reeves, 2005).

Contrastingly, in research by SMEs (Small and Medium Enterprises) to become sustainable in the medium and long term, production planning systems using the MRP methodology have become the solution for many organizations. The MRP concept, developed by Orlick (Ptak & Smith 1994) around 1975, broke the paradigm of the MRP models. Production planning systems using the MRP methodology have become the solution for many organizations.

Based on the Order Point policies, A planning and control system for inventory, manufacturing, and scheduling is known as material requirements planning (MRP). This methodology transforms the master production schedule into a detailed schedule so with it may buy components and raw materials. This approach, which is primarily used in the manufacturing and fabrication sectors, is a push form of inventory control, meaning that businesses utilize forecasting to identify client demand for products. The manufacturing or fabrication business will project the number and kind of items it will buy, as well as the quantity of raw materials needed to make those products. It then urges the consumers to buy the merchandise.

For companies to remain competitive, it is necessary to define a methodology to estimate inventory control policies for finished products and raw materials along the supply chain, considering the randomness of the demand for finished products and the supply times between stages of the chain. Although there is currently a set of models and solution methods to support inventory system decisions, a clear and unified methodology is required to provide such support.

The Demand Driven MRP Institute proposes an innovative solution that takes into account the adversities faced by an organization in today's globalized and competitive environment. DDMRP emerged with the objective of mitigating the effects of variability and volatility in production operations and in the supply chain, to foster visibility and speed. This model is a fusion of MRP and DRP (Distribution Requirements Planning) tactics combined with the 'pull' philosophy and signals from Lean and TOC (Theory of Constraints). DDMRP includes innovations in the field of planning and execution to obtain improvements in lead time compression and visibility during execution. It takes the Lean focus on waste reduction and visibility into execution and accompanies it with a new set of demand-driven planning tactics that bring a new dimension to visibility into planning across the entire enterprise and supply chain (Ptak & Smith 2016).

In contrast to the above, Ptack, in his book Demand Driven Requirements Planning, presents the first implementation of DDMRP in Latin America in the company Maquila Internacional de Confecciones (MIC). In the preliminary analysis it was found that the company had unsatisfactory service levels, constant shortages of raw materials and finished product due to purchasing, production and distribution decisions based on inadequate demand forecasts. In addition, it had long lead times to market, excessive amounts of work in process (WIP) inventory used to maximize production efficiency and constant conflicts between sales and production. The proposed model for the company was based on two fundamental propositions of DDMRP: strategic inventory positioning and determination of appropriate buffer sizes. Control buffers were placed on new product launches. These were adjusted according to production lead time and expected demand in each period. For purchased raw materials, which had long lead times compared to the planning horizon, strategic buffers were placed to mitigate variability in raw material availability. The buffer levels were calculated considering the average daily usage, the lead time and the minimum quantity to be launched to the market. The implementation of the model generated a 60% increase in sales, a 40% decrease in inventory cost overruns and the percentage of unfulfilled demand due to shortages was reduced to 2%.

The inventory models that have been studied are useful to solve similar problems presented by Syd Laboratorio Cosmetico SAS. The mathematical models that use different types of linear, mixed and other types of programming generate optimal solutions, however, many of them are not the most appropriate to implement in the company due to their complexity. ERP systems that implement MRP are able to efficiently integrate all areas of the organization, but do not consider the use of buffers, which leads to shortages and excess inventories. Finally, theoretical models such as Lean Manufacturing and Just-in-

Time lack visibility into the actual flow of materials through the supply chain. Lean is designed to make everything independent and does not consider the dependencies that exist between processes. Therefore, the DDMRP model is the one that best meets the current needs of the company Syd Laboratorio Cosmetico SAS, on which this thesis will be focus.

Testimonies on the effectiveness of DDMRP

The DDMRP Institute website includes testimonies from businesses that have used DDMRP to completely transform their planning processes. Aerospace, automotive, bio-tech & pharma, construction & building supply, consumer products, distribution, electronics and technology, hospitality, petrochemical and many other industries are all represented by the companies in the case studies. Some relevant company testimonials for the case study are listed below, explaining briefly the advantages brought about by the deployment of the DDMRP.

The demand for cosmetics and beauty products is becoming more volatile, there is intense pressure to shorten lead times, and product renewal rates are rising. The entire value chain is under threat from this tendency. With a combination of lean and demand-driven initiatives, ALBEA decided to create an agile supply chain as a solution to this problem. As a result, it has reduced lead times from three to one week, eliminated shortages at customers' filling lines, reduced inventory liability, and achieved 100% customer satisfaction.

In an extremely dynamic internal and external environment, DDMRP provided inventory reductions of 30%+, lead time reductions to the distribution network of more than 50%, and service levels of 9+% for Allergan, a $7+B pharmaceutical firm and manufacturer of Botox. from the Global Online Seminar Series 2015 for Demand Driven World.

Peláez Hermanos SA was able to dramatically increase its profitability and competitiveness by implementing the Demand Driven Operating Model. Despite the industry's complexity for spare parts and the high degree of demand unpredictability with extremely long lead times from its suppliers. They have more than 30% fewer working capital inventories now. This has made it possible for their business to pay off debt and make new investments. Now that they are debt-free, they can compete and succeed in a challenging market.

Coca Cola Beverages Africa manufactures Coca Cola bottles and is in charge of 40% of the continent's total production. Demand and supply planning expert claims that the SKU-level forecasts were only 60% accurate and therefore unsatisfactory; after implementation, there was a decrease in the number of stock-outs and an improvement in the percentage of on-time deliveries from 70% to over 80%. The implementation allowed for a shift in focus away from improving forecast accuracy and resulted in a 29% reduction in working capital.

One of the top producers of kitchen appliances (ovens, refrigerators, etc.) in Colombia is Haceb, which is also a key partner for Whirlpool there. Results of the DDMRP include a 96.2% service level, a 27% rise in revenues, a 12% decrease in inventory, an 80% decrease in stock-outs, a 12% decrease in transportation costs, and a 40% decrease in finished goods returns.

ACESCO, a leading company in Colombia, manufactures and distributes flat and galvanized steel materials primarily for construction and industrial applications. ACESCO's demand-driven operating model reinforces its 50-year continuous commitment and focus on its customers, helping it to maintain the desired levels of operational excellence for business sustainability in the complex and extremely uncertain global steel landscape. Some of the results of the DDMRP implementation were that market conditions favored a 13% increase in sales, which allowed for a 19% decrease in inventory and a 17% reduction in lost sales.

Research Methodology

In the first instance, for the diagnosis of the production planning program of Syd Laboratorio Cosmetico`s hair dye line, a detailed investigation of the current planning process was carried out, where the methodology implemented by the company and its performance were studied. This study identified the main characteristics that give rise to possible weaknesses in the current model.

The criterion for the selection of the items was the historical demand and the unfulfilled demand from January 2017 to June 2022. Based on this information, a pareto diagram was made, identifying the most sold and most unfulfilled item.

To gather information on the production process of the selected pareto product, the target sample size was calculated using the following equation:

$$n = \frac{z_{\alpha}^{2} \times \sigma^{2}}{e^{2}}$$

where:

$\boldsymbol{z_{\alpha}}$= value from the table of probabilities of the standard normal distribution for the desired confidence level (Z = 1.96 for 95% confidence)

σ^2= the variance was obtained by taking the first process times.

e= error percentage (5%).

This formula derivates of The Central Limit Theorem and is used to determine the sample size in studies where the goal is to estimate the mean of a continuous outcome variable in a single population.

By substituting the values:

$$n = \frac{1.96_{0.05}^{2} \times 0.25^{2}}{0.05^{2}} = 99.92 \sim 100$$

The result obtained was 99.92, approximately 100 samples.

The industrial facility in Cali, Colombia, was visited on three separate occasions to gather information. At each stage of the process, 100 samples were taken during these visits, and the plant management and operators were questioned. The hair dye line's process flow diagram was modified based on the information gathered, and the manufacturing process was examined to see if there were any critical issues that could result in non-compliance with the planning. The factors that might be included in the DDMRP model were obtained using the data collected; nevertheless, a priority matrix was created to identify the crucial variables. Lastly, the critical variables and process times were classified as stochastic or deterministic, in order to establish the characteristics of the input data of the simulation and in the case of stochastic variables to establish the probability distributions.

Subsequently, to define the weekly production and inventory plan for the hair dye line, the DDMRP model proposed in the book Demand Driven Requirements Planning was used. The

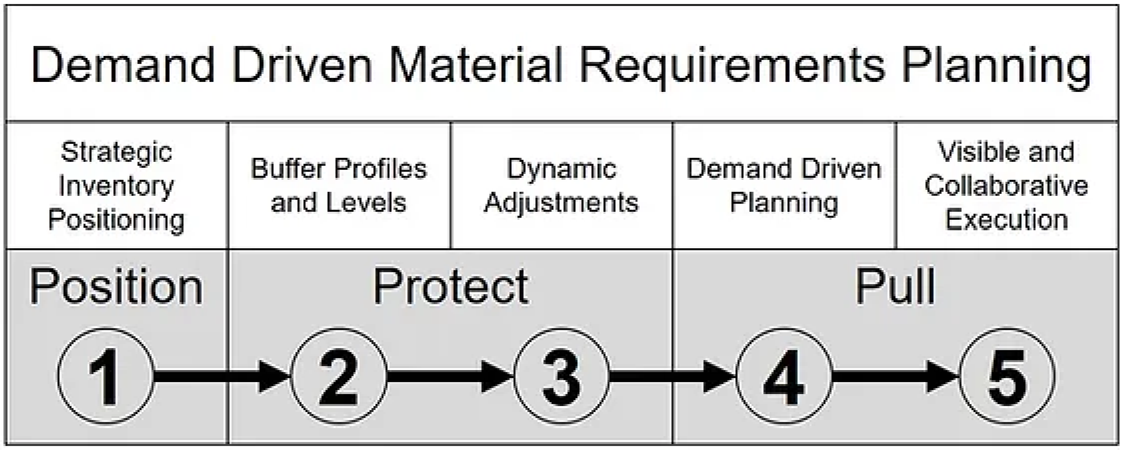

Figure 2. Demand Driven Material requirements planning. *Ptak, C. & Smith, C. (2016). Demand Driven Material Requirements Planning DDMRP version 3.*

With the Demand Driven MRP the critical points that must be protected within the supply and manufacturing processes were identified, for this a detailed analysis of the following factors was performed:

- Tolerance time of customers, this is the time the customer is willing to wait before looking for an alternative source to supply their demand.
- Time it takes for the company to reach the market with its products, known as Potential lead time of the market.
- Order visibility horizon of orders.
- Demand and supply variability.
- Protection of critical operations.
- Lead time for each raw material or product produced.

The critical points are protected through the location of decoupling points, these refer to the places where the inventory is strategically located to create independence between processes and consequently comply with the orders. To ensure the proper functioning of the decoupling points, a mechanism was implemented to mitigate the effects caused by demand and supply variability called quantity buffer; for the control points, time buffers were implemented to protect the production order schedule and capacity buffers to control the production rate in case of being affected by variability.

To establish the location of the quantity buffers, material explosion diagrams were designed for each item analyzed and a material correlation matrix was created. Based on the location of each buffer, the critical path was established to determine the lead time for each part and finished product. This time is known as decoupled lead time and allows that the variability of the supply of raw materials does not alter the lead time of the finished product. Therefore, the decoupled lead time was calculated only taking into account the processing times. It is important to emphasize that a rigorous control of each buffer must be exercised to ensure that the processes within the chain are stable.

Once the quantity buffers were positioned, the factors that have the greatest impact on the calculation of the size of the zones were determined, which are: the demand variability factor and the lead time factor. For this purpose, the ranges established in the Demand Driven Requirements Planning book for raw materials and finished products were considered. According to the relevant classification of the lead time and variability level for each raw material and finished product, the factor values were chosen.

Then, the individual attributes that characterize each raw material and finished product were established; the main attributes are:

- Average daily usage (ADU): this is a dynamic attribute since it depends on demand behavior. It is obtained using a forecasting method for trendless demands, called moving average.
- Decoupled lead time (DLT): production time for each part.
- Minimum order quantity (MOQ): quantity established by the supplier for each raw material.
- Demand order cycle (DOC): time elapsed between order placement.

Then it proceeded with the calculation of the quantity of buffer zones based on the DDMRP model as shown in the following figure.

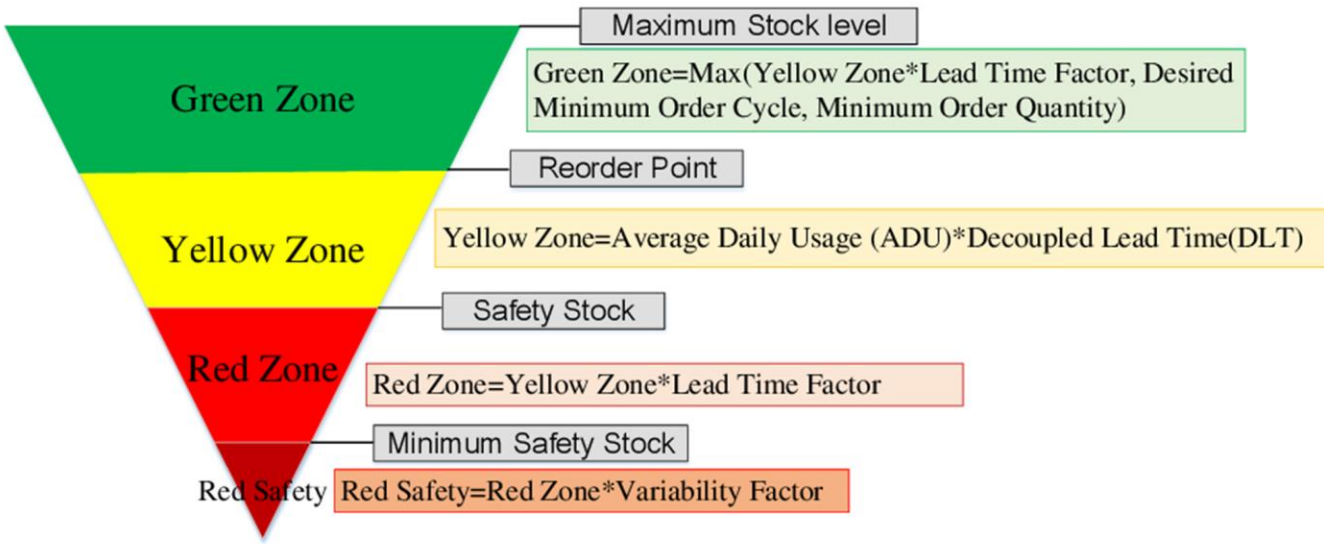

Figure 3. Part buffer calculation. *Ptak, C. & Smith, C. (2016). Demand Driven Material Requirements Planning DDMRP version 3.*

The first, the green zone, is used to determine the frequency and size of the orders. This was obtained by selecting the result of the method with the highest value. The methods used were the calculation of the order cycle time, the lead time factor and the minimum order quantity. The yellow zone indicates the time to place orders and was calculated using the lead time factors and the average daily usage. The third, the red zone, generates alerts indicating that the inventory will be depleted very soon and is divided into two components: the base and the safety base. For the calculation of these, the average daily usage, the lead time factor and the variability factor are taken into account. Based on the calculation of the zone sizes, the upper levels of each zone were calculated: green upper level (TOG), yellow upper level (TOY), red upper level (TOR). The following table shows an example of the relevant calculations to obtain the size of the zones and upper levels of each one.

Parameter	Unit of measure	Zone	
Average Daily Usage	Units		**Max (LTf, MOQ,MOC)**
Buffer Profile	(P,M;D;S.M.L;L,M,H)		Lead time factor
Minimum order quantity (MOQ)	Units		MOQ
Demand order Cycle (DOC)	Days	Green Zone	Minimum order cycle
Decoupled lead time (DLT)	Days	Yellow Zone	**DLT * ADU**
Lead time factor	%		**Base + Safety stock**
Variability Factor			Base
	%	Red Zone	Safety stock

Table 1. Part buffer parameters.

Based on the proposed model for the production planning of the hair day line, a Monte Carlo simulation was performed. Given the characteristics of the model, it was decided to use AnyLogic software. For the selection of the software, an investigation was made about the alternatives that exist in the market. The selection criteria were: the scope and restrictions of the free versions of each of the alternatives, the quality of the graphic animation and the level of complexity of the user interface. In making the comparison, it was found that AnyLogic allows users to extend the simulation models with java code. This makes it easier for the user to make modifications to the model, also visual environments can be created that make it easier to understand the models.

For the creation of the Monte Carlo simulation model under the DDMRP methodology, the diagnosis of the current production planning schedule and the DDMRP design for the hair dye line were taken into account. Additionally, a two-year simulation time frame was established. Considering that from the first to the fourth month, the model must adjust to the input data; from the fifth to the ninth month, the model stabilizes and from the tenth to the twenty-fourth month, the behavior of the model with respect to future demand is observed. Therefore, for the first year of simulation, the actual demand for the years 2019 and 2021 were used and for the second year, based on the probability distribution that follows the actual data, a stochastic demand was generated. On the other hand, to determine the probability distribution of the variables, a data analysis tool known as Minitab software was used.

Finally, by means of a financial analysis, the use of the DDMRP model in the selected production line of the company Syd Laboratorio Cosmetico SAS was evaluated. The analysis was performed based on the results obtained in the simulation and the current performance of the company.

To measure the financial impact, first, the inventory costs incurred by the company in the year 2021 under the current model were calculated. Then, for the year 2022, it was worked under the assumption that the cost structure will be similar to that of last year.

The inventory cost was calculated as the sum of storage costs and maintenance costs. Other fixed costs such as rent and salaries. Similarly, variable costs such as raw materials and other utilities were also taken into account. It is important to highlight that a lot of raw materials are shared in several products of the hair dye line, therefore, for the calculation of the actual costs, an average of the costs per item unit was considered. In addition, the losses generated by unmet demand were obtained by multiplying the profit obtained from each reference by the non-compliant units.

As result, a benefit/cost analysis of the implementation of the DDMRP model was performed that contains the calculation of the net present value (NPV) and the benefit cost ratio (BCR) analysis.

Simulation of the planning model under DDMRP

First, the process flow diagram corresponding to the planning process under DDMRP was designed Figure 20. After that, the following data sets were created:

[j] = Final goods (0, 1...3}
[i] = Raw materials (4,5…50}

Then, the following variables and parameters were declared to develop the proposed model:

Parameters

- Minimum quantity to order
- Decoupled Lead time
- Demand order cycle
- Lead time factor
- Quantity of raw material according to item

Variables

- Variability factor
- On hand inventory
- On order inventory
- Demand
- Net flow
- Quantity to order
- Average weekly usage

Then, the following functions were created to run the model:

- Initialization: in this all the initial data were entered which take the parameters and variables of each of the sets. This function is only used at the beginning of the simulation.
- Buffer calculation: this function performs the operations required to obtain the values that indicate the buffer levels. The operations are:
- Average weekly consumption calculation
- Variability factor calculation
- Calculation of the upper levels: red, green and yellow.
- Order generation: this function generates the number of units to be ordered for each raw material and finished product, by means of the following operations:
- Net flow calculation
- Quantity order calculation

The functions, buffer calculation and order generation, are performed weekly for the 50 buffers. In the DDMRP model created in AnyLogic software, a control chart was designed based on the design established by the DDMRP model. In this chart, the status of the model can be visualized at the level of inventories, demand and supply orders at any instant of time. Finally, for the measurement and analysis of the behavior of the model with respect to time, a graph was created for each of the established performance indicators.

Description of the simulation model and the rules applied

To obtain the number of simulations, the necessary simulations were performed until the range limits of the service level data remained at a service level of 97%. This happened in week 12. Then, after 12 runs of the simulation model, the results obtained were documented and analyzed against the historical performance of the company's current planning model.

Performance requirements

The design of the DDMRP model for the Bentouch hair dye production line meets the following performance requirements.

- **Benefit/cost analysis of DDMRP model implementation**

$$\frac{DDMRP\ Benefits}{DDMRP\ Costs} > 1$$

The resulting design should bring a decrease in inventory cost overruns and an increase in service level through the implementation of the DDMRP model.

$$Inventory\ turnover = \frac{Demand}{On\ hand\ inventory}$$

$$Inventory\ cost = Cost \times Average\ on\ hand\ inventory$$

The Monte Carlo simulation of the DDMRP model should yield inventory performance indicators such as:

- **Service level**

$$1 - \frac{expected\ value\ of\ shortages}{expected\ value\ of\ the\ demand}$$

- **Percentage of unfulfilled demand**

$$1 - \frac{unfulfilled\ demand}{demand}$$

- **Percentage of excess inventory**

$$1 - \frac{unfulfilled\ demand - on\ hand\ inventory}{on\ hand\ inventory}$$

It is important to consider that in order to meet the demand the on-hand inventory must be greater than or equal to the demand. Additionally, the DDMRP model establishes that the excess inventory should be calculated as following.

$$\text{Excess inventory} = \frac{on\ hand\ inventory - Top\ of\ yellow\ (TOY)}{Top\ of\ yellow\ (TOY)}$$

Performance tests

The probability distribution identification test was performed to measure the actual demand behavior of the products to be studied. This in order to identify the behavior that best fits the data. For the analysis, a confidence level of 95% was taken into account, where the results obtained indicated that the real data follow an exponential probability distribution. The goodness-of-fit tests are shown in Annex 2.

Restrictions

The following restrictions were implemented in the simulation model to ensure the feasibility of the DDMRP design.

- **The storage capacity of inventories**

$$\sum_{i=0}^{46} On\ hand\ inventory\ \times Volume(i) + \sum_{i=47}^{50} On\ hand\ inventory \times Volume\ (i)$$
$$\leq Storage\ capacity$$

i= raw materials $\{1,2...46\}$

j= finished products $\{47 \ldots 50\}$

$$\forall i, j \in I$$

- **The production capacity of the process**

$$\sum_{k=20}^{41} Order\ quantity\ (kl) \leq Production\ capacity$$

k= number of working days $\{1,2 \ldots 7\}$

l= items $\{1,2 \ldots 50\}$

$$\forall k, l \in I$$

- **The number of workers they have for the production of the line of hair dyes**

$$number\ of\ employees\ required\ (l) \leq Number\ of\ employees\ available$$

l= items $\{1,2 \ldots 50\}$

$$\forall j \in I$$

Standard Compliance

The basic components of a system in a simulation model are as follows:

a) **Entities:** Set of raw materials and set of finished product references.
b) **Attributes:** Parameters
c) **Activities:** Functions that allow weekly results to be obtained.
d) **System states:** The system state is represented in the different levels of the buffers.
e) **Events:** Every week there is an event generated.

These components are adjusted in the design of the DDMRP model for the hair dye production line of the company Syd Laboratorio Cosmetico SAS.

Selection of products for the case study

The company's portfolio consists of 11 products of which the products with the highest sales and rotation according to a Pareto analysis (see figure 4) are; Hair dyes, Bleaching Powder, Repairing Hair Treatment, and Shampoo Mix. The Pareto analysis shows that the Hair Dyes, Bleaching Powder, and Repairing Hair Treatment lines account for 70% of the units sold in 2021. Additionally, it is expected that the hair dye line will have a sales growth of up to 13%, putting itself in the line with the largest percentage of units sold, according to a sales prediction that was also created using these data for the years 2022 and 2023. In light of this, a study was done on the hair dye line's behavior in 2021, and it was noticed that 6210 out of the 42891 units demanded were not provided, which is equal to 14.47 % of unfulfilled demand. Consequently, for the case study of Syd Laboratorio Cosmetico SAS, it was decided to focus on the line of hair dyes.

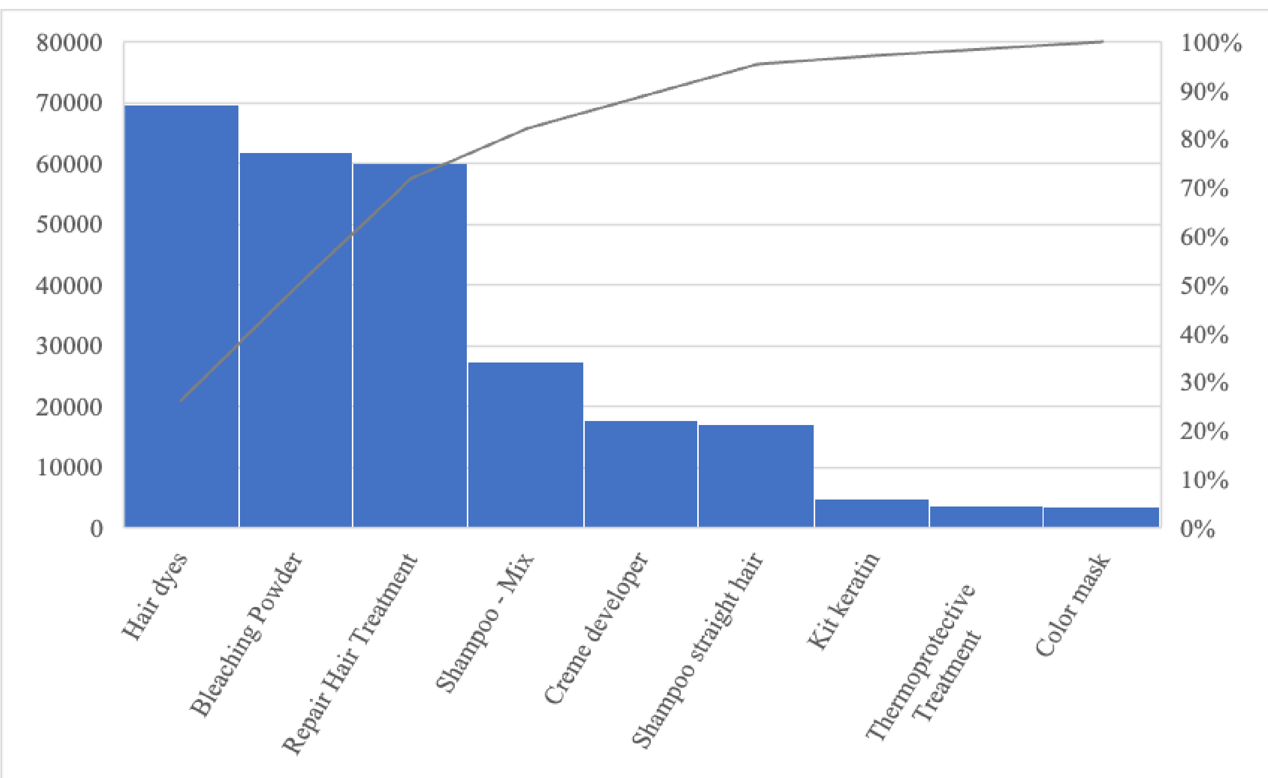

Figure 4. Units sold by product in 2021.

Production Strategy

It is important to know that the company manages the Make to Stock (MTS) strategy since it maintains a steady inventory and schedules manufacturing as items become unavailable. However, only items of the production machines (primary ingredients) are made to order (MTO). The system where a production is carried out prior to receiving an order is typically referred to as "Make to Stock" when considering a production plan from the perspective of order time. With this approach, the specifications are established based on an understanding of the customer's needs in advance, and engineering, purchasing, and manufacturing are each carried out in turn. Once production is complete, the finished goods are distributed to each order. Following engineering, the purchasing and production stages are repeated until the product's life cycle is complete. Since there is no direct connection between the receipt of an order and its production in the Make to Stock system, the production plan is created in accordance with the quantity determined by the demand prediction. Additionally, there is a product's inventory that sits between demand and production, thus at a factory it is feasible to equalize cycle variation or seasonal variation and carry out stable production.

Company overview

Syd Laboratorio Cosmetico SAS is a Colombian company that manufactures, markets and maquila hair cosmetic products with the highest quality standards. It has a national presence with constant growth through its authorized distributors in the main cities of the country as Cali, Medellin, Bello, Itagui, resulting in greater coverage and brand recognition.

As well, it is very important for the company to open new markets and customers. Its products are exported to other countries such as Panama, Costa Rica, Venezuela, Ecuador and now the United States. The company is in charge of fulfilling and satisfying the needs of its clients.

History

SYD Laboratorio Cosmetico SAS was born in 2007. In the beginning, the company used third-party laboratories to manufacture its products. These laboratories, known as maquilas, were in charge of taking the raw materials and producing each of the hair products. In the meantime, SYD Cosmetic Laboratory was in charge of marketing them and finding customers in the cosmetics industry.

In 2014 in Bogota, Colombia, the company built its own plant for the manufacture of the Bentouch product line. At the same time, it also continued with the third-party manufacture of some products that generated higher profitability with outsourced laboratories.

In 2015 they began exporting their products to Ecuador and in 2016 to Costa Rica and Panama. In 2017 they located in the city of Cali, Colombia and expanded the manufacturing plant to generate a massive production, with this increased capacity they began to produce by tons and hundreds of units of product. Today they have their own facilities in Yumbo with 1500 square meters and 25 employees.

Mission

To provide women with quality hair products that strengthen and restore the vitality of their hair.

We are a national company focused on the development, manufacture, production and marketing of cosmetic products mainly in the hairdressing and hair care market.

Vision

To be recognized as one of the leading hair cosmetics companies by 2030.

Audience

Women of all ages and men who want to dye their hair.

What makes the company unique

The trajectory that the company has had in the professional hairdressing market and shops specializing in beauty products has allowed it to strengthen the processes of development, manufacture, production and marketing of beauty products. As a brand it was founded in 2014, however its professional staff has more than fifteen years of experience and knowledge in the hair health, hairdressing and cosmetics market. In addition, by having its own laboratory, it has been able to venture into advanced developments through the technology of new products, guaranteeing their quality.

Product lines

- **Bentouch mix**: It is a mixed channel with multi-channel services such as: grocery stores, supermarkets, minimarkets, drugstores, self-service stores. They represent 30% of production.

- **Bentouch professional use:** This is the professional line for beauty shops and academies. It is the one that represents the most for the brand with 70% of the production.

Product portfolio

These are the Products that SYD cosmetic laboratory sells and manufactures:

- Hair dyes: Permanent hair coloring with or without ammonia.
- Bleaching Powder.
- Creme developer.
- Repair hair treatment.

- Kit Keratin treatment and Keratin shampoo.
- Shampoo Mix: Shampoo without salt.
- Shampoo with argan oil.
- Color mask.
- Thermal Protective Treatment.

Star product

Repair hair treatment: It not only serves as a conditioner, but also brings many benefits to the hair. It seals the cuticle, protects the hair from the effects of the sun and heat. The moisturizing and nourishing properties of Elastin and Panthenol increase the hair's natural shine and elasticity. Vitamin E has an antioxidant effect that helps to strengthen the hair fiber against breakage and repair damaged hair. Its conditioning ingredients reduce resistance to brushing, provide an anti-frizz and end-locking effect. In addition to its excellent conditioning properties, this product provides softness, shine, silkiness and a depolarizing effect on the hair due to the cationic nature of the cream.

Business unit

SYD Cosmetic Laboratory also creates and manufactures third party brands. It has its own laboratory and has the possibility of manufacturing other products by implementing a consultancy in the commercialization of hair beauty lines. The company is in charge of manufacturing as it has its own certifications, registered formulas and installed capacity.

Cosmetics industry overview

The global beauty industry, comprising skin care, color cosmetics, hair care, fragrances, and personal care, has experienced positive growth in recent years. The total global cosmetics market size was valued at $529.1 (Euromonitor International,2022) billion in 2021 (see figure 5) with an annual growth rate of 4.13%., and is projected to reach $721.6 billion by 2026, registering a CAGR of 6.3% from 2022 to 2026.

Today, cosmetics have become an indispensable element of people's modern lifestyle. The growing awareness of external care along with the inner intellect of the individual has become one of the main factors driving the use of cosmetics in the global market. In addition, along with women, the use of cosmetics among men in their daily routine is increasing, which can be clearly seen in an increase in the demand in the global cosmetics market. Despite the COVID-19 crisis, the industry has responded positively and brands have shifted their manufacturing to the production of disinfectants and cleaning products. Hence, these lifestyle changes have led to growth in the global cosmetics market.

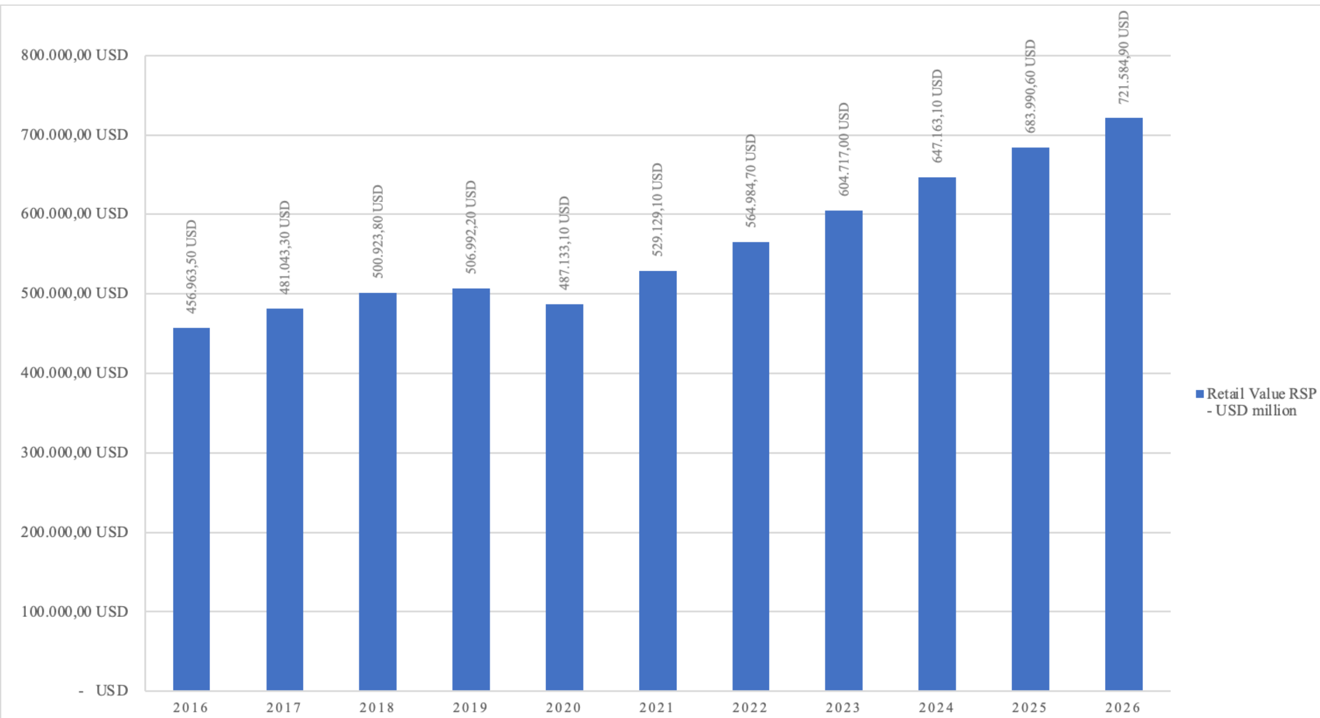

Figure 5. Global market size in the cosmetics industry from 2016 to 2026.

One of the world's most dynamic and quickly expanding cosmetic markets is in Latin America. In 2021 it reported a market size of $77.1 billion, representing 14.56% (see figure 6) of the global market size. By 2026, the region's market for cosmetics and personal care will be worth $54.1 billion with a CAGR of 7.32% (Euromonitor international,2022). In addition, the region consumes more cosmetics and personal care items per person than the rest of the world combined and 75% of Latinas consider beauty an important part of their culture.

The U.S. cosmetics market, on the other hand, was valued at $127.1 billion in 2021, accounting for 24.02% of the worldwide beauty and cosmetics market. It is anticipated to increase at a CAGR of 4.37 % (see figure 6) over the course of the forecast period to reach $127.79 billion by 2026. This is a result of both the rising demand for natural cosmetics and the high rate of global brand penetration. The U.S. cosmetics sector is also benefiting from the rise of the female workforce and the number of beauty salons. Over the next five years, it is anticipated that factors such as increased per capita spending on personal appearance, a robust regulatory environment, and expansion in the beauty and cosmetics business would increase demand for cosmetics.

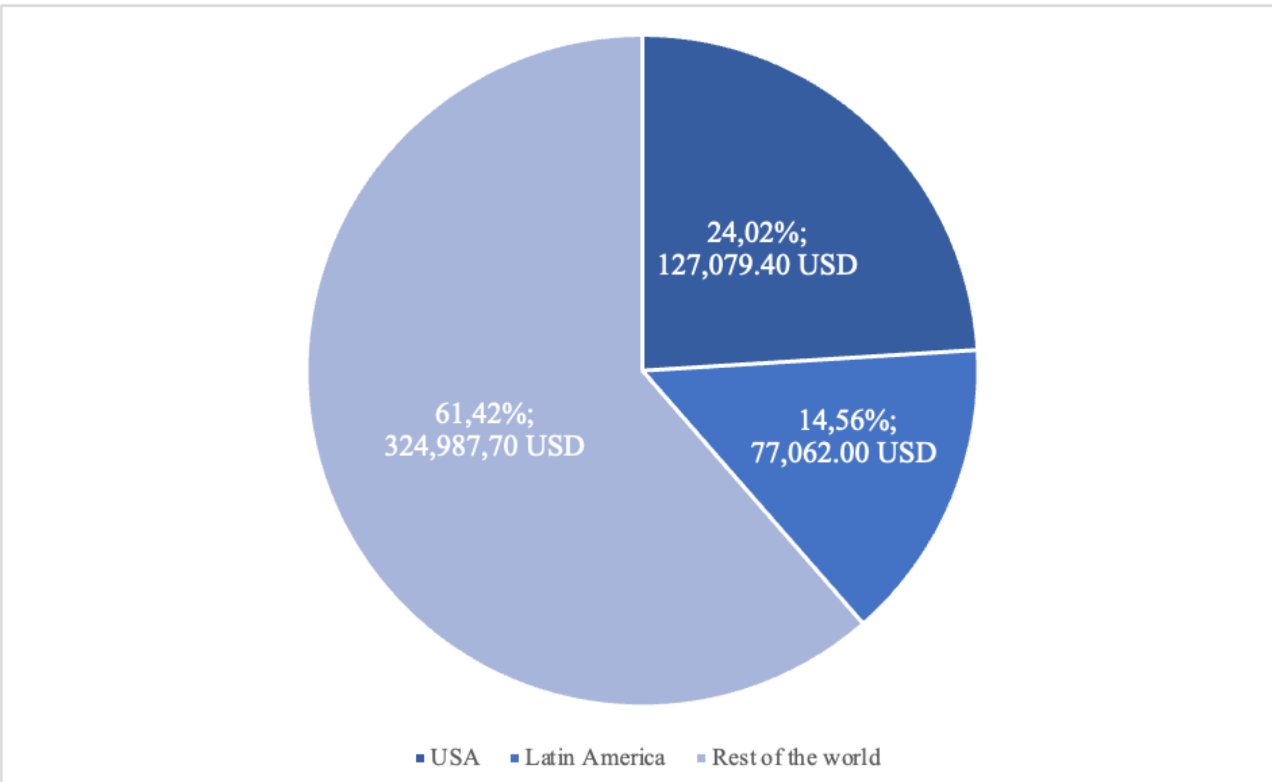

Figure 6. Market size by region in 2021. (USD million).

About the national market, Colombia is a significant exporter of cosmetics and personal care products. In 2019, Colombia was the second largest exporter of cosmetics and personal care in Latin America and the Caribbean (Procolombia, 2020). Buyers from other countries laud Colombia's high-quality goods and first-rate customer support.

The cosmetics and personal care industry in Colombia is renowned for its flexibility in responding to market trends, strict quality controls, high production rates, and vast expertise in brand development. Additionally, Colombia has a great deal of potential for making cosmetics using natural materials. It ranks second in the world for flower biodiversity and has the highest biodiversity per square meter on the entire planet. Besides, the nation is home to 311 different kinds of continental and coastal habitats.

In recent years, the cosmetics industry has experienced strong growth that brings economic benefits to the country and to the groups that participate in its value chain. The size of the market grew at a rate of 2% between 2016 and 2021 (see figure 7) and it is expected that by 2026 the sector will reach an average annual growth of 3.8% compared to 2021. This demonstrates the sector's potential as a driver of the national economy.

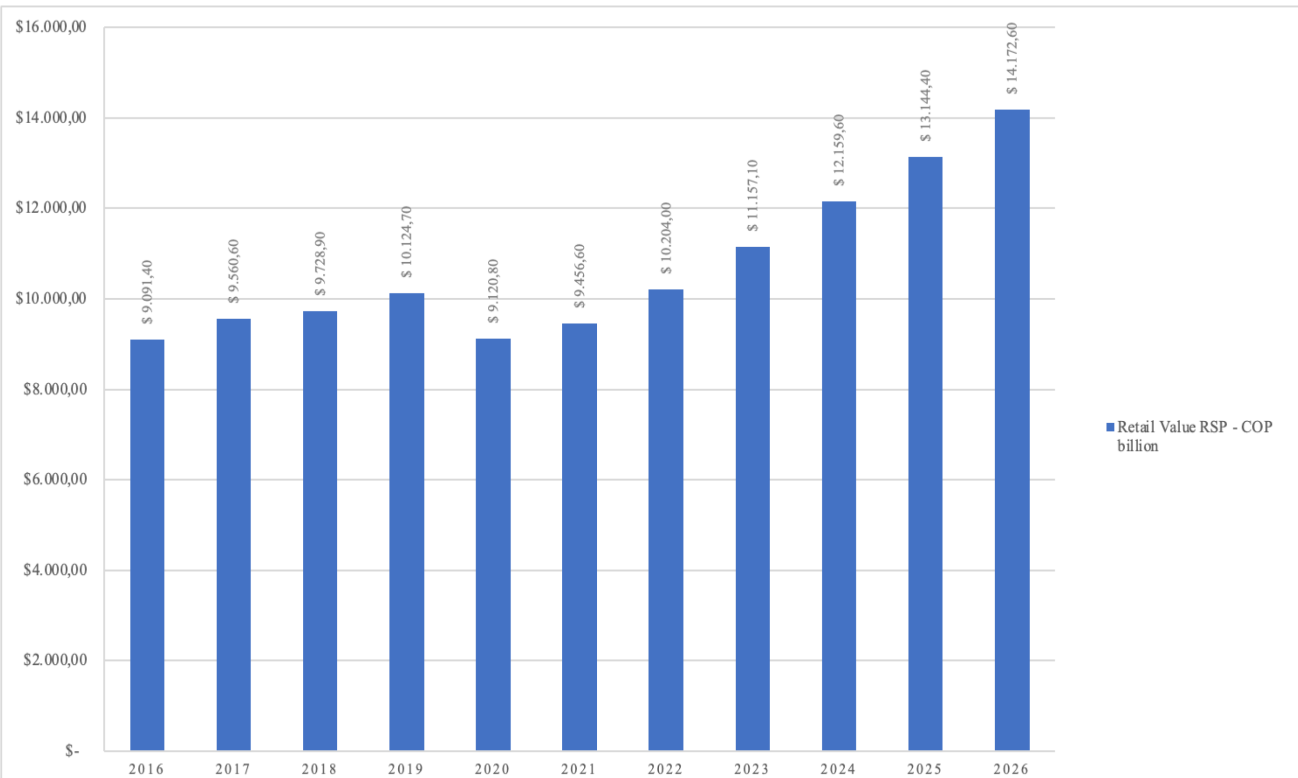

Figure 7. Colombia market size in the cosmetics industry from 2016 to 2026. (COP billion).

In light of the aforementioned, sales of cosmetics and personal care products have performed exceptionally well in Colombia in recent years. Colombia benefits from preferential tariffs on exports to many countries in the region (U.S., Canada, Mexico, Chile, Peru, Uruguay, Bolivia, and Paraguay, among others). The country benefits from its trade agreements in several ways, including a streamlined cosmetics trade process to access Pacific Alliance and Andean Community nations (CAN). Moreover, Colombian cosmetics exporters can provide solutions for various marketing tactics, including private branding, professional beauty sales, and retail sales.

Analysis

The following session is dedicated to the analysis of the DDMRP model applied to the case study.

Problem identification

To improve and organize the planning and resource management processes within the business, Syd Laboratorio Cosmetico SAS purchased the SAI OPEN information system. This was done to remain competitive in the industry and efficiently meet the demands of its clients. Based on the MRP (Materials Requirements Planning) technique, this system is an accounting program for small and medium-sized businesses. However, when they implemented it, the company did not obtain the expected results and, consequently, decided to complement the system with the Microsoft Excel software tool.

One of the main functions of the system described above is the company's production planning. This begins with the analysis of historical data on sales and unfulfilled demand for the last thirteen months. Subsequently, the schedule of new product launches, promotions, and discounts to be carried out during the period is analyzed. Next, the current inventory level is analyzed using the tool that the company calls the buffer, which is obtained by dividing the target inventory level into three equal parts. Once the buffer is established, the current inventory is placed at the corresponding level. This system provides a production prioritization method, i.e. if the current inventory is in the third level, the quantity needed to reach the target inventory is established; if it is in the second level, the delivery dates of the next orders are taken into account to determine if it is necessary to generate a production order if so, the quantity needed to reach the target inventory is ordered; otherwise, if it is in the first level, it is considered unnecessary to generate a production order. Finally, based on all the information analyzed, the final quantities to be manufactured by reference are established, and the bill of materials, the supply order, and the production order are generated.

According to the Business Development Manager of Syd Laboratorio Cosmetico SAS, this model affects the production planning program because it is based on inadequate inventory management techniques and unrealistic lead time calculations. Additionally, it does not provide a clear prioritization system and does not allow for adequate follow-up on execution. In recent years, the company has managed the situation by leveraging with partners and with its suppliers; however, at the end of 2017, the company made a move to a new plant that, due to lack of planning, generated a delay in its orders, which caused a drastic drop in revenues and an increase in unfulfilled demand (Di) for an approximate average value of $20.4 million pesos in hair dye's line, this demand was not recovered. Similarly, there was an increase in orders pending invoicing (Back orders), which represent the value that was not invoiced due to not having the products on time, but which remain pending to be delivered in the following period for an approximate average value of $17.4 million pesos. Figure 8 shows the company's situation from 2017 to June 2022. The problem worsened in the period of the COVID-19 crisis, years 2020 and 2021, in which the company had to adapt to the situation, leaving aside the implementation of projects and decreasing its production because of delays with raw materials or new laws implemented that limited labor. This resulted in low production during these years and consequently, some of the orders from non-priority clients were delayed, causing a critical situation in cash flow.

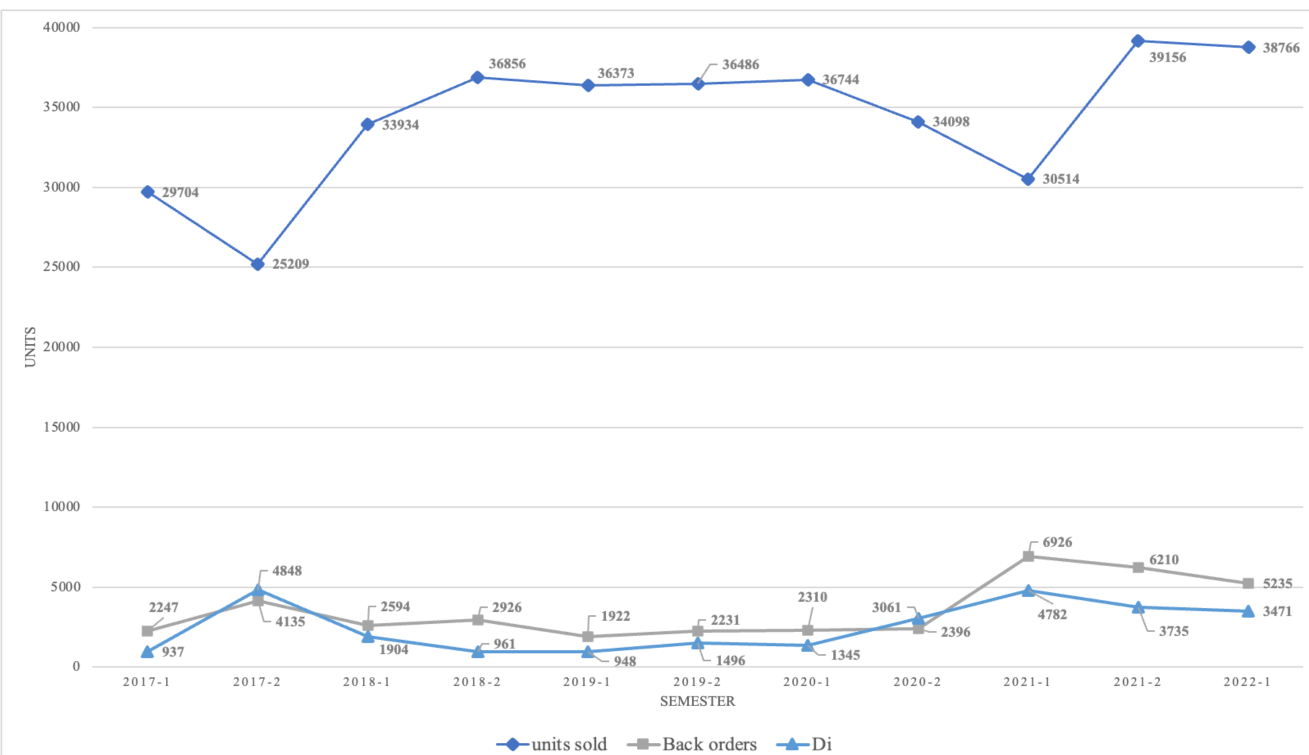

Figure 8. Sales in the line of hair dyes of Syd Laboratorio Cosmetico SAS from 2017 to 2022.

Because of the critical situation that arose as a consequence of the relocation of the plant and the COVID-19 period. SYD Laboratorio Cosmetico SAS developed a diagnosis of its production lines to identify those that needed to be addressed as a priority. First, they performed a Pareto analysis of the units sold in 2021 for each production line. The company found that the lines of Hair dyes, Bleaching Powder and Repairing Hair Treatment reflects 70% of the units sold. Once these results were obtained, sales were forecast for 2022 and 2023, obtaining as a result that the Hair dyes production line will have a growth in sales of up to 13%, positioning itself as the line with the highest percentage of units sold. Given this, a study was conducted on the performance of the hair dyes line during the year 2021 and it was found that 6210 units were not delivered out of 42891 demanded, equivalent to 14.47% of unfulfilled demand.

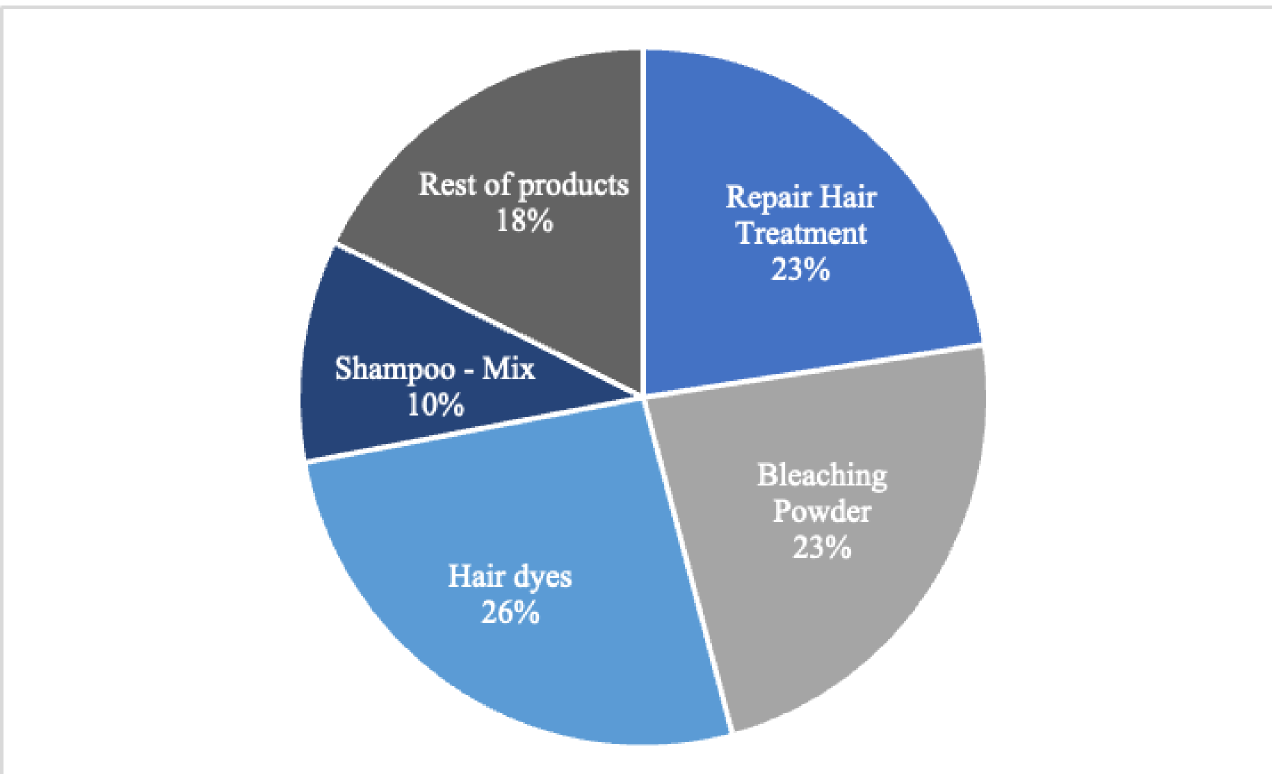

Figure 9. Sales by product in the year 2021 of the company Syd Laboratorio Cosmetico SAS.

Due to the above, it can be concluded that Syd Laboratorio Cosmetico SAS problem lies in production planning, which leads to a decrease in the level of service and an increase in inventory costs. These costs are composed of: cost of storage and cost of shortages. The company manages a performance indicator based on the percentage of unfulfilled demand in each period and has established a maximum value equivalent to 0.1%, which represents the target service level. According to the data collected, the service level indicator is significantly above the target with an average value per period of 7.65%.

In the second period of the year 2021, a reduction in late orders and unfulfilled demand was achieved. This, together with the prospect of entering a high-demand market such as the United States, has given the company the opportunity to implement a new planning system that seeks to reduce or eliminate unfulfilled demand and, at the same time, reduce inventory, which is currently close to $259 million pesos in the hair dyes line.

Bearing in mind that the problem currently faced by Syd Laboratorio Cosmetico SAS is centered on inventory management, an investigation of the current models that have been proposed to solve similar problems was carried out. One model that has shown satisfactory results in similar problems is DDMRP, a "multi-level methodology that is applied across multiple tiers of the supply chain to provide planning and execution with integrated visibility from the beginning to the end of the supply chain processes" (Demand Driven Institute, 2011). The efficiency of the DDMRP model is essentially due to the implementation and issue of control points known as "Buffers", which are located at strategic points in the supply chain to create independence between the different processes.

One of the main differences between Syd Laboratorio Cosmetico SAS current inventory model and DDMRP is the method used to calculate the units to be produced. In the current model, only the inventory on hand is taken into account, generating excess inventory and a low level of service, since the quantity needed to reach the NOI index is ordered without taking into account the demand and orders on the way. Meanwhile, with the DDMRP model, production orders are generated only when they are actually needed, thus satisfying demand and maintaining a low inventory level. This is why DDMRP is considered the most appropriate model to meet the current needs of Syd Laboratorio Cosmetico SAS.

Based on the above information, by means of a simulation, the research question that the thesis wants to solve is: What are the effects on inventory costs generated by the use of a DDMRP model in the hair dyes production line of Syd Laboratorio Cosmetico SAS?

Engineering Design Component

The following session describes the components used in the creation of the modeling process and implementation of the DDMRP methodology in the case study.

Design Statement

The final result of the research and case study thesis consists of the following deliverables:

1. Complete model under DDMRP in the production planning and inventory management to define the monthly production plan, with weekly resolution, in the hair dye production line.

2. Monte Carlo simulation model to evaluate the use of the DDMRP model.

Design Process

Based on the methodology established in the book Demand Driven Requirements Planning, a DDMRP model was designed and developed for the production planning of the hair product line in the company Syd Laboratorio Cosmetico SAS. For this, a detailed guide was elaborated where all the critical aspects that represent the characteristics of the company were analyzed and determined, in order to ensure that the model fulfills its main objective: to protect and promote the continuous flow of relevant information through the use of decoupling points and buffers of quantity, capacity and time. Thus, mitigating potential risks caused by demand and supply variability.

Guide to the application of the DDMRP model in production planning and inventory management

Due to the diagnosis performed for the company Syd Laboratorio Cosmetico SAS where it was found that the percentage of excess inventories was high, a DDMRP model design was created to analyze how the model could guarantee the availability of finished products to satisfy the demand of its consumers and reduce inventory costs.

In the next session, the key aspects to build the model based on the company's environment were determined and the necessary components for the model design were developed, as proposed in the Demand Driven Requirements Planning, and adjusted to the company's characteristics in the hair dye production line.

Determination of key factors

The following are the six key factors determined for the company Syd Laboratorio Cosmetico SAS, focusing on their four hair dye products.

1. **Customer Tolerance Time**
   In the case of SYD Laboratorio Cosmetico SAS, the average time that customers are willing to wait to receive their orders is 3 working days in the same city (Cali) and 8 working days for the rest of the cities in the country. This time was determined in conjunction with the company's sales and planning team. Taking into account that the model is based on the company's production process, the customer's tolerance time will be the one indicated for the city of Cali.

2. **Potential Market Lead Time**
   The potential market time frame established for the beauty and cosmetics sector in which the company is located is 1 working day for orders in the same city and 5 working days for the rest of the country's city, since in this time the company could acquire a larger market share by reaching its customers in a more effective and efficient way.

3. **Sales Order Visibility Horizon**
   The order visibility horizon is set at 1 week, since it should be longer than the consumer's tolerance time. By having a longer horizon, the probability of seeing peaks in demand is higher and therefore the risk of not meeting demand in certain periods can be mitigated.

4. External Variability

External variability refers to those variables where it is necessary to measure variability and which depend on external factors.

4.1 Demand Variability

The case study analyzed the variability in demand for the four products of the hair dye line. The results for the four items are displayed in Table 2.

Item	Description	Product Line	Rank
FG-001	Hair dye 60 gr	Professional use	High
FG-002	Hair dye 100 gr	Professional use	High
FG-003	Hair dye with hydrokeratin 50gr	Mix	High
FG-004	Hair dye Ammonia- free 60 gr	Professional use	High

Table 2. Ranking of item demand variability.

4.2 Supply variability

The classification of the suppliers' variability for each of the raw materials used by the chosen references is shown in Table 3.

Item	Description	Demand variability level	Item	Description	Demand variability level
005	Water	Low	026	5-Diamine Sulfate	Low
006	Propylene glycol	Low	027	4-Chlororesorcinol	Low
007	Stearyl Alcohol	Low	028	5-Amino-6-chloro-O-Cresol; 6-Amino-M-Cresol	Low
008	Cetyl Alcohol	Low	029	M-Aminophenol	Low
009	Ethabolamine	Low	030	N,N-Bis (2-Hydroxyethy)-P-Phenylenediamine Sulfa	Low
010	Ceteareth-50	Low	031	2,4-Diaminophenoxyethanol HCI	Low
011	Cocamidopropyl betaine	Low	032	P-Aminophenol, P-Methylaminophenol Sulfate	Low
012	Methoxyisopropanol	Low	033	P-Phenylenediamine	Low
013	Lauryl Alcohol	Low	034	Resorcinol	Low
014	Aminopropyl Phenyl trimethicone	Low	035	2,6- Dihydroxyethylaminotoluene	Low
015	Argania Spinosa Jernel Oil	Low	036	4,5-Diamino-1-(2-hydroxyethyl)-1h- Pyrazole	Low
016	Fragrance	Medium	037	2-Amino-4-Hydroxyethylaminoanisole Sulfate	Low
017	Sodium sulfite	Low	038	2,6-Diaminopyridine	Low
018	Thioglycolic Acid	Low	039	Hc Yellow No2	Low
019	Tetrasodium Edta	Low	040	Acid violet 43	Low
020	Ammonia	Low	041	Keratin	Medium
021	2-Methylresorcinol	Low	042	Hydro Keratin	Medium
022	5-Amino-O-Cresol	Low	043	Aluminum Collapsible Tube	Medium
023	1-Naphthol	Low	044	Stamped cardboard box	Low
024	2-Amino-3-Hydroxypyridine	Low	045	Plastic gloves	Low
025	Toluene-2	Low	046	Creme developer	Low

Table 3. Ranking of raw material demand variability for the hair dye products.

5. Inventory leverage and flexibility

Refers to common components that will help develop in the process of compressing the lead times of the hair dye line products.

5.1. Type of Relevant Lead Times

The different lead times that each component and completed product have been listed in Table 4. There are two different kinds of lead times: MLT stands for the manufacturing lead time, or the time it takes for Syd Laboratorio Cosmetico SAS to make an item, and PLT is for the purchasing lead time, or the time it takes for the company to buy the material from a third party.

Item	Type	Item	Type
001	MLT	025	PLT
002	MLT	026	PLT
003	MLT	027	PLT
004	MLT	028	PLT
005	PLT	029	PLT
006	PLT	030	PLT
007	PLT	031	PLT
008	PLT	032	PLT
009	PLT	033	PLT
010	PLT	034	PLT
011	PLT	035	PLT
012	PLT	036	PLT
013	PLT	037	PLT
014	PLT	038	PLT
015	PLT	039	PLT
016	PLT	040	PLT
017	PLT	041	PLT
018	PLT	042	PLT
019	PLT	043	PLT
020	PLT	044	PLT
021	PLT	045	PLT
022	PLT	046	MLT
023	PLT		
024	PLT		

Table 4. Type of lead time by item.

In table 4 it is possible to identify that the products manufactured by the company Syd Laboratorio Cosmetico SAS refer to the 4 products of the hair dye line (items no.001, 002, 003, 004) and to the product item no.046 which is also produced by the company.

6. Critical Operation Protection

The Supply Chain encompasses a wide range of activities including sourcing, materials management, operations planning, distribution, logistics, retail, demand forecasting, order fulfillment, and more. Critical operations are those of the covered business, including related services, functions, and support, where the failure or interruption of activity could have an impact on the process's efficiency or turnaround time.

The operations identified as critical within the supply chain of Syd Laboratorio Cosmético's hair dye line is the following:

- The dispensing of raw materials is a critical operation because it depends on the availability of raw materials. This operation must be controlled to avoid an accumulation of variability due to suppliers.
- The mixing step to produce the hair dye products is an operation of high relevance since it depends on the dispensing of raw materials and it has long delays when the raw material is not ready.
- The operation of pouring the mixture of hair dyes in collapsible tubes is a point that must be protected to mitigate risks of delays and non-compliance within the supply chain.
- The preparation of machines and material for folding and corrugating the packaging boxes is considered a critical operation within the process because its capacity is usually limited by the number of operators**.**

Design of Material Explosion Diagrams without Buffers

The first step in locating the strategic decoupling points is to create the material explosion diagrams to determine the lead time for each reference and to establish, within the structure, the positioning of the stops that allow decoupling parts of the chain to mitigate variability and protect the decoupling points. Below, the material explosion diagrams can be visualized without taking into account the positioning of the stops. The times inside the circles at the top left of each raw material/component correspond to the delivery time of the suppliers or the transformation time of the component or the finished product. transformation time of the component or the finished product.

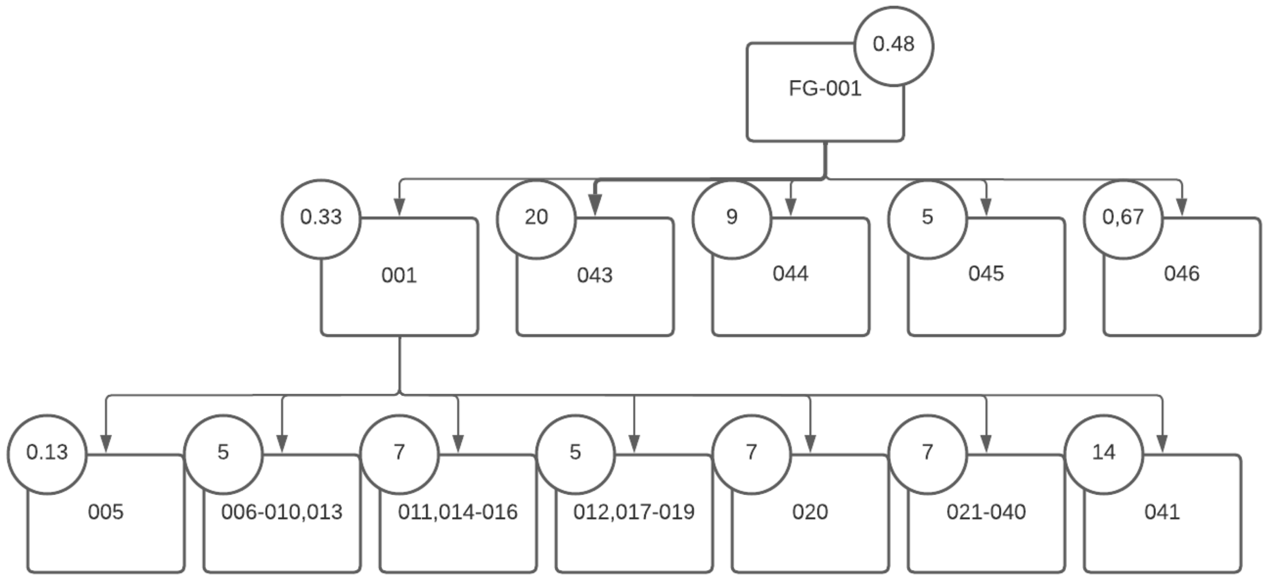

Figure 10. Bill of materials for product FG-001.

To determine the time, it takes the company to deliver product FG-001, considering the variability of the supplier in delivering the raw materials on time, the accumulated time in each route of the structure is calculated. The longest accumulated time is taken as the lead time of that final good. In this case, the longest route is 21 days. This is obtained as follows:

Cumulative Lead time: *20 + 0.48= 20.48 days*

Approximately 21 days

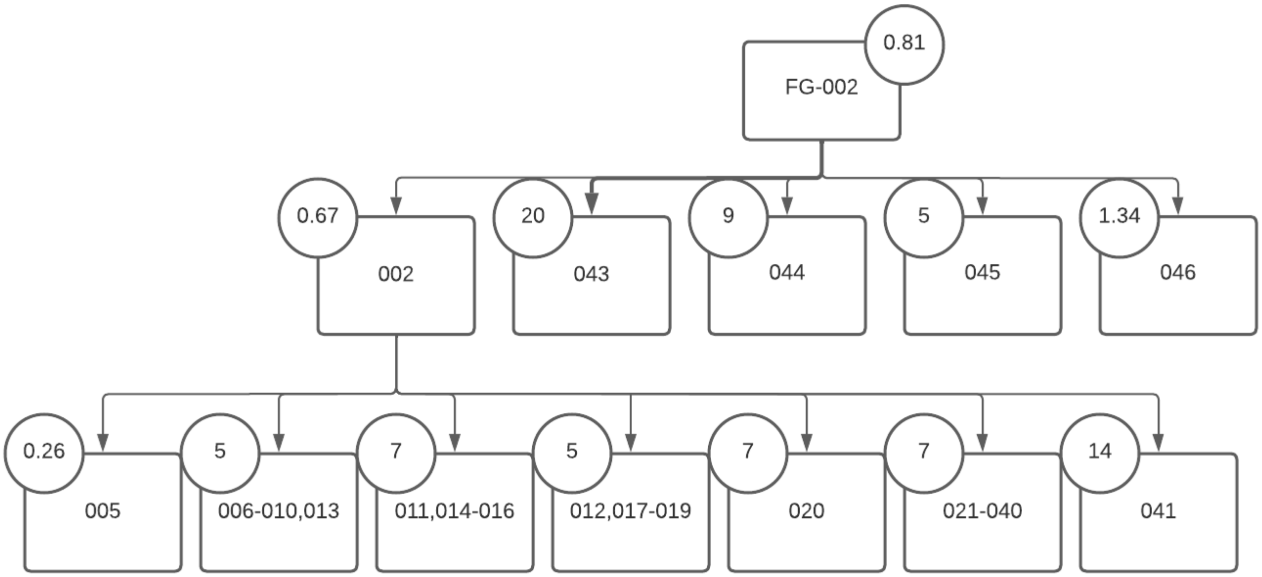

Figure 11. Bill of materials for product FG-002.

For the product FG-002, the highest accumulated time is 20.81 days, being the highest time, it is taken as the Lead Time of the item. This time is obtained by adding the time of the components route of the previous product, the raw material 043 with the time of manufacturing FG-002.

Cumulative Lead time: *20 + 0.81= 20.81 days*

Approximately 21 days

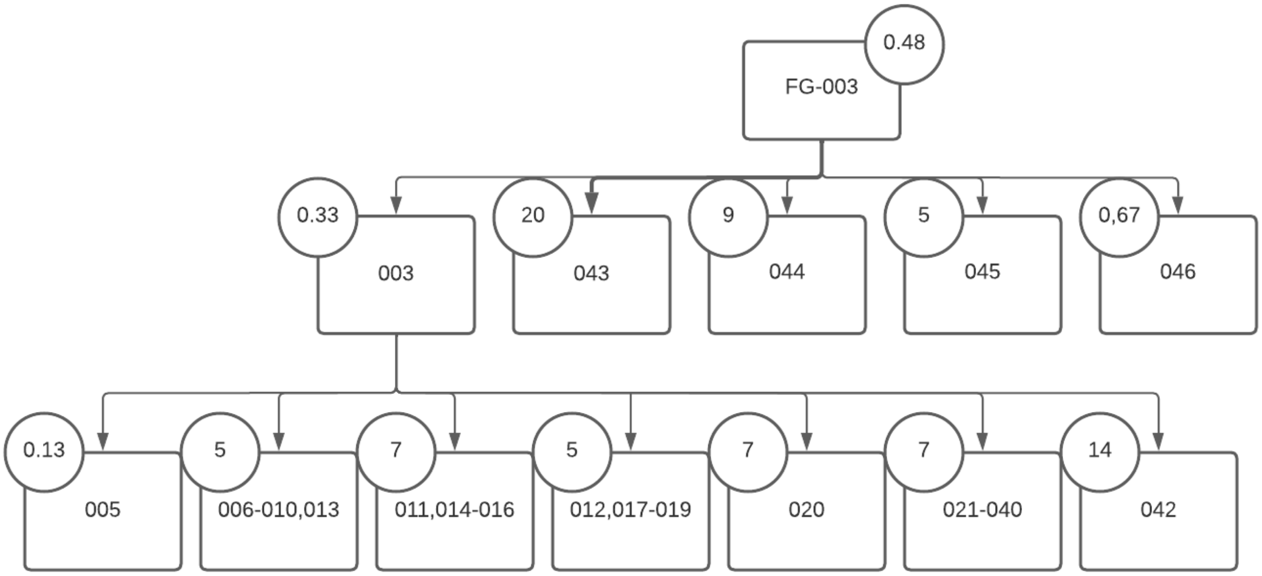

Figure 12. Bill of materials for product FG-003.

By not having protection and control over raw materials, the chain is exposed to variability due to their availability. This must be taken into account when calculating the final lead time to the customer. As with the first item, the longest accumulated time is approximately 21 days; since it is the longest time, it is taken as the lead time of the product. This is calculated as follows:

Cumulative Lead time: *20 + 0.48= 20.48 days*

Approximately 21 days

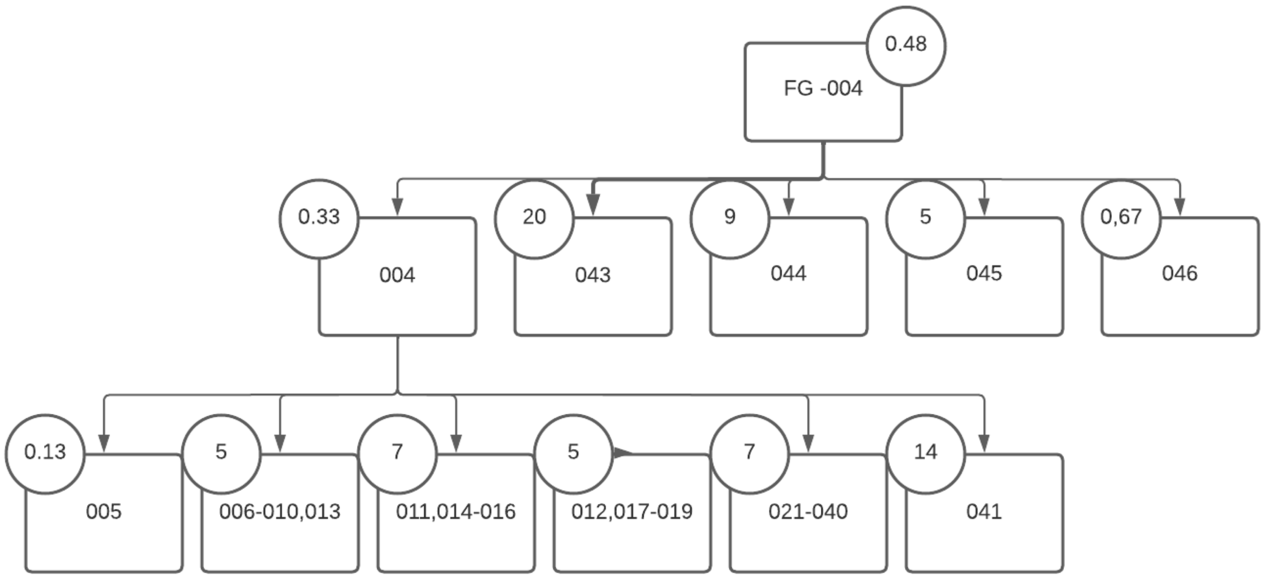

Figure 13. Bill of materials for product reference 004.

The lead time of the product FG-004 is also 21 days. This time is obtained by adding the delivery time of the raw material supplier 043 and the processing time of the final product.

Cumulative Lead time: *20 + 0.48= 20.48 days*

Approximately 21 days

Bill of Material correlation matrix

To identify the multifunctional decoupling points where the buffers should be positioned requires the use of a tool known as a material explosion matrix. The following matrix can be used to identify the components that require equal materials. The numbers within the matrix represent the number of times the connection appears in all the BOMs of the references within the product family. product family.

		Parents items							
		FG-001	FG-002	FG-003	FG-004	001	002	003	004
Components items	001	1							
	002		1						
	003			1					
	004				1				
	005					1	1	1	1
	006-010, 013					1	1	1	1
	011,014-016					1	1	1	1
	012,017-019					1	1	1	1
	020					1	1	1	
	021-041					1	1	1	1
	41					1	1		1
	42							1	
	43	1	1	1	1				
	44	1	1	1	1				
	45	1	1	1	1				
	46	1	1	1	1				

Table 5. Bill of materials correlation matrix.

In this case, table 5 shows that there are no shared intermediate components but it can be identified that the raw material is largely the same for the 4 different references, 69% of the total raw materials are shared. However, the composition of the four hair dyes is completely different and must be discriminated against in each of the products of the two lines, Professional Use and Mix.

Location of Buffers within Bill of Materials Diagrams

Several iterations were performed in order to find the best buffer positioning for the case study and to test the robustness and correctness of the model. The decoupled lead time path for the final goods is depicted as the following figures that shown the 4 diagrams with the material explosion for each finished product with their respective buffers iterations that represent the different paths connecting final goods (FG) and raw material components.

Taking into account the established decoupling points and the material explosion matrix, it was decided to place the buffers in the raw materials and in the final goods to protect the variability that can affect the chain due to the demand of the items and the supply of raw materials.

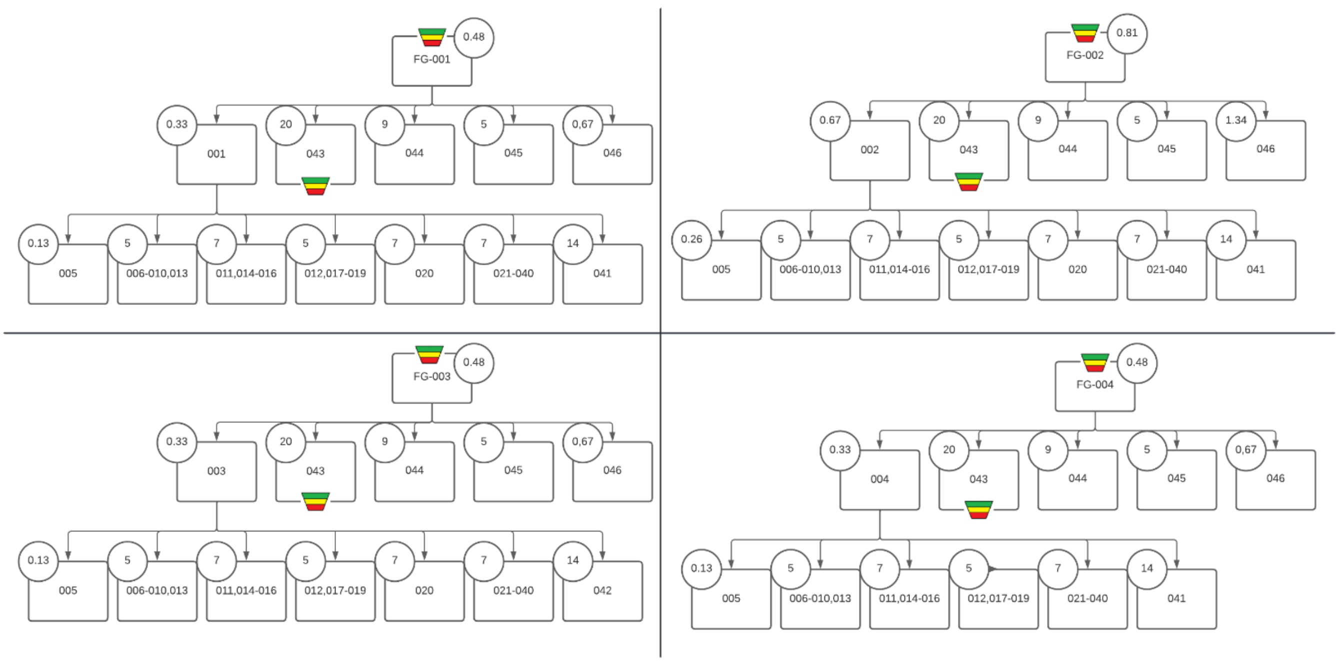

Figure 14. FG's compressed lead time chain and 043's decoupled lead time chain. Iteration no.1.

The figure 14 shows the decoupled lead time for subcomponent 043 being compressed from 20.48 days to 14.81 days for items FG-001, FG-002, FG-004 and in the same way it is reduced from 20.81 days to 15.48 days for FG-003. Likewise, with the location of the quantity buffer in subcomponent 43 there is a great reduction of the cumulative lead time corresponding to 27.68% for FG-001, FG-002, FG-004 and 25.61% for FG-003.

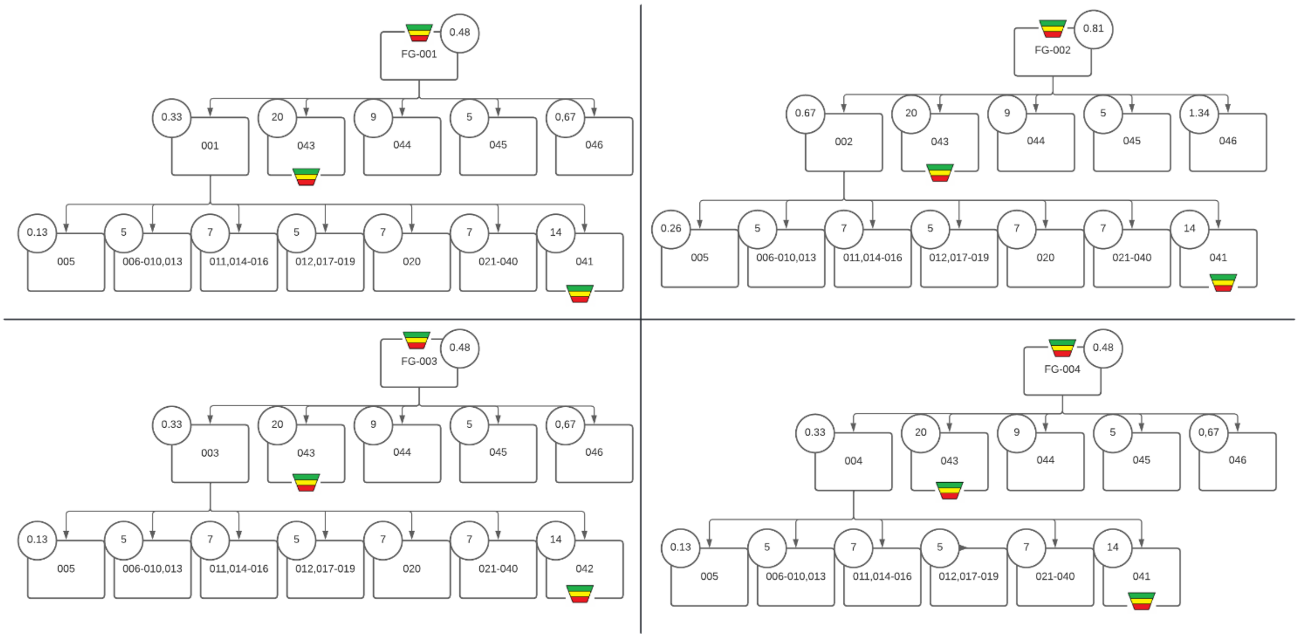

Figure 15. FG's compressed lead time chain and 042,041's decoupled lead time chain. Iteration no.2.

Based on the reduction time of the previous point, it was decided to perform a new iteration for the next critical point identified. Therefore, the decoupled lead time for subcomponents 001,002 and 004 being compressed from 20.48 days to 9.48 days as 9.81 days from 20.81 days for 003. By decoupling the purchased part 042 and 041.

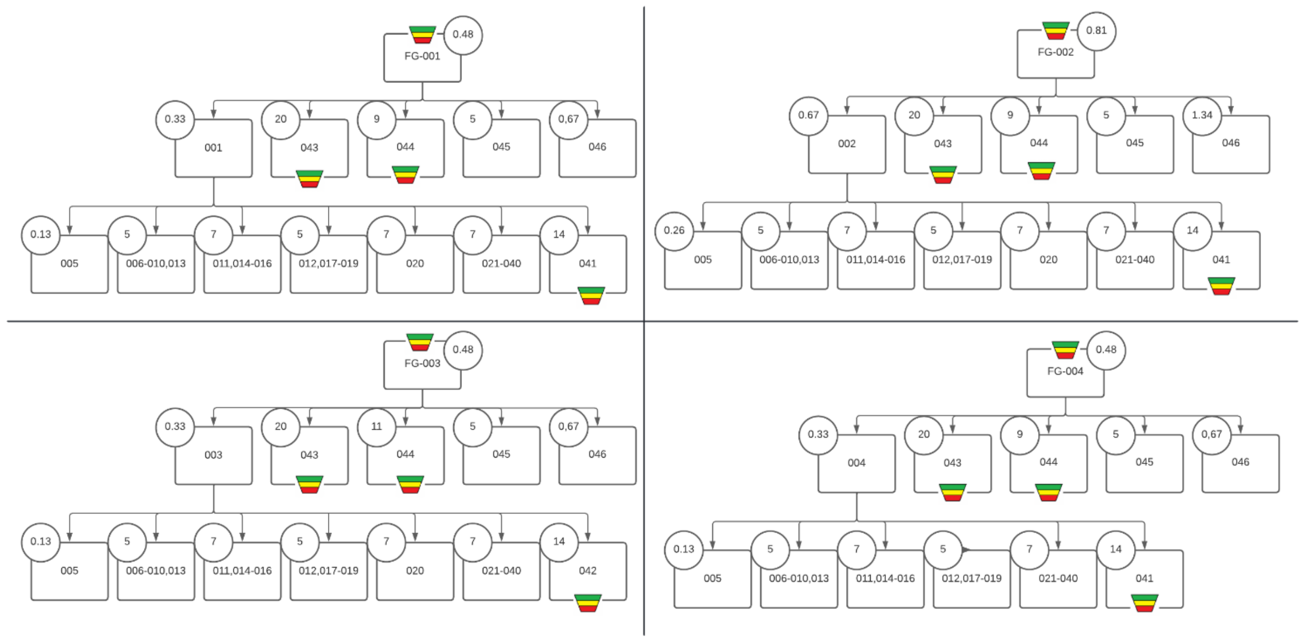

Figure 16. FG's compressed lead time chain and 044's decoupled lead time chain. Iteration no.3.

For the Iteration no.3, the decoupled lead time was chosen for subcomponent 044 that was compressed from 20.48 days to 7.81 days for items FG-001, FG-002, FG-004 as 8.48 days from 20.81 days for item FG-003.

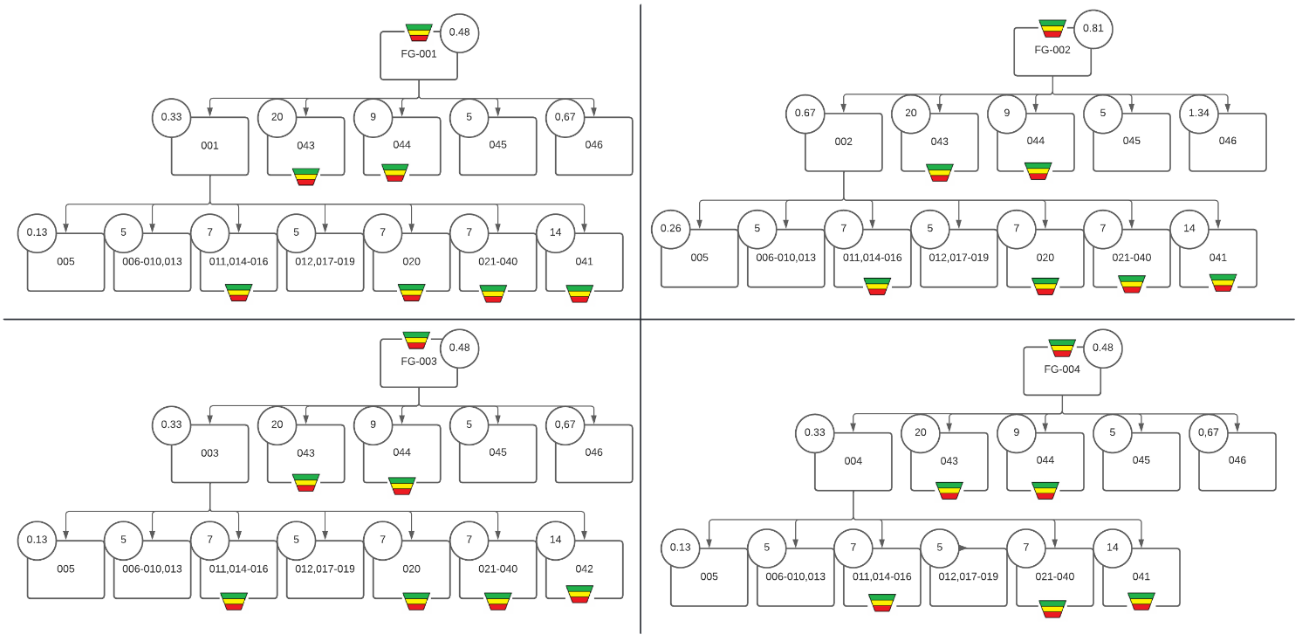

Figure 17. FG's compressed lead time chain and 011,014-016,020,021-0,40's decoupled lead time chain. Iteration no.4.

Finally, in iteration number 4, the purchased items with a lead time of 7 days were compressed. With these the cumulative lead times were compressed from 20.41 days to 5.81 days for items FG-001, FG-002, FG-004 and from 20.81 days to 6.48 days for item FG-003, having a reduction of more than 68% for the four finished products.

By exercising specific control over the raw material selected, a new lead time known as decoupling lead time was calculated. By taking into account the variability of raw material supply independently, the lead time of the item is reduced to only the processing time of the components and the finished product. When comparing the lead times, a reduction from 21 days to approximately 5-6 days is obtained. This time is calculated by adding up the times on each route within the structure from each buffer. All possible routes were calculated and the longest route is chosen. The calculation is performed as follows:

Decoupled lead time product FG-001: *5+0.33+0.48 = 5.81 Days*

Decoupled lead time product FG-002: *5+0.67+0.81 = 6.48 Days*

***Decoupled lead time product FG-003**: 5+0.33+0.48 = 5.81 Days*

***Decoupled lead time product FG-004**: 5+0.33+0.48 = 5.81 Days*

By decoupling the points in the supply chain, it is ensured that raw materials are always available at the right time to produce at any time. This generates a great reduction in the times considered important to deliver orders to customers in the shortest possible time.

Strategic inventory positioning

Considering the factors presented above, the positioning of the decoupling points where the quantity, time and/or capacity buffers will be located is determined. The following illustration depicts the complete model under DDMRP in the hair dye production line. The diagram illustrates each part of the production process, the operators, and the location of the quantity, capacity and time buffers.

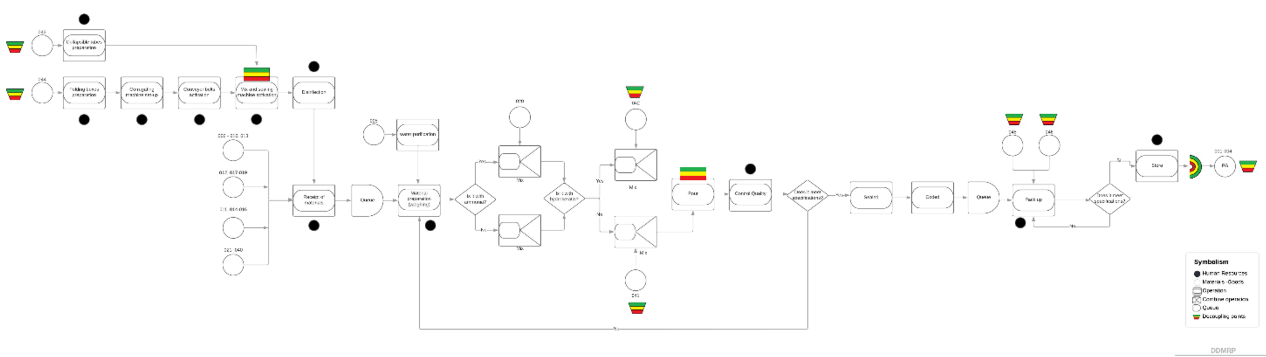

Figure 18. Strategic decoupling in the production process of the hair dye line.

The buffers shown in Figure 18 and Appendix 1 allow independent control of the decoupling points so that they do not affect the efficiency of the chain. Control must be rigorous and frequent so that the different areas of the process do not suffer the bullwhip effect.

Quantity buffers were located by performing position tests within the material explosion diagrams for each product as described above. In these tests, the decoupled lead time of the main item was calculated to obtain the best position that will generate the lowest possible decoupled lead time and protect the process from any variability; which for three of the four products was 1 day and 2 days for the remaining product. Additionally, in the material correlation matrix, it was found that 69% of the raw materials are shared by the four products analyzed. Based on the tests performed, the quantity buffers were positioned in all the raw materials of the four final goods. The quantity buffers were also placed in the finished products, in order to reduce the effect within the chain caused by the variability in demand of each item.

Regarding the capacity buffers, in the initial diagnosis it was found that the pour and mix and sealing machine activation are critical operations within the chain. This is due to the fact that both operations involve parallel processes and have the greatest capacity to increase the production rate. For this reason, the capacity buffers were positioned in both of these operations. Additionally, time buffers were placed on finished products to control the scheduling of orders and ensure that they are shipped to customers on the established dates.

Strategic Buffer Calculation

Item Type

Because buffers are positioned in this model only to protect raw materials and finished products, there are two types of components:

- **Manufactured(M):** for products manufactured in-house.

- **Purchased (P):** for raw materials that are not manufactured in-house.

Lead Time and Variability

These two factors are classified as follows:

Lead time Category		Variability Category	
S	Short	L	Low
M	Medium	M	Medium
L	Long	H	High

Table 6. Lead time and variability category.

Buffers Profile Design

For this model, two types of buffer profile were created, one for manufactured items and one for purchased materials. The classification ranges are then specified to determine the lead time factor and the variability factor according to the profile type for each raw material or finished product.

Manufactured (M)				
Category	Range (Days)	Lead time factor	Variability category	Variability factor
Long	1	25%	High	75%
Medium	0.31- 1	41%	Medium	50%
Short	0.05-0.31	70%	Low	25%

Table 7. Buffer profile for manufactured items.

Purchased (P)				
Category	Range (Days)	Lead time factor	Variability category	Variability factor
Long	30-45	30%	High	100%
Medium	12-30	50%	Medium	60%
Short	1-12	80%	Low	40%

Table 8. Buffer profile for purchased items.

Defining Individual Part Attributes

The following attributes define characteristics of the raw materials and finished products that are used to calculate the size of the buffer zones.

1. **Average Daily Consumption (ADU)**

   Because the planning horizon was set as 1 week, for each component and finished product, the average weekly consumption is calculated from the average demand of the last 24 weeks. The Average daily usage (ADU) will be updated daily to maintain a high flow of real information into the model.

2. **Components and parent items lead time**

   The lead times established in the following table are determined taking into account these criteria: if the item is manufactured, the decoupled lead time is used and if the item is purchased, the lead time provided by the supplier is used.

Category	Component/FG	Lead time (days)
Final Goods	001	0.94
	002	1.74
	003	0.94
	004	0.94
Components	005	0.13
	006-010, 013	5
	011,014-016	7
	012,017-019	5
	020	7
	021-041	7
	041	14
	042	14
	043	20
	044	11
	045	5
	046	1.34

Table 9. Lead times of final goods and components.

3. **Minimum Order Quantity (MOQ)**
   Considering the minimum order quantities established by raw material suppliers affects the model since they restrict the calculation of optimal inventory levels.

Calculation of Buffer Zones

The second step of DDMRP is related to buffer that refers to a level of stock that is carefully sized and maintained, this mechanism allows a decoupling point to stay decoupled. This session focuses on the sizing considerations of strategic inventory buffers. In the company Syd Laboratorio Cosmetico SAS, the calculation of buffer zones will be performed weekly and will be calculated for each component and finished product.

The parameters required for the calculation of the size of the zones are:

- **Average daily usage (ADU):** it was calculated by observing the activity over a period of time; for the case studied, the length of period was 24 months. The historical data were recorded weekly and the ADU results from dividing the last 24 months weekly usage value by 7.

- **Buffer profile:** Is made up of a series of letters and values that identify each component studied. In this case, the first letter denotes the part type: "P" for purchased, "M" for manufactured, and "I" for intermediate components. The following category is lead time: "S" for short, "M" for medium, and "L" for long. The third letter denotes the level of variability: "L" for low, "M" for medium, and "H" for high.

- **Part Minimum Order Quantity (MOQ):** The number of products that Syd Laboratorio Cosmetico SAS must purchase from their suppliers in a single order. It is considered to the parts and SKUs that do require minimum order quantity and that can affect buffers levels, specially when they are large in relation to the rate of use.

- **The Demand Order Cycle (DOC):** Imposed or desired order cycle in days according to several type of times to be considered such as customer's tolerance time, competitors' time, expected production times, among others.

- **Lead Time:** the part's unique lead time in days for any manufactured or intermediate item, this lead time is the decoupled lead time of the part.

- **Lead Time Factor:** Percentage of the time that depends on supplier variability. Their categories can be seen in the table 7.

- **Variability factor**: Percentage of variability that depends on demand variability. their categories can be seen in the table 8.

As a calculation example of calculation, the following table shows a summary of the required parameters and the sizes of the buffer zones for the finished product FG- 001.

<table>
<tr><th colspan="6">FG-001</th></tr>
<tr><th>Parameter</th><th>Value</th><th>Unit of measure</th><th colspan="3">Zone</th></tr>
<tr><td>Average Daily Usage</td><td>65</td><td>Units</td><td rowspan="4">Green Zone</td><td colspan="2">195</td></tr>
<tr><td>Buffer Profile</td><td>M,M,H</td><td>N.A.</td><td>Lead time factor</td><td>80</td></tr>
<tr><td>Minimum order quantity (MOQ)</td><td>1</td><td>Units</td><td>MOQ</td><td>1</td></tr>
<tr><td>Demand order Cycle (DOC)</td><td>3</td><td>Days</td><td>Minimum order cycle</td><td>195</td></tr>
<tr><td>Decoupled lead time (DLT)</td><td>5,81</td><td>Days</td><td>Yellow Zone</td><td colspan="2">378</td></tr>
<tr><td>Lead time factor</td><td>41%</td><td>N.A.</td><td rowspan="3">Red Zone</td><td colspan="2">271</td></tr>
<tr><td rowspan="2">Variability Factor</td><td rowspan="2">75%</td><td rowspan="2">N.A.</td><td>Base</td><td>155</td></tr>
<tr><td>Safety stock</td><td>116</td></tr>
</table>

Table 10. Buffer calculation for part FG- 001.

The left part in table 10 shows the parameters referred to the attributes of part 001, which were explained above. On the other hand, the right part shows the calculation of the buffer zones for part FG-001. In this case, the green zone has a value of 195 units, which means the typical order size to be produce according to the average order frequency of item 001. The yellow zone has a value of 378 units which represents the inventory coverage in the buffer and the last one, the red zone, with a value of 271 units, represents the embedded safety in the buffer.

Calculation of buffer levels

The buffers for each raw material and finished product were sized considering the key parameters specific to each.

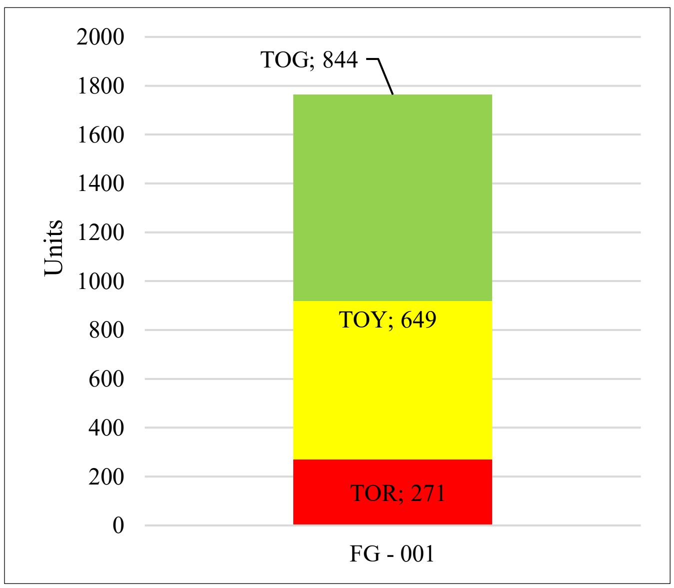

Figure 19. Buffer levels calculation for item FG-001.

The figure 19 shows the three upper levels of each zone for item FG-001. The calculation of each value is explained below.

Top of Green (TOG)= Top of Yellow + Green Zone = 649 + 195 = 844.

Top of Yellow (TOY)= Red Zone + Yellow Zone = 271 + 378 = 649.

Top of Red (TOR)= Red Zone = 271.

According to the calculation, the top of green with a value of 844 units represents the maximum stock level for item FG-001. The reorder point is represented by the top of yellow, which has a value of 649 units, and the minimum safety stock is represented by the top of red, which has a value of 271 units.

Dynamic Adjustments

The adjustments to the time and quantity buffers will be made weekly, in order to ensure a constant flow of information. In the quantity buffers, inventory levels will be updated according to the average weekly usage, the net flow will be updated considering the inventory on hand of the inventory that was ordered and is on its way minus the demand that is received. Additionally, adjustments to time buffers will be made for each production order. The size of the zones will correspond to the times required for each order. Depending on the environment in which the company finds itself as time goes by, adjustments must be made to the factors that mainly affect the buffer levels. These factors are:

- Lead time factor
- Variability Factor
- Number of Periods considered for calculating the Average weekly usage

Subsequently, to analyze the model and evaluate the DDMRP results, a Monte Carlo simulation was performed in AnyLogic software. The simulation has a control panel where it is possible to visualize: the current inventory levels (TOG, TOY, TOR) of the quantity buffers, the orders that are on their way, the weekly demand of the visibility horizon and the percentage of inventories with respect to the target levels established for the buffers. This table was designed for the 46 raw materials and for the 4 finished products analyzed. The boxes at the bottom represent link buttons that allow visualizing the performance indicators and the parameters and variables of the model. The following figure shows the scorecard at an instant in the simulation time for the part FG-001.

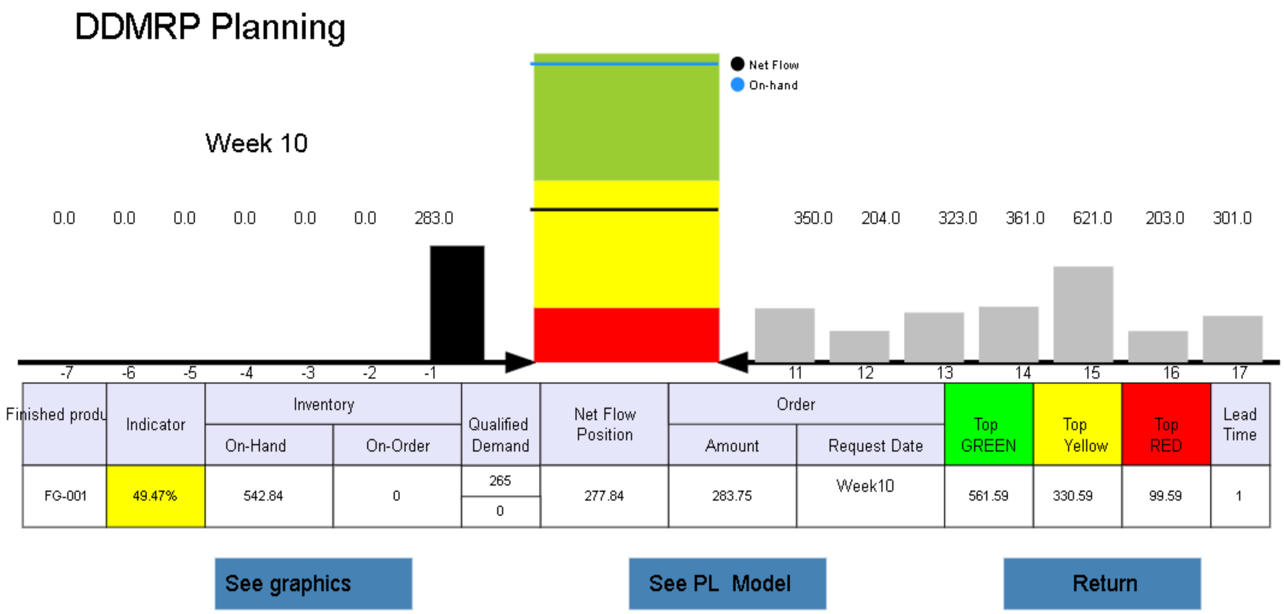

Figure 20. Simulation model under DDMRP planning.

After running the simulation model, for item FG-001 in week 10 there is an inventory on hand of 542.84 units, summing this value with the inventory on order which is 0 and subtracting the demand for that period of 265 units, a net flow value of approximately 277 units is obtained. This value is less than the TOY and therefore an order is generated for 283.75 units to reach the upper level of the green zone. Since the lead time for this item is 1 week, it can be seen in the left diagram that the order is received in week 11. In contrast, the diagram on the right shows the demand from the next weeks, week 11 to week 17 week 17 for item FG-001.

Although production capacity has not had a negative impact on demand fulfillment, the production process was designed to have a more visible control of production capacity. A simulation model was developed for the production process that reflects the operation of the plant under the DDMRP model.

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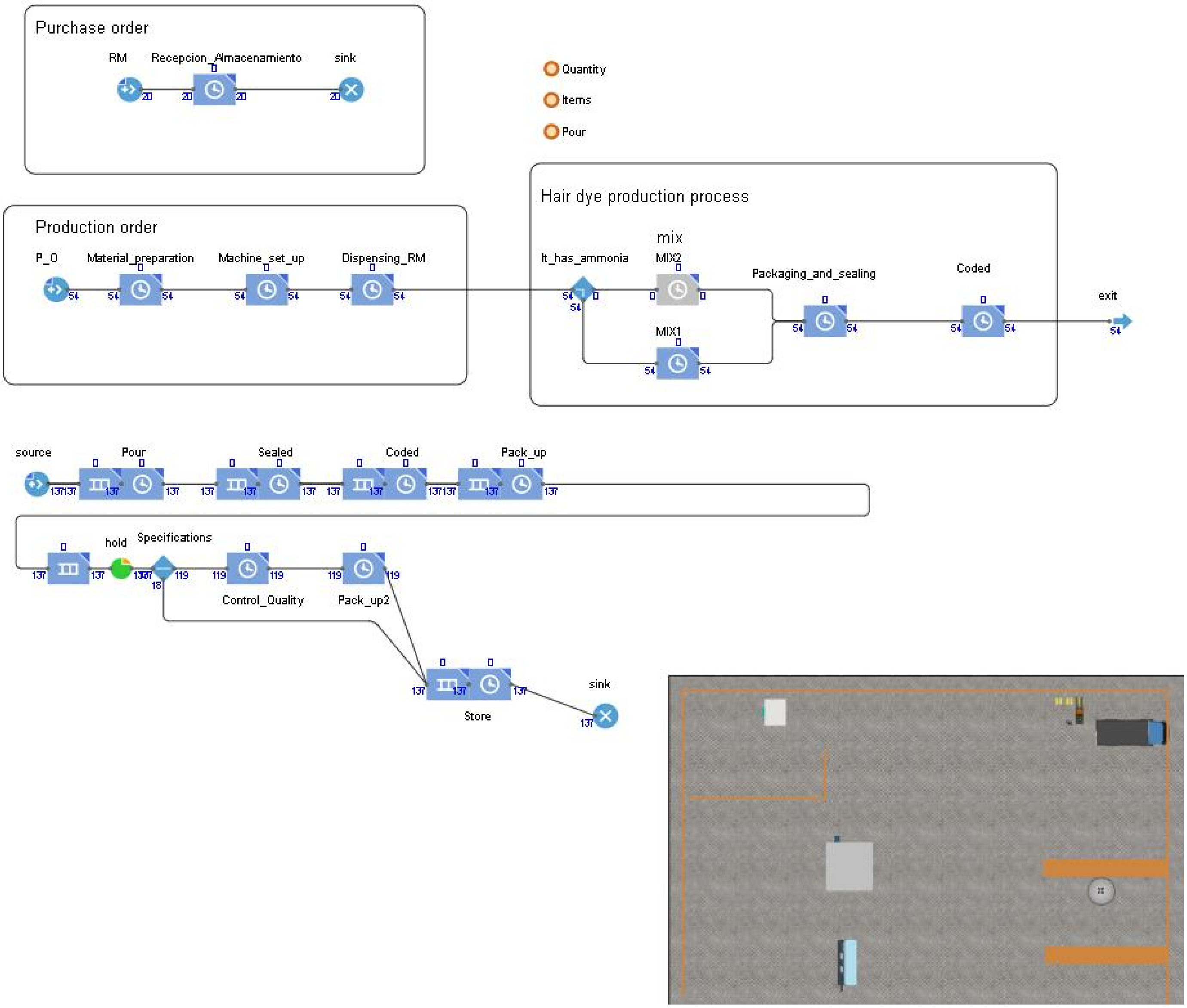

Figure 21. Simulation production process in AnyLogic software.

Discussion of results

The Monte Carlo simulation was used to examine DDMRP's performance in relation to previously established indicators at various time instants. The average of the results from the 12 runs was used in the analysis and the indicators' results for each product after 105 runs in the hair dye line were as follows.

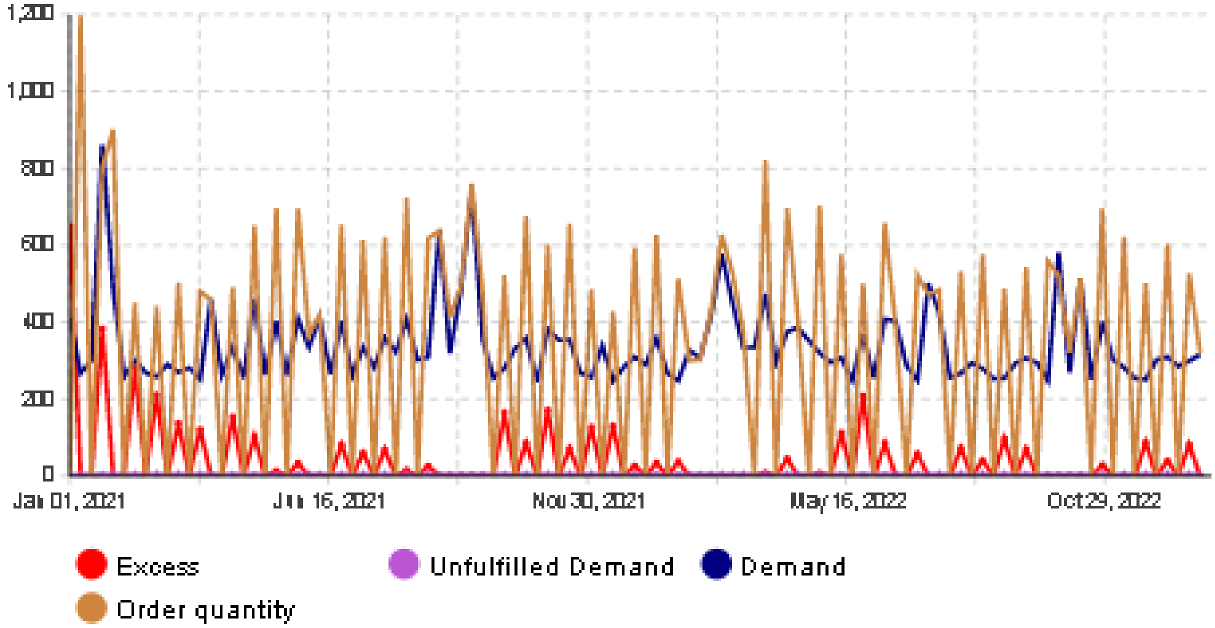

Figure 22. Indicators vs. time for item FG-001.

Figure 22 shows the significant reduction of overstocking in the inventory shown at the beginning of the simulation. The demand for item FG-001 is in the range of 200 to 900 units per week during the two years of observation and there is no unfulfilled demand presented. Although, item FG-001 had higher stock levels at which demand can be met, randomness is evident with peaks reaching 400 units and 600 units in January 2021. However, the service level remains above 95%.

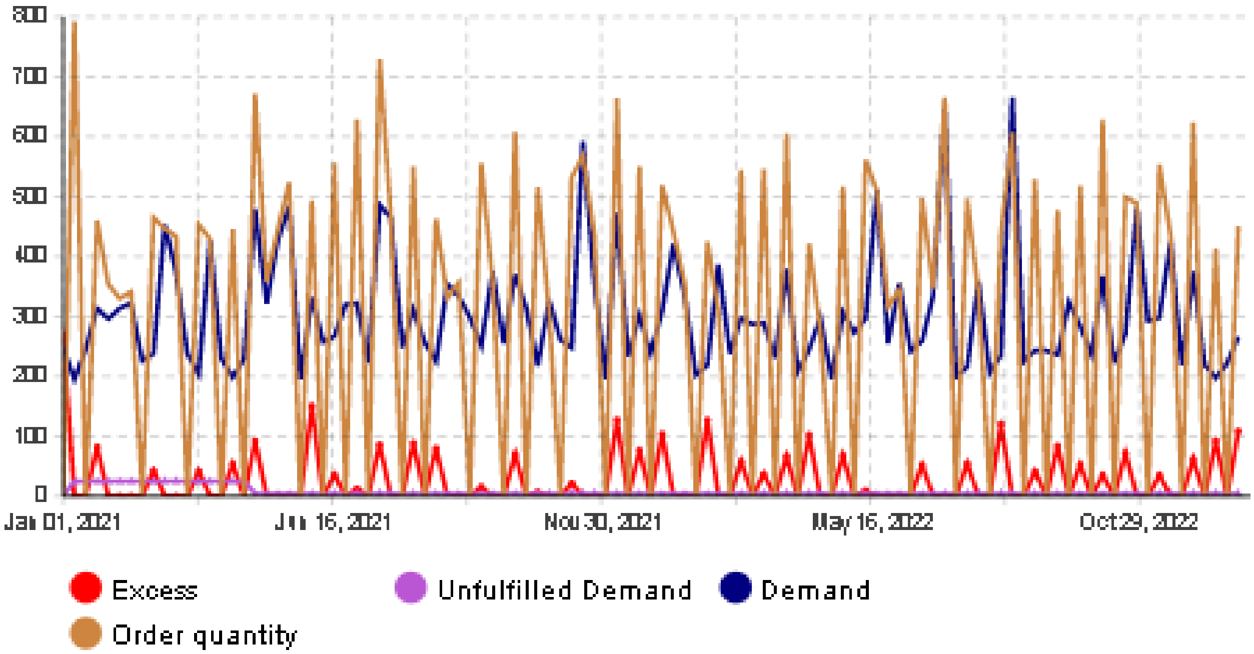

Figure 23. Indicators vs. time for item FG-002.

Similarly, it is possible to observe in figure 23 how the unfulfilled demand for item FG-002 stabilizes over time. Demand for item FG-002 is highly erratic in a range between 200 and 700 units. The excess of inventory is more erratic and reaches peaks almost of 200 units. Because of low inventory levels, low levels of unmet demand, and low levels of both, the service level continues to be above 95%.

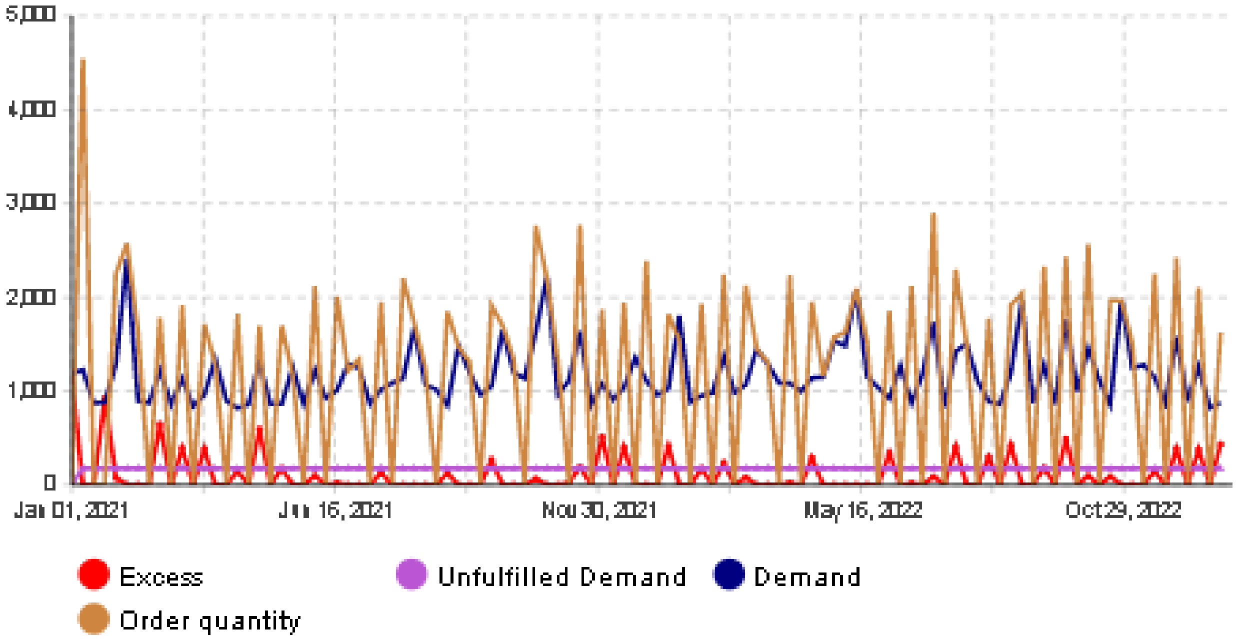

Figure 24. Indicators vs. time for item FG-003.

For item FG-003, there is fixed unfulfilled demand from 2021 to 2022 of 100 units approximately. Inventory levels were maintained between 0 and 1000 units and demand reach over the 25000 units. The service level continues to be within the acceptable range for the organization because the quantities that cause unfulfilled demand are small in contrast to the amounts that cause satisfied demand.

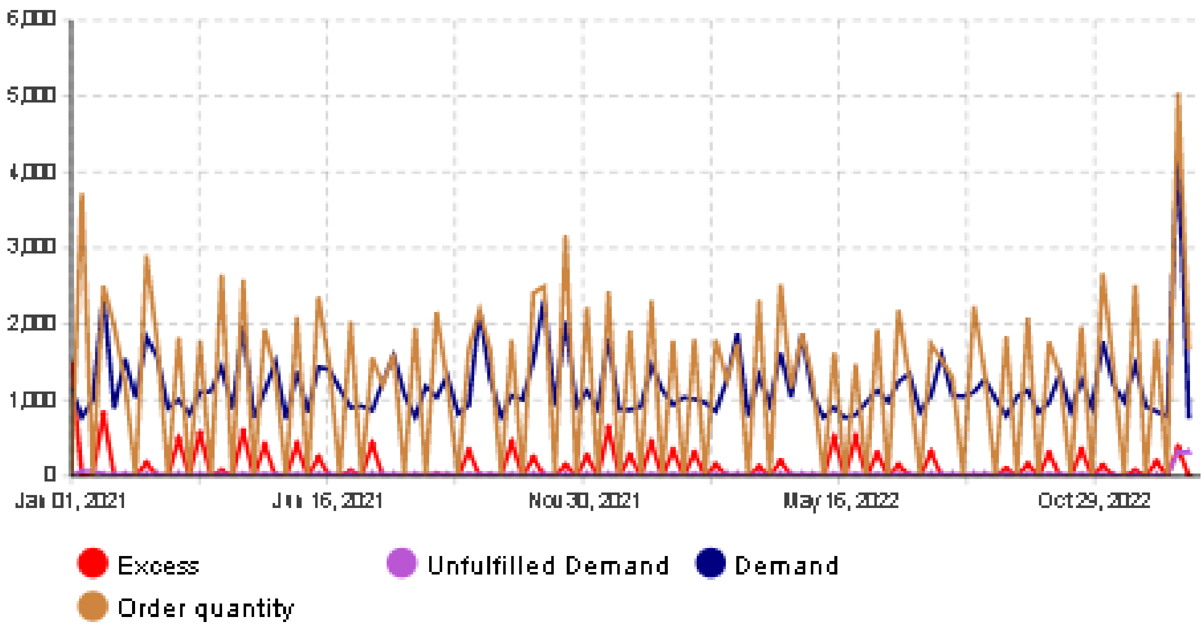

Figure 25. Indicators vs. time for item FG-004.

It is clear from figure 25 that demand for item FG-004 is slightly variable, which suggests high inventory levels. There is no unfulfilled presented between the 2021 and 2022. This implies that the variability of demand was absorbed by the factors considered in the calculation of zone sizes. The service level was high and the excess inventory was low. The model for this product is stabilized, which will allow a decrease in costs.

The four references provided excellent service, based on the behaviors described above. This is supported by the weighted service level obtained during the simulation's 120 weeks.

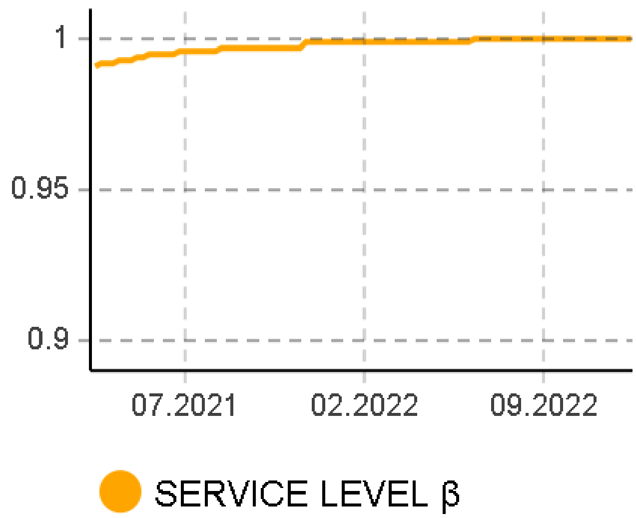

Figure 26. Service Level weighted from 2021 to 2022.

As shown in the figure 26, the average service level of the Syd Laboratorio Cosmetico's four hair dye line products have remained between 97% and 100% over the course of two years.

Through the simulation it was possible to observe the real-time behavior of each of the quantity buffers. As can be seen in the following illustration, the quantity buffer followed a dynamic behavior, adjusting weekly to the behavior of the demand and the inventory on hand remained at the yellow level despite the high variability of the demand.

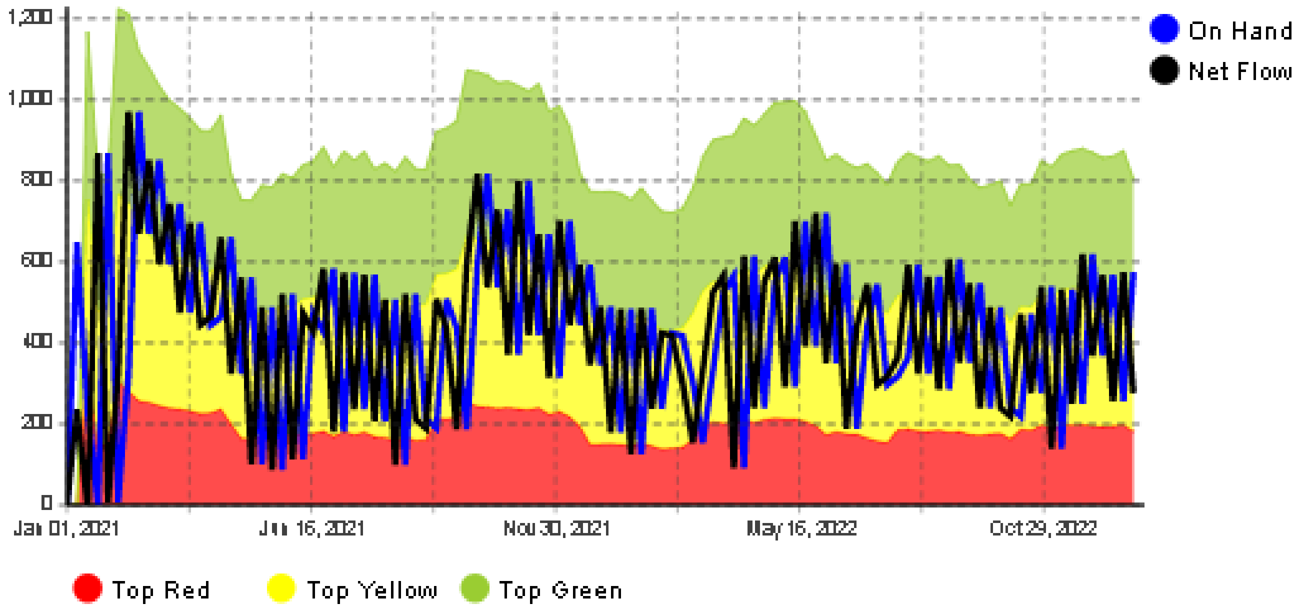

Figure 27. Quantity buffer vs. time for item FG-001.

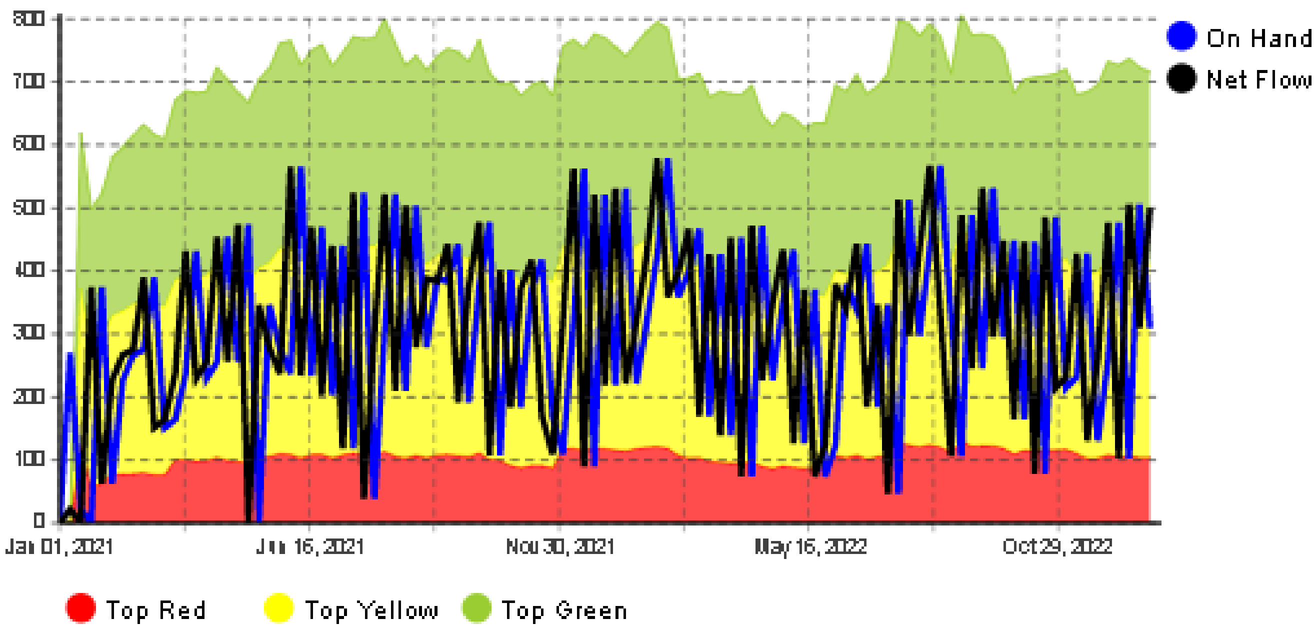

Figure 28. Quantity buffer vs. time for item FG-002.

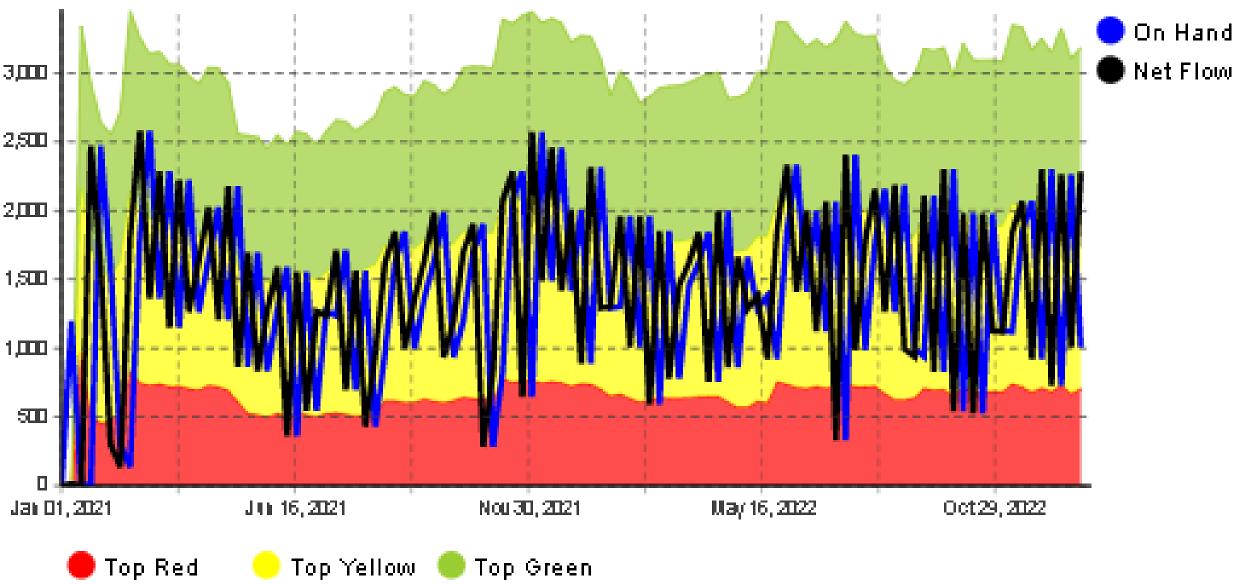

Figure 29. Quantity buffer vs. time for item FG-003.

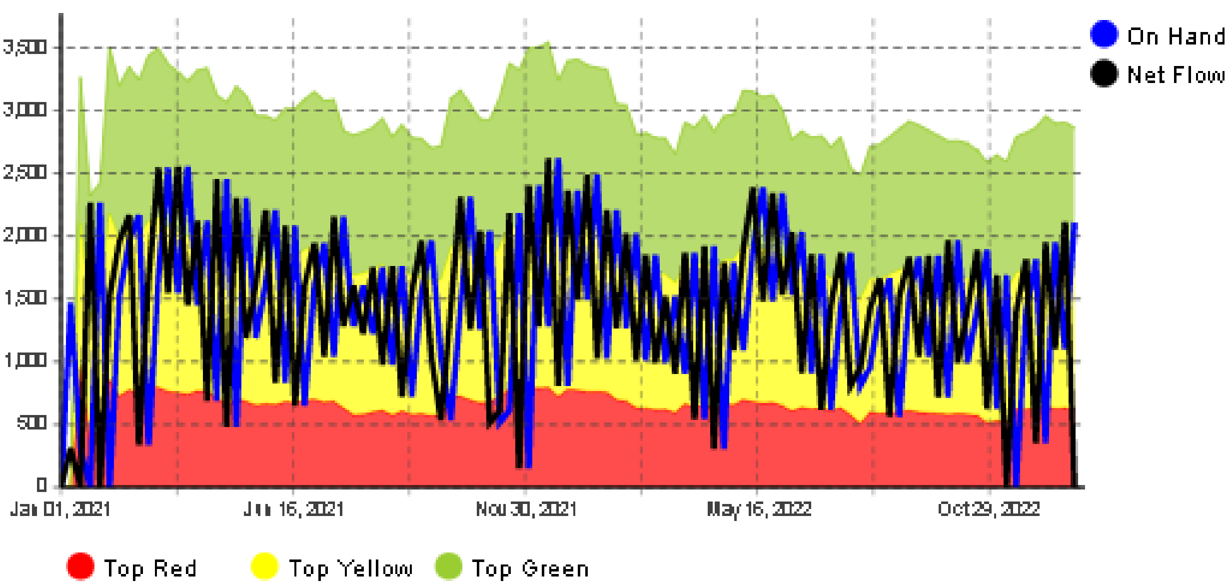

Figure 30. Quantity buffer vs. time for item FG-004.

In contrast, the simulation revealed that the capacity buffers in the hair dye production line are not used because the process fulfills the orders during the simulated time frame. In other words, the safety measures established for each zone are not used. Additionally, with the time buffers, the orders received weekly were programmed according to a FIFO policy by references for the weekly production in the company. The results of this scheduling policy allowed the company to produce the quantities required for each period without generating delays in delivery dates.

Finally, the DDMRP has an operational impact since it: generates a higher level of service, satisfies the needs of customers with more competitive costs, offers the possibility of generating new business, allows customer loyalty and increases competitiveness in the industry to which they belong. Similarly, it allows greater stability within the supply chain, protecting its available resources; it manages to synchronize all areas of the company so that its flow of information and products is done quickly to respond to demand signals and allows real-time monitoring to correct deviations between planned and executed.

The use of the DDMRP model in hair dye production line generates a significant financial impact for the company Syd Laboratorio Cosmetico SAS, with a benefit-cost ratio superior of 1. This means that the company can begin to obtain benefits from the model in a two-year horizon.

Benefit-Cost analysis

In order to perform a benefit-cost analysis for the implementation of the DDMRP implementation model, the NPV and the benefit-cost ratio (BCR) were calculated by comparing the simulation data for the years 2021 and 2022. Calculations can be found in the appendix 3.

The Net Present Value (NPV) of an investment is the sum of all future cash flows (positive and negative) discounted to the present. NPV analysis is a type of intrinsic valuation that is widely used in finance to determine the value of a company, investment security, capital project, new venture, cost-cutting program, or anything else that involves cash flow. The benefit-cost ratio (BCR), on the other hand, is an indicator that depicts the relationship between the relative costs and benefits of a proposed project, expressed in monetary or qualitative terms.

			2022 Risk DDMRP
Investment	$ 1.200.000	**NPV**	$ 29.755.548
WACC calculation	10%	PV revenues	$ 218.633.970
Period (moinths)	12	PV Expenses	$ 145.140.862
Tax rate	33%	**BCR**	**1,51**

Table 11. BCR, NPV Analysis.

The investment generated by the implementation of the model refers to: consulting, the implementation of the model and the possible costs that may be generated by the operational changes. The time frame is 12 months. According to the context of the country in which the company is located, the tax rate is 33% and the WACC calculated is 10%. The final result, as shown in the table 11, is that the investment is worth $ $29.755.548 COP today, and with an NPV greater than zero, the company should pursue the project. Additionally with a BCR of 1,51 that is greater than 1.0, the project is expected to deliver a positive net present value to a firm and its investors.

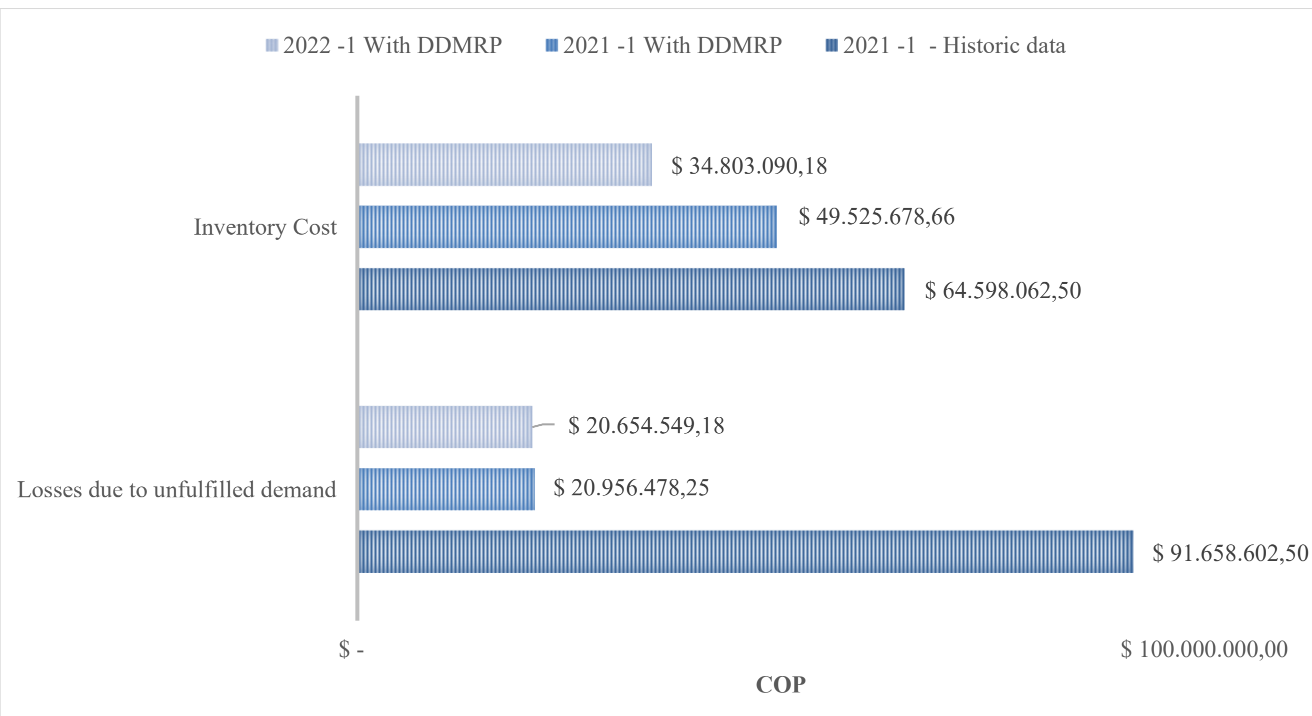

Figure 31. Costs and losses comparison for the hair dye line.

According to the results in Figure 31, losses due to unfulfilled demand decreased by 77.14% for the year 2021 compared to the real behavior of the same year. In addition, from 2021 to 2022 the unmet demand decreased by 0.61% under the DDMRP model, which means a decreasing behavior in losses and an increase in the perception of new customers. Furthermore, inventory costs reflected a decrease of 23.33% with respect to the DDMRP model in 2021 and 46.12% with respect to 2022 under the DDMRP model.

According to the financial analysis, the implementation would result in cost savings for the company Syd Laboratorio Cosmeticos SAS as well as an increase in sales of the Bentouch hair dye line.

Critical issues in the DDMRP implementation process

As demonstrated previously, shifting from traditional planning logic to a demand-driven approach reduces inventory levels and, consequently, inventory costs. Notwithstanding, when applying DDMRP, some factors must be taken into account that can affect the company's success and profits. Some of the criticalities found were as follows.

DDMRP triggers inventory orders based on sales and consumption data rather than forecasts. The methodology assists companies in ensuring that they always have the right products in the right place and in the right quantity by matching materials to market demand. However, in the case of Syd Laboratorio Cosmetico SAS, having the right information for the hair dye line was more complicated, this because the raw material consumptions vary for each product depending on the color of dye desired, so sorting and having a fixed quantity of raw materials was not the best option to find the actual needs and consumption. Consequently, it was decided with the person in charge that the maximum amount of raw material would be the value taken into account to identify the quantities used in the four identified hair dye’s products, since the use of the materials depends on a unique formula for each hair color that can have a greater complexity to identify each type of color in each hair dye product.

It should be noted that the demand in the DDMRP methodology may vary, but the average must remain fairly constant for the calculation of average daily consumption (ADU) to be accurate. If this is not the case, manual intervention will be necessary, which could be a frequent and very important control for the management of the company.

While determining where product should be stored is one of DDMRP's strengths, determining how much should be stored in those locations is one of its major challenges. Inventory buffers must naturally adapt to demand whenever product demand patterns display trends or seasonality; otherwise, service levels may change uncontrollably. Through the use of a seasonality factor that can be applied to safety buffer levels, DDMRP takes this fact into account.

DDMRP significantly reduces lead times, which is beneficial in any supply chain. However, some lead times cannot be easily reduced, limiting the extent to which the methodology can provide value. This could imply that DDMRP is most useful for companies that source everything locally or are considering doing so.

Despite the good results, it is necessary to recognize the sensitivity of the model to the value of parameters such as: decoupled lead time (DLT), order frequency and variability. These should not be assigned empirically and must follow all the necessary rigor based in the methodology to be determined.

Conclusions

In numerous cases, inventory management is supported by a system that limits and defines the inventory model to be used. It is difficult to completely adapt a system to a company's situation, and the methods used in the systems can be difficult to comprehend. This limitation may cause planners to question and modify the inventory policy a lot of times, resulting in inventory shortages or excess inventories. A structured process for defining inventory policy is proposed in this thesis to support inventory decision making and to reduce inventory levels in order to reduce maturities.

Given the behavior of the demand for hair dye products, it can be inferred that the most representative weaknesses of the current model of the company Syd Laboratorio Cosmetico SAS are; The total dependence on forecasts and the absence of inventory policies that protect the variability of supply and demand. Also, the tools used by the company do not provide relevant information for the operations planning and execution, in the current circumstances.

A detailed model with parameters based on the DDMRP methodology is presented, as also a simulation tool built within the theoretical framework of inventory management. It has been demonstrated through simulation in the planning system used that the implementation of an inventory model is required as a frame of reference to control the variability of inventories in warehouses. Planning systems, while useful, do not adapt to all situations, and when decisions must be made that are outside the norm, the only way to determine if the right decision on inventory policy is being made is to use a planning system. A structured model is the only way to determine whether you are making the correct inventory policy decision.

On the other hand, the positioning of the decoupling points in the materials structure allows for the risk of non-compliance with demand to be mitigated without incurring excess inventories. This is primarily due to the structure's use of an independent control system for each raw material. Each system is responsible for monitoring demand and supply behavior in order to order the required quantity. The efficiency of the quantity buffers is mainly due to the strategic calculation of the average daily usage, the variability factor and the lead time factor. These three factors are essential for the definition of buffer levels. If the factors do not correctly take into account the variability of demand and supply when calculating the quantities to be ordered, excesses or shortages may occur.

It is important to emphasize that the definition of the policy is a process that is always under continuous improvement and requires feedback. The process of modification and change needs to be facilitated. The inventory policy cannot be static, but must be under constant review to adapt to the new needs of the company.

Consequently, the company Syd Laboratorio Cosmetico SAS is interested in implementing the DDMRP model in all its production lines, since the benefit-cost analysis of the model on the Bentouch hair dye line revealed a value of 1.51, which is greater than 1. That is to say that the project is feasible and has the potential to provide significant benefits to the company, both economically and operationally. In addition, the company also intends to employ the AnyLogic software's simulation model as a tool for the analysis of its production processes and inventory management.

As a significant benefit, the simulation model developed may also be applied in the cases of a reduction in process time or a process improvement because it incorporates both Demand-Driven MRP analysis and production process modeling, including all operations and activities.

It is important to understand that the model can be implemented in Syd Laboratorio Cosmetico SAS as applied to the Bentouch hair dye line but to start swiftly and with knowledge of the facts, it is vital to point out that a training of the teams must be conducted, along with the time frame required for the model's experimentation, the execution, and post-execution enhancement phases.

Training staff members in the new logic's principles and application is a necessary component of updating the planning process. This is by no means a small matter, especially in the corporate context where, typically speaking, the planning of orders and production plans is left to personnel with in-depth professional knowledge in this area. By challenging the operational inertia that staff who have been using conventional MRP logic for order planning for years have absorbed, it is possible to ensure that the shift to a wholly novel method is fully assimilated.

Switching to a new management software not only causes issues with data management and service continuity, but it also creates a significant barrier for staff adaptation to a new technological solution. Given the complexity of management software, learning the functionalities in depth is a time-consuming process. However, it is fair to say that we are in the midst of a transition period in management software interfaces, which are becoming more user-friendly and intuitive.

With the DDMRP implementation, the company can identify supply or manufacturing requirements based on the update orders and not base its planning on forecasts as in its previous planning management. In this way, stocks can be constantly adapted to the evolution of demand. Product stocks are more visible and the same priorities can be shared throughout the company. Teams are less dedicated to emergency management and more to prevention and substantive improvement.

Recommendations

It is recommended that the DDMRP methodology be implemented throughout the entire supply chain in order to speed up the flow of materials and reduce buffers in distribution centers. Also, to perform a design of experiments to accurately determine the optimal combination of factors for the calculation of the quantity buffer levels.

As a second phase, it is suggested to continue the study with a proposal that integrates the entire supply chain management, especially with inventory planning with suppliers, in order to reduce inventories throughout the entire chain. In order to speed up the flow of materials and reduce buffers in distribution centers, it is advisable to use the entire product portfolio. This proposal should be directed at all its product portfolio and as well taking into account the complexities of the supply matrix.

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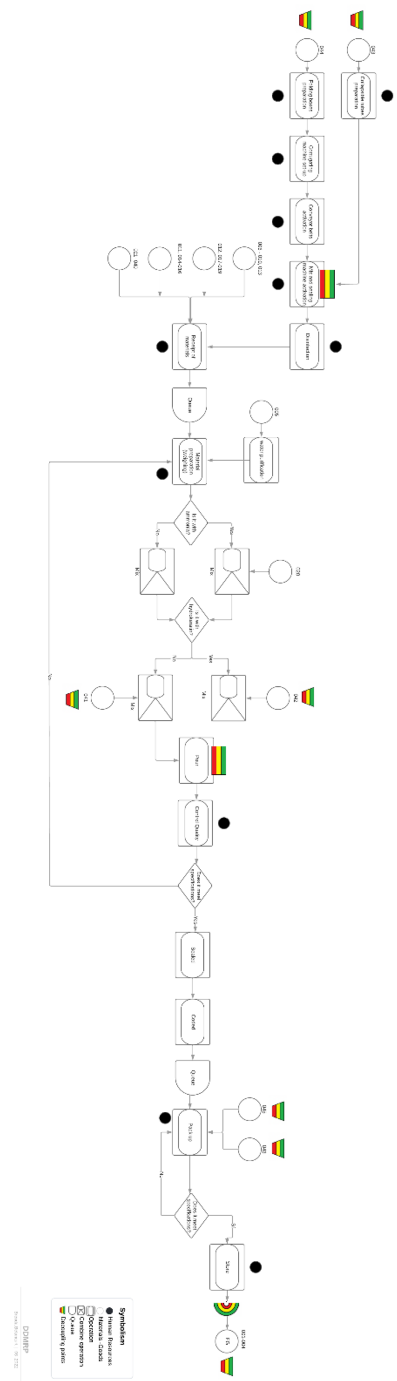
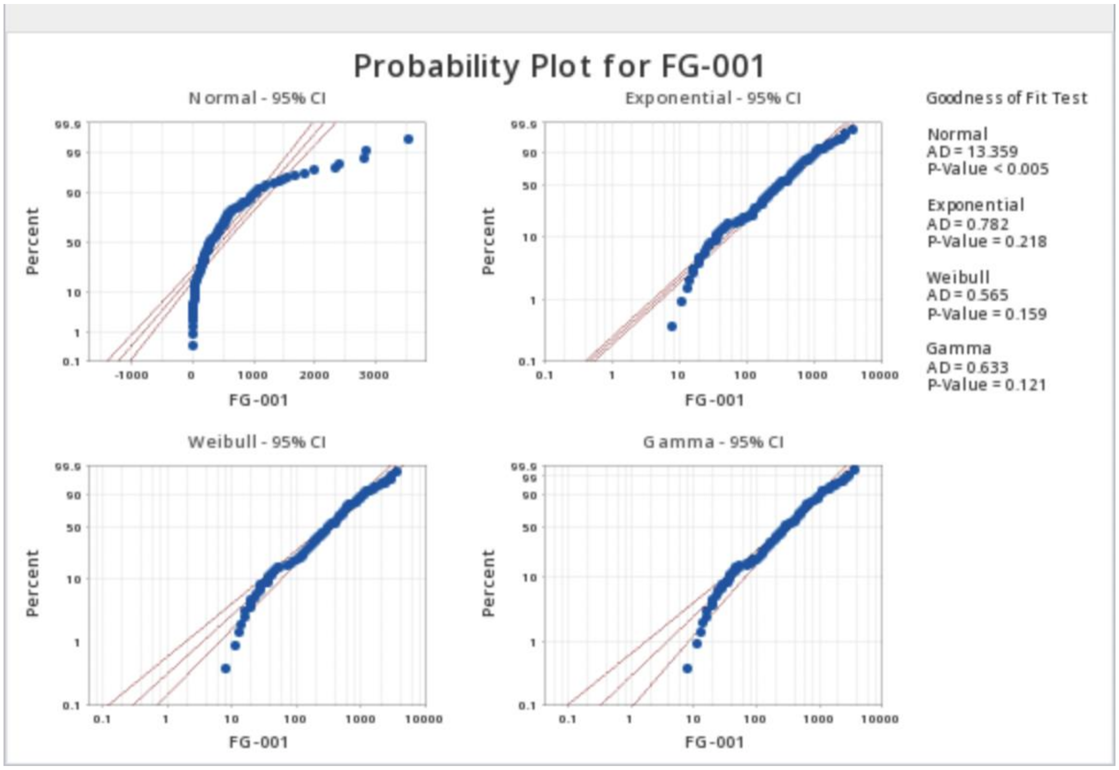
Appendix

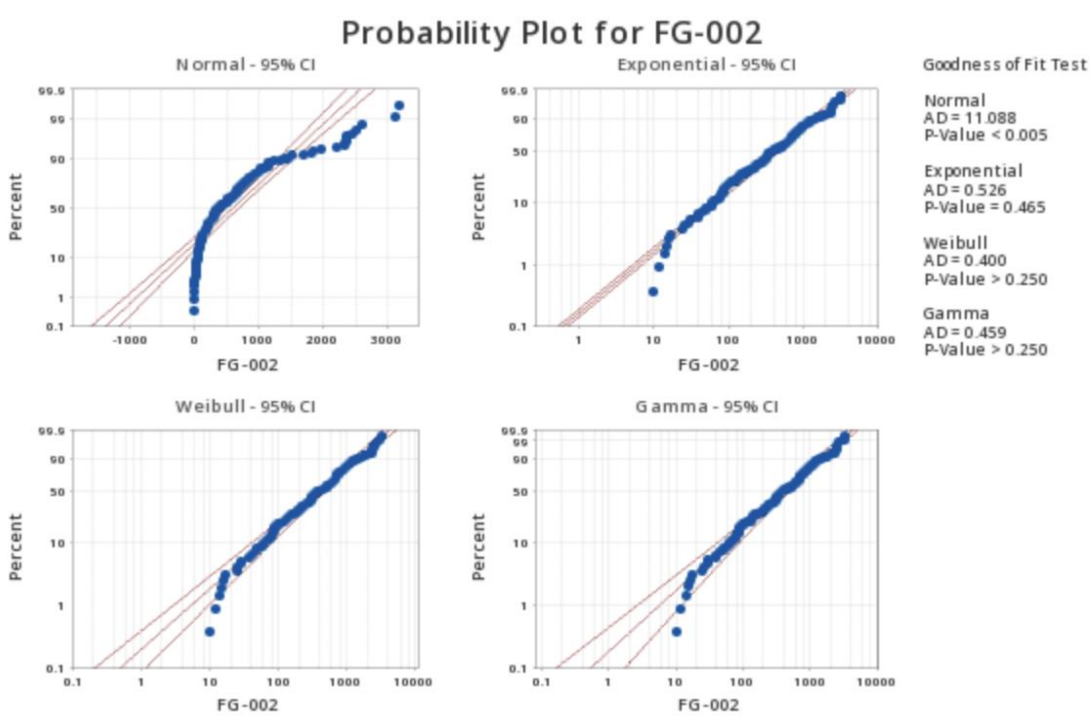
Appendix 1



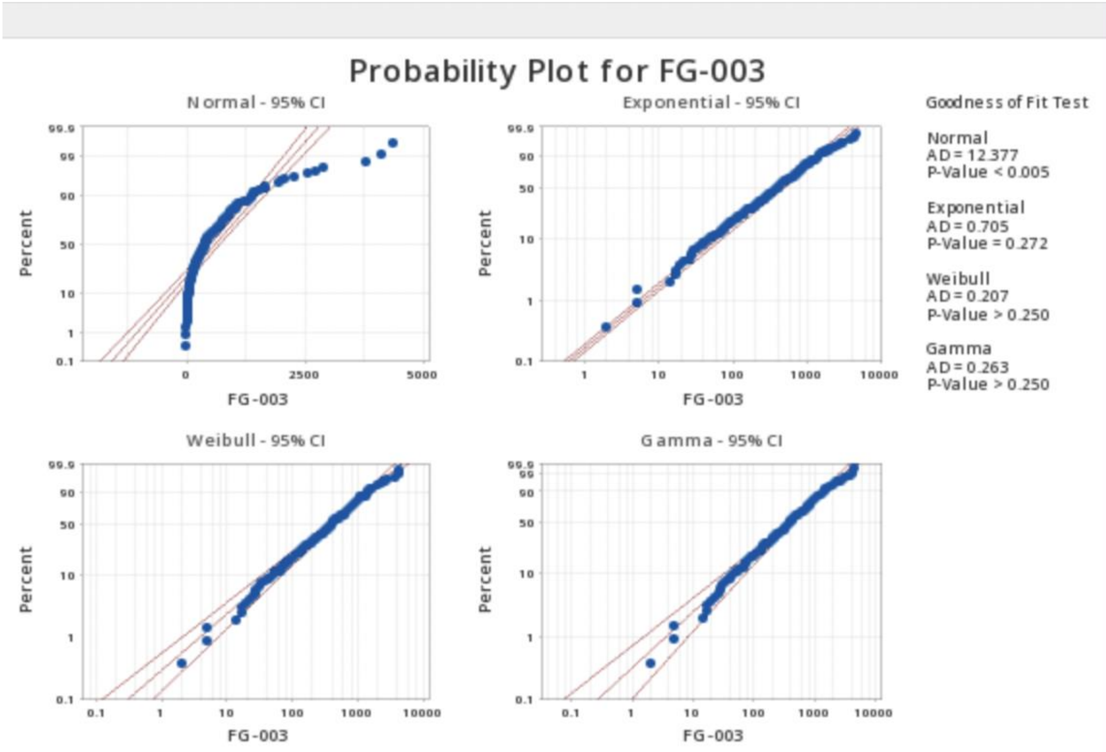
Appendix 2

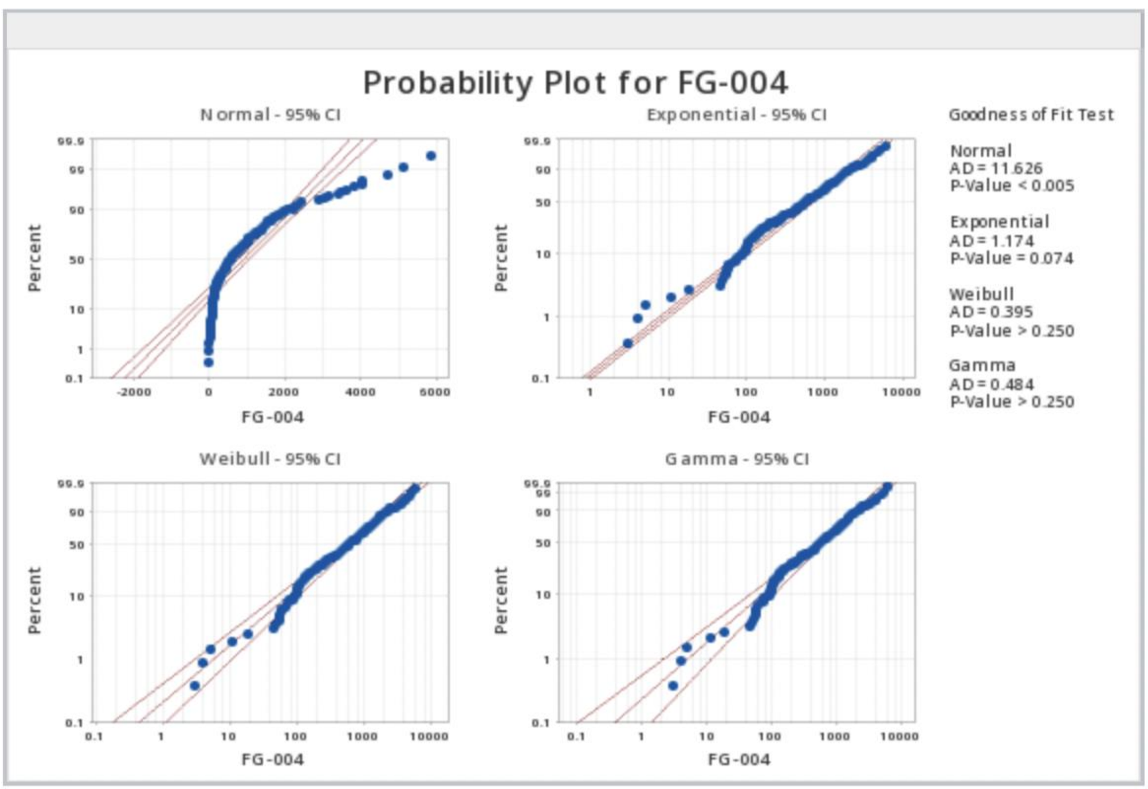


Probability Plot for FG-001
Normal - 95% CI
Exponential - 95% CI
Weibull - 95% CI
Gamma - 95% CI
Percent
FG-001
Goodness of Fit Test
Normal
AD = 13.359
P-Value < 0.005
Exponential
AD = 0.782
P-Value = 0.218
Weibull
AD = 0.565
P-Value = 0.159
Gamma
AD = 0.633
P-Value = 0.121



Probability Plot for FG-002
Normal - 95% CI
Exponential - 95% CI
Weibull - 95% CI
Gamma - 95% CI
Percent
FG-002
Goodness of Fit Test
Normal
AD = 11.088
P-Value < 0.005
Exponential
AD = 0.526
P-Value = 0.465
Weibull
AD = 0.400
P-Value > 0.250
Gamma
AD = 0.459
P-Value > 0.250


Probability Plot for FG-003
Normal - 95% CI
Exponential - 95% CI
Weibull - 95% CI
Gamma - 95% CI
Percent
FG-003
Goodness of Fit Test
Normal
AD = 12.377
P-Value < 0.005
Exponential
AD = 0.705
P-Value = 0.272
Weibull
AD = 0.207
P-Value > 0.250
Gamma
AD = 0.263
P-Value > 0.250


Probability Plot for FG-004
Normal - 95% CI
Exponential - 95% CI
Weibull - 95% CI
Gamma - 95% CI
Percent
FG-004
Goodness of Fit Test
Normal
AD = 11.626
P-Value < 0.005
Exponential
AD = 1.174
P-Value = 0.074
Weibull
AD = 0.395
P-Value > 0.250
Gamma
AD = 0.484
P-Value > 0.250

Appendix 3

DDMRP RISK													
Periods (months)	**2022-00**	**2022-01**	**2022-02**	**2022-03**	**2022-04**	**2022-05**	**2022-06**	**2022-07**	**2022-08**	**2022-09**	**2022-10**	**2022-11**	**2022-12**
Income		$ 32.776.381,48	$ 27.608.000,00	$ 37.434.000,00	$ 26.606.000,00	$ 35.650.000,00	$ 29.811.000,00	$ 40.853.000,00	$ 39.710.000,00	$ 28.269.000,00	$ 26.004.000,00	$ 31.372.000,00	$ 25.927.000,00
Variable costs and expenses		$ 6.000.000	$ 6.000.000	$ 6.000.000	$ 6.000.000	$ 6.000.000	$ 6.000.000	$ 6.000.000	$ 6.000.000	$ 6.000.000	$ 6.000.000	$ 6.000.000	$ 6.000.000
Raw material		$ 5.300.000,00	$ 5.300.000,00	$ 5.300.000,00	$ 5.300.000,00	$ 5.300.000,00	$ 5.300.000,00	$ 5.300.000,00	$ 5.300.000,00	$ 5.300.000,00	$ 5.300.000,00	$ 5.300.000,00	$ 5.300.000,00
Utilities		$ 700.000,00	$ 700.000,00	$ 700.000,00	$ 700.000,00	$ 700.000,00	$ 700.000,00	$ 700.000,00	$ 700.000,00	$ 700.000,00	$ 700.000,00	$ 700.000,00	$ 700.000,00
Contribution margin		**$ 26.776.381**	**$ 21.608.000**	**$ 31.434.000**	**$ 20.606.000**	**$ 29.650.000**	**$ 23.811.000**	**$ 34.853.000**	**$ 33.710.000**	**$ 22.269.000**	**$ 20.004.000**	**$ 25.372.000**	**$ 19.927.000**
Fixed costs and expenses		$ 18.974.503,28	$ 19.577.696,17	$ 19.530.396,53	$ 19.439.657,59	$ 18.989.850,97	$ 21.295.602,64	$ 20.684.437,48	$ 18.769.240,25	$ 15.506.432,67	$ 17.569.093,31	$ 20.184.639,68	$ 17.403.147,43
Lease		$ 8.662.500	$ 8.662.500	$ 8.662.500	$ 8.662.500	$ 8.662.500	$ 8.662.500	$ 8.662.500	$ 8.662.500	$ 8.662.500	$ 8.662.500	$ 8.662.500	$ 8.662.500
Inventory storage and handling costs		$ 2.222.610,12	$ 2.484.867,90	$ 2.464.302,84	$ 2.424.851,12	$ 2.229.283,03	$ 3.231.783,76	$ 2.966.059,78	$ 2.133.365,33	$ 714.753,34	$ 1.611.562,31	$ 2.748.756,38	$ 1.539.411,92
Inventory maintenance costs		$ 2.889.393,16	$ 3.230.328,27	$ 3.203.593,69	$ 3.152.306,46	$ 2.898.067,94	$ 4.201.318,88	$ 3.855.877,71	$ 2.773.374,93	$ 929.179,34	$ 2.095.031,00	$ 3.573.383,30	$ 2.001.235,50
Salary		$ 5.200.000	$ 5.200.000	$ 5.200.000	$ 5.200.000	$ 5.200.000	$ 5.200.000	$ 5.200.000	$ 5.200.000	$ 5.200.000	$ 5.200.000	$ 5.200.000	$ 5.200.000
Operating margin		7.801.878,20	2.030.303,83	11.903.603,47	1.166.342,41	10.660.149,03	2.515.397,36	14.168.562,52	14.940.759,75	6.762.567,33	2.434.906,69	5.187.360,32	2.523.852,57
Interest		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Income before taxes		**$ 7.801.878**	**$ 2.030.304**	**$ 11.903.603**	**$ 1.166.342**	**$ 10.660.149**	**$ 2.515.397**	**$ 14.168.563**	**$ 14.940.760**	**$ 6.762.567**	**$ 2.434.907**	**$ 5.187.360**	**$ 2.523.853**
TAXES (33%)		$ 2.574.620	$ 670.000	$ 3.928.189	$ 384.893	$ 3.517.849	$ 830.081	$ 4.675.626	$ 4.930.451	$ 2.231.647	$ 803.519	$ 1.711.829	$ 832.871
Utilidad neta		**$ 5.227.258**	**$ 1.360.304**	**$ 7.975.414**	**$ 781.449**	**$ 7.142.300**	**$ 1.685.316**	**$ 9.492.937**	**$ 10.010.309**	**$ 4.530.920**	**$ 1.631.387**	**$ 3.475.531**	**$ 1.690.981**
Depreciation expense		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Fixed asset investment	$ 1.200.000												
Investment in working capital													
Market value of fixed assets													
Gain on sale of fixed assets													
Working capital recovery													
Credits received	$ -												
Interests		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Loan amortization		$ 100.000,00	$ 100.000,00	$ 100.000,00	$ 100.000,00	$ 100.000,00	$ 100.000,00	$ 100.000,00	$ 100.000,00	$ 100.000,00	$ 100.000,00	$ 100.000,00	$ 100.000,00
Free Cash Flow (FCF)	-$ 1.200.000	$ 5.127.258	$ 1.260.304	$ 7.875.414	$ 681.449	$ 7.042.300	$ 1.585.316	$ 9.392.937	$ 9.910.309	$ 4.430.920	$ 1.531.387	$ 3.375.531	$ 1.590.981

IRR		10%	EA		

WACC calculation		10,0%			
Cost of debt (AE)		18,00%	EA		
After-tax cost of debt (AE)		12,06%	EA	PV revenue	$ 218.633.970
Cost of equity (AE)		10%	EA	PV Expenses	$ 145.140.862
Total initial investment		$ 1.200.000			
Value of debt		-$ 0			
Capital contributed by investors		$ 1.200.000			

NPV		$ 29.755.548
BCR		1,51