POLITECNICO DI TORINO

Master of Science in
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Master of Science Thesis

Development of a calculation model for material management using Demand Driven MRP (DDMRP) for a company in the Food Industry

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ABSTRACT

The selection of a proper procurement system is one of the most critical decisions from a company's strategic plan, as this not only plays an important role in defining production continuity but also helps to shape the entire supply chain. The "Demand Driven Material Requirement Planning" model offers a dynamic way to manage the procurement order creation process, bringing in the consistency offered by a classical MRP system, but with the flexibility derived from the decoupling point buffers. This case study presents the application of the previously mentioned model in a Aromitalia, a multinational company from the alimentary sector located in Settimo Torinese, Italia.

Aromitalia's business context allows us to evaluate the models' advantages and criticalities in an international scenario, with a complex supply chain containing suppliers and clients from different corners around the world. In order to properly assess the model adaptability to the company's context, an ABC product discrimination was developed to select a product code that can properly represent Aromitalia's catalogue as a whole, given a set of factors like BOM complexity, annual consume and income percentual representation.

After the 2-month simulation period, a cost analysis is realized to evaluate the overall improvement derived from the new model implementation in comparison to the current company's procurement system, which showed promising results not only when taking into consideration the financial KPIs but the overall operational and business processes like warehouse management, inventory administration and time usage optimization.

CONTENTS:

1. INTRODUCTION

Supply chain management has become one of the most discussed topics of the late years, especially when considering the amount changes derived from a global pandemic that closed borders and limited any kind of commercial activities during a two year period, creating a big hole in the budget not only at a country scale but also at the level of individual companies who had to either close or reduced their production capacities for big time intervals generating all kind of financial and managerial problems.

Such is the case of a multinational enterprise such as Aromitalia, a company within the alimentary sector specialized in the production of ice cream and pastry ingredients, with different production plants in Italy, Argentina, Brazil and Mexico. With the beginning of 2023, a global pandemic that seems to be setting back, reopening borders and markets that seem to be getting back into its original tracks, the supply chain management team within Aromitalia faces a whole new set of challenges in this evermore globalized world.

This thesis focusses in the evaluation of a DDMRP system within the Aromitalia's business processes. Starting with bibliographical research of the DDMRP background and the different material procurement planning models such as the one proposed by Ptak and Smith, in addition to all required concepts needed before starting the own applied model development. Continuing with a complete analysis of the company's catalogue and an ABC discrimination in order to find a product code that properly represents Aromitalia's production process, both in total output and in gross income representation. This product will also serve as a sample for understanding the material procurement methodologies and routines.

Once the product has been selected and the BOM has been studied, a two month period simulation will be carried out in which the results from both the current MRP system and the proposed DDMRP system will be gathered. Said results will be analysed with two different set of scopes, the first one related to the cost improvements and the financial feasibility of the project implementation, and the second scope related to the operational benefits in matters of improved warehouse management, inventory administration and optimized time usage within the procurement planning department.

1.1. Objectives

In order to validate the model and thesis development the following objectives are proposed:

Table 1. Thesis objectives

Objectives	***Method/Tool***
Analysis and understanding of the theorical framework from the MRP and DDMRP models by Ptak and Smith.	Research and assessment of the bibliographical material and previous works done on the subject
Diagnosis and analysis of the Aromitalia's production and business processes in order to comprehend the model's implementation context.	Empirical study of the manufacturing planning process by working within the production department and usage of engineering tools such as "process flow analysis" and "supply chain analysis"
DDMRP model development based on the parameters stablished within the Aromitalia's supply chain context.	Application of the DDMRP theorical modelling by Ptak and Smith under the constant interaction with the plant director and material procurement department for parameter and fact verification.
Model implementation cost-benefit assessment.	Financial and Operational comparison of the results obtained with the current MRP model and the proposed DDMRP model.

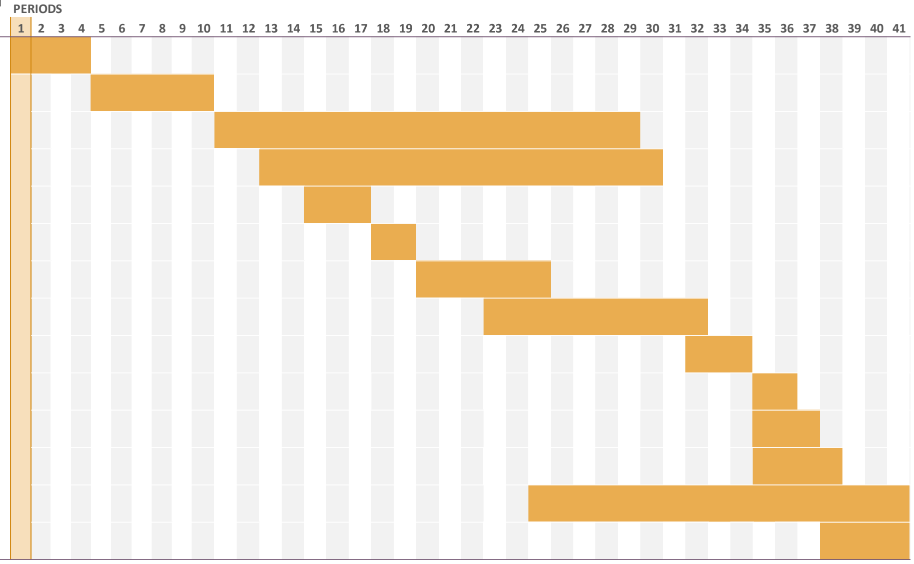
1.2. Development Plan

The following Gantt chart exposes the project research and development plan, divided by the main macro activities needed to carry out the model progress, starting from a more research and theoretic approach at the beginning, and later a more labour/development approach at the end. The whole project encapsules a 38 week period in which the model was developed in conjunction to the additional work developed for Aromitalia during the mentioned time period.

Figure 1. Project Gantt Chart

DDMRP Development

ACTIVITY	START	DURATION
DDMRP Background Theory Research:	1	4
Ptak & Smith DDMRP Theory Research	5	6
Company's production methods analysis	11	19
Company's material procurement analysis	13	18
ABC Product Analysis	15	3
BOM Product Analysis	18	2
Data Collection	20	6
DDMRP Model Development	23	10
DDMRP Simulation	32	3
Buffer Result Analysis	35	2
MRP vs DDMRP Analysis	35	3
DDMRP Results Cost Analysis	35	4
Report Writing	25	17
Conclusions	38	4



As seen on Figure 1, the model work plan was divided on a series of macro activities linked to the thesis objectives to evaluate the DDMRP model in an alimentary production context. These activities were:

- **DDMRP Background Theory Research:** As with all investigation projects, the first step is to do a background and bibliographic study in order to gain the knowledge and tools necessary to start developing and evaluating the DDMRP model in the given environment.

- **Ptak & Smith DDMRP Theory Research:** Once the general concepts have been researched and understood, its crucial to continue with the applied theory and vanguard models such as the DDMRP theory by Ptak and Smith which will work as a foundational base for the development of this project.

- **Company's production methods analysis:** One the largest macro activities contained inside this project is the analysis and understanding of the company's production and planning methodologies which is crucial for setting-up the parameters required by the DDMRP model.

- **Company's material procurement analysis:** At the same time the production process is getting analysed, its common that doubt surges in regards to the previous steps required to get to the production planning, this being the raw material procurement process which is the main focus of this specific case study as it the main target for the DDMRP target.

- **ABC Product Analysis:** One critical step in the model development is the decision of the product to be analysed and simulated. In this case it was decided to use the ABC product categorization as a discrimination process to identify a product code which properly represents the production process based on total output and percentage in the company gross income generation.

- **BOM Product Analysis:** Once the product code is decided upon, the model development continues with a critical analysis of the product BOM in order to identify and comprehend the different product levels and characteristics. This step is of great importance due to the implications related to Strategic Buffer Positioning and the identification of the decoupling points.

- **Data Collection:** In this phase, all the required information will be extrapolated form the company's ERP system based on the selected product and timeframe.

- **DDMRP Model Development:** The most significant step in the entire project, in which based on the previous theoretical and empirical data recollected, the DDMRP model is created to simulate the behaviour of the inventory and procurement orders for the selected timeframe.

- **DDMRP Simulation:** After the model has been created and the parameters values have been selected, the model will be simulated within a two-month timeframe selected in conjunction with the material procurement department in which the model results will be compared with the ones obtained by MRP model currently used by the company's ERP system.

- **Buffer Result Analysis:** The obtained buffer values will be evaluated in terms of the On-hand value in comparison to the each of the buffer areas. Additionally, it will be examined how the buffers represent the company's present behaviours and how would they fit in the current situation in case they end up being applied.

- **MRP vs DDMRP Analysis:** An important part of this model analysis resides in the behavioural comparison between the two previously mentioned models and how they adapt to comply with the company's current and real procurement methodology. It then becomes imperative to analyse code per code the variations that occur when changing the method of creating the procurement orders.

- **DDMRP Results Cost Analysis:** An important aspect of the project viability, if not the most important one, is the project's financial feasibility. A thorough evaluation of the economical values obtained from the simulation is then due in order to obtain a positive review by the company's board of directors.

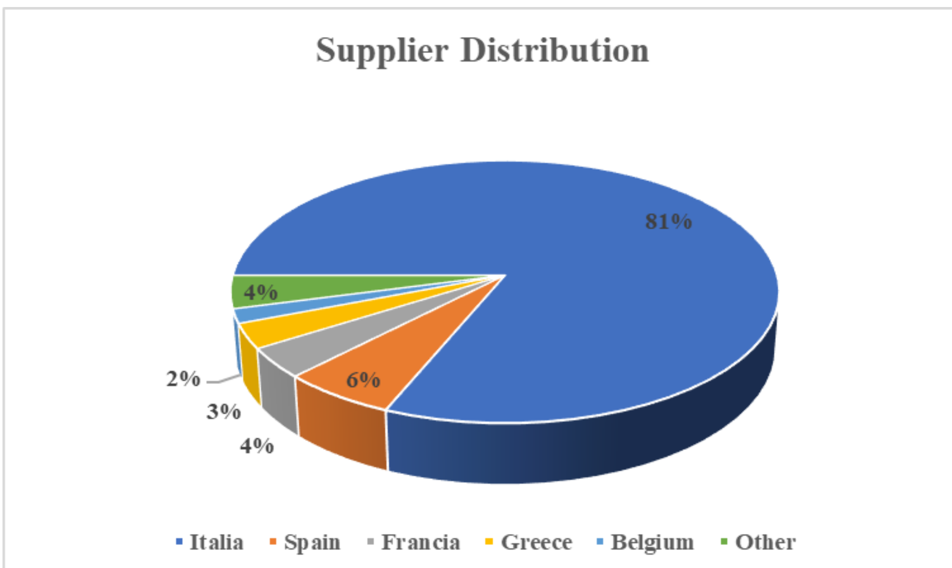
- **Report Writing & Conclusions:** Finally, the last step missing is the creation of the report that clearly explains the set of actions taken and the respective results obtained, with the addition of the analytic conclusions of the respective simulation and comparison results which clarify and quantify if the model would bring and improvement to the company is they were to be applied.

2. THEORICAL FRAMEWORK

2.1. Supply Chain

Before start talking about what a Material Resource Planning program does or its main advantages, it is better to start by explaining the general concept that gives reason study, this being the Supply Chain Management. First of all, a Supply Chain is considered as a defined network of companies and people who join forces towards the creation and delivery of a finished product. On general terms, the links on this chain can be categorized as Suppliers whose main objective is the raw material gathering, the manufacturer who transforms these raw materials into a finished product and the distributor who deliver the product to the end consumers.

Figure 2. G.E.I S.p.A supplier distribution



It then becomes clear that an establishing an appropriate SCM (Supply Chain Management) is a critical objective for any company, as optimizing this chains results in a shorter time to market, lower production costs and better resource usage. In a world that becomes more and more globalized each year, having an optimal SCM helps companies to remain competitive and ensure a long run stability. Even though a Supply Chain can be oversimplified as the links between Supplier, Manufacturer and Distributor, when approaching the SCM concept in a more profound way it should be mentioned that is also made out of other important areas such as Research and Development, Marketing, Finance and Costumer Care/Service.

Many types of SCM models have surged during the years trying to accommodate to the different company structures and its main strategical objectives, a few worth mentioning are:

- Fast Chain Models: these types of SC models are characterized by a short time to market and are typically used by companies whose production is trend-dependant, the limited response time surges as the company needs to be able to get the merchandise to the final consumer as fast as possible in order to profit the ongoing trend as long as it lasts. The research and development team in this type of SCM is generally characterized by small project with limited deadlines, which usually don't get delve into deeper concepts.

- Flexible Models: Mainly used by companies who work on personalized products or seasonal demands, a flexible supply chain model is able to properly adapt to cyclical demand peaks followed by long periods of almost none existing demands. The success of this models depends on the company's ability to previously prepare for the high demand season and to shut down in a controlled manner once the demands start to decrease. One key aspect of this type of SCM model is its close dependence on accurate demand forecasting.

- Continuous Models: usually adopted by companies with a steady production that experience little to no product variations during the year. This type of models require a company structure that is built around high demand products with a big material flow though the production processes, which lead to a tight output and inventory control. In order to properly satisfy the supply chain requirements, the material acquisitions department must constantly order new raw materials and have a real-time picture of the inventory to avoid going into stock-out.

A common doubt that surges when talking about SCM is how closely related this is to logistics, or even if they are an interchangeable term. However, when talking about SCM in a holistic manner, logistics compose only a small link within the whole supply chain. Logistics can be defined as the group of activities necessary to move objects or information from the starting link to its final destination. Joining both concepts, we can then describe logistics as the activities that ensure a stable connection from one stage to another throughout the complete production process.

Probably one of the harshest periods of recent history was the Covid-19 pandemic, and supply chain management was not in the clear regarding its influence. The border shutdown and capacity control at production plants caused significant damage to the supply chain structure, as manufacturing cost and delivery times skyrocketed at a pace never seen before. Supply of essential products became uncertain due to the continuous shift in border policies and unforeseen demand peaks for goods such as masks and hand sanitizer. This was an incredible test to SCM, and a reminder of how important it is to stablish a safe and robust structure in order to survive the everchanging global economy.

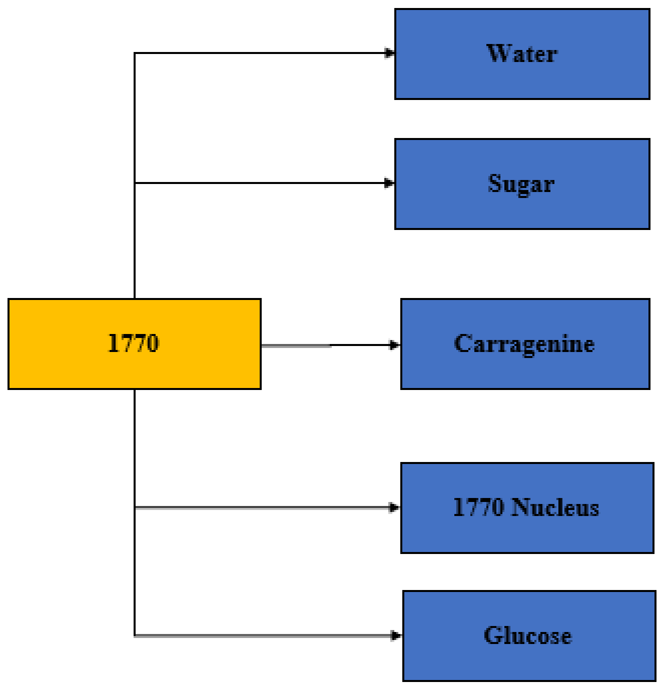
2.2. Bill of Materials (BOM)

Another fundamental concept needed before entering into the understanding of what an MRP is and what it serves for, is the one of Bill of Material or BOM for short. The BOM can be described as a detailed list of all the raw materials, components or assemblies needed to complete the final product with the respective required quantities. It is in a nutshell, a blueprint of everything that is needed to build a product.

There are multiple advantages that come from the usage of a BOM within a production process, some of the most known are its use for estimating total material costs, to control and avoid material shortages, reduce production waste and find product vulnerabilities. Its importance when talking about an MRP then becomes clear, as this list of materials can be used for tracking and planning material requirements which will then lead to a raw material acquisition order.

Figure 3. Bill of Materials for single level products

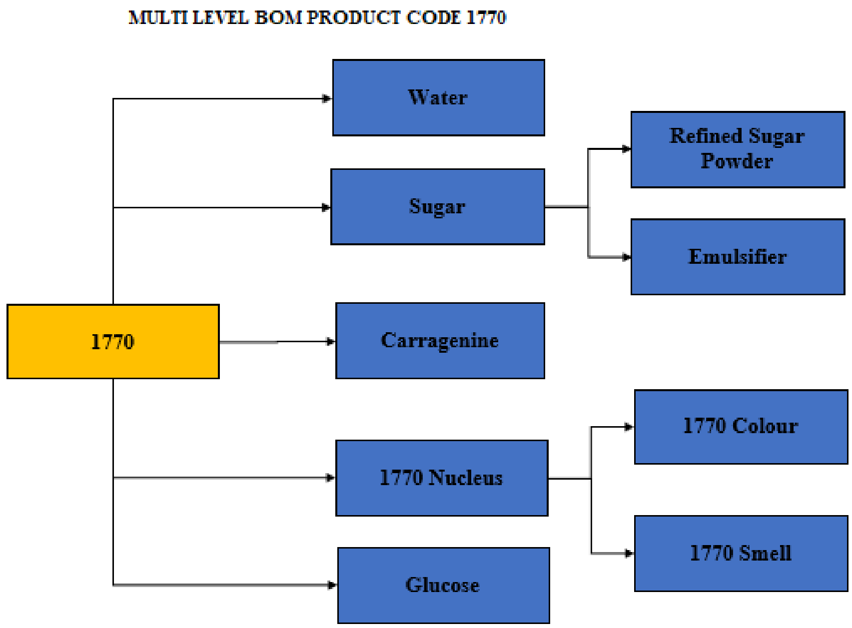
SINGLE LEVEL BOM PRODUCT CODE 1770



At Figure 3, it can be observed the typical BOM structure with the finished product at the top and the ramification of all the needed components at the bottom. This specific case of BOM consist of only 1 sub-level of components, which can be useful when trying to get a general picture of what parts/elements compose a finished product but clearly lacks any depth needed for a more detailed and specific analysis, as the one required for structuring an MRP.

Additionally, while a product description with such a general scope might be useful for marketing or administrative uses, any engineering or R&D focus might become difficult due to the lack of specifications. One clear example of this can be substituting a component in case of defect or lack of availability, the single level BOM lacks the required information between "father and child" components needed to analyse or predict any possible implications caused by a product modification.

Figure 4.Bill of Materials for multi- level products



Multi-level bill of materials, such as the one depicted in Figure 4, require a significantly bigger amount of effort to be created. This difficulty arises from the fact that all structural relationships from parent and child components needs to be specified and depicted in the graph. This type of BOM can be used as a foundation block for a production planning system, a material procurement system, or even a whole ERP system. The information gathered includes critical information necessary for basic business processes like production planning, product costing, material procurement and quality control.

A more detailed version of the previously discussed BOM is a Manufacturing Bill of Materials or MBOM for short. A MBOM can be described as an all-inclusive list of not only a product components but the required manufacturing sequence needed to assemble the finished product, as well as the assembly lead times between the father product and its subcomponents. These lead times then allow the MRP to calculate the reorder point for the raw materials in order to avoid production delays related to unavailability.

2.3. Material Resource Planning (MRP)

The last indispensable concept needed before entering into what an MRP does and its importance to modern business processes is the “Bullwhip effect”, which is usually described as the amplification effect that misinformation suffers when traveling upstream or downstream the supply chain. This misinformation can move the inventory level from a point of out-stock to excess inventory in a few actions. A clear example of this effect is when based on an exciting prospect, a business decides to order a bigger amount of raw materials to cover the forecasted demand, its supplier seeing the increased orders decides to order more raw materials himself to cover for possible demand peaks and the cycle continues to repeat itself all the way up the supply chain until it reaches the first link, whose receives an enormously increased amount of orders.

As commerce and economical interactions have become more global, businesses are required to optimize and develop more agile processes in order to maintain competitive in a market that is more and more hostile each year. To help with the expanding business operations, Rolls-Royce and General Electric engineers in 1950s developed the famous MRP system which aided activities such as production planning, inventory management and procurement and product costing.

Based on the information received from the BOM, the MRP system is able to calculate all the material requirements derived form the “dependant demand”, this demand regroups all the raw materials needed to cover the manufacturing processes given a set timeframe. The MRP then helps the production departments stablish an appropriate time and amount of raw materials to be ordered based on a given set of factors such as suppliers lead-times, minimum order quantities and warehouse availability to name a few. This detailed and synchronized list of required materials then transform into transfer orders at the distribution centres, an assembly order at the production plant and a reorder signal to the respective suppliers.

The main objective of a properly configured MRP is to properly coordinate a company’s replenishments in order to drastically reduce the overall inventory, avoiding in this way the expenses related to having “ a little bit of everything all the time”. Calculating the component demand based on the father product demand drastically reduces calculation efforts and uncertainty derived from inaccurate component forecast.

However, even a powerful tool such as an MRP brings its own set of problems, one of which is unsolvable as it is linked to the own nature of how the tool works and calculates the order plans. Having such a rigid structure and a strong link between each level of the BOM makes the system results very “nervous” to any minor change to the calculation parameter or input information, a sell order for an additional product unit may derive in multiple purchasing orders if the inventory levels go below the safety level. This problem worsens when we take into consideration purchasing batches and minimum order quantities, as an additional unit requirement for a specific component may derive in a purchasing order for thousands of units if the minimum order is big enough.

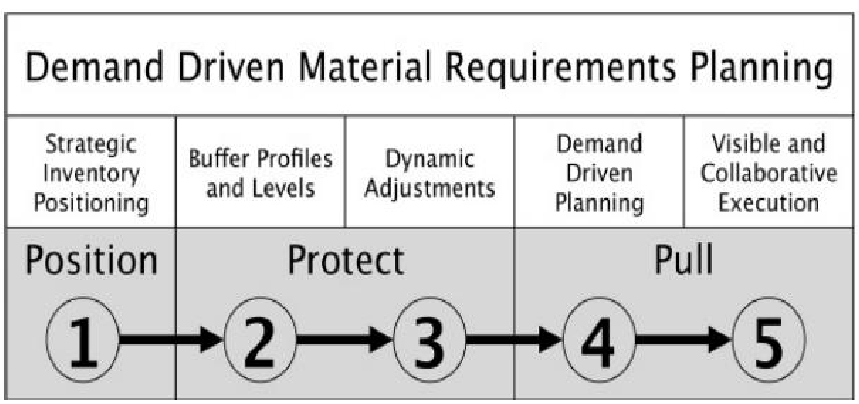
2.4. Demand Driven Material Requirement Planning (DDMRP)

The Demand Driven Material Requirement Planning is a term created in PeopleSoft around the year 2002, it originated as an effort to improve the not optimal results observed when implementing and utilising a regular MRP within businesses with new and everchanging requirements. This newly generated concept can be defined as a model able to generate procurement orders and help schedule production, based on a combination of critical factors like:

- Actual demand
- Strategic decoupling points
- Stock control points
- Capacity buffers

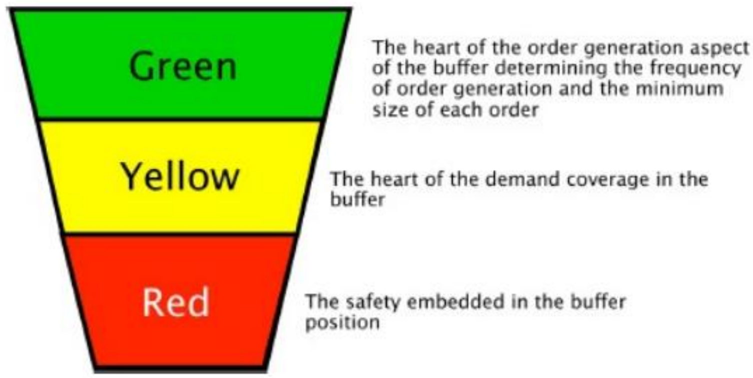
The calculation of these parameters is guided by a set of five components, as seen in Figure 5, which together stablish the sequence necessary to accomplish the DDMRP mantra "position, protect and pull". Starting with the first of the terms, "Strategic Inventory Positioning" helps determine where the decoupling points will be placed within a product BOM. "Buffer Profile and Levels" will determine the amount of protection that will be given to each of the already placed decoupling points. "Dynamic adjustments" indicate the foreseen variation of the buffers constructed around the pre-defined parameters (operational, administrative, sales, etc), while the last two set of concepts indicate how the system is executed and analysed.

Figure 5.DDMRP Components



There are several advantages derived from utilising a DDMRP, we can start by mentioning how it helps promote and protect the flow of relevant information upstream and downstream the supply chain, which then derive into cost and investment reductions of non-urgent or non-useful materials. It also allows companies to reduce and compress lead times, by the use of decoupling points, which help mitigate demand signal variations, preventing the negative effects originated from the system "nervousness" typical of regular MRPs.

Figure 6. DDMRP Buffer classification



3. CONTEXT

3.1. Aromitalia (G.E.I S.p.A) History

The history of G.E.I. S.p.A. dates to the beginning of the last century, when under the name of Norzi SA the company, founded in 1908, produces aromas and essences for particular industries such as: sweets, pastry, wine, liqueurs and carbonated drinks. In 1942 Guglielmo Ferrero took over the company Norzi SA incorporating the activity into the company APE SA. The rapid growth of the business allows in 1956, by acquiring the Gilmio company, to expand the production to the most sophisticated preparation of ingredients for ice cream powder for professional use.

The curious approach, in the formulation of recipes, to help synthesize and simplify the meticulous and elaborate processes that Italian gelato masters use for the production of ice cream, will soon create the premises for the success of the ingredients distributed under the Aromitalia brand.

In 1972 the Gruppo Essenziero Italiano (G.E.I. Spa) was founded, which accomplished the dream of the founder Guglielmo Ferrero to create a complete company within which there are brands such as Aromitalia (semi-finished products for ice cream and pastry), Nectar (research, development and production of essences and aromas), Gelsystem (a company specialized in the construction of new ice cream parlors) and an efficient research and development laboratory.

In the following years, his son Cristiano Ferrero would lead G.E.I. Spa to expand its production and distribution boundaries, first in Germany in 1976, then in Spain in 1979 by founding Aromitalia

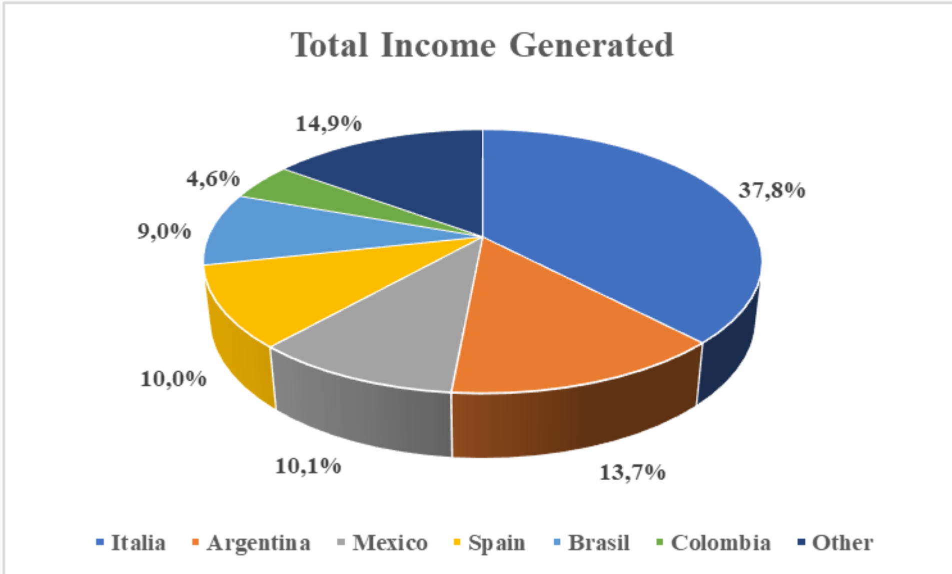
Iberica SA, in 1980 in Argentina with a plant equipped with an efficient production activity able to fully supply all South America, in 1997 in U.S.A., in 1998 in Brazil adopting the same production and distribution model stablished in Argentina, in 2003 Mexico by establishing "Natural It Mexico SA" and in 2009 in Romania directly with "Helite Italia Flavor srl".

Figure 7. Map representation of G.E.I S.p.A production plants

3.2. Current Situation

Aromitalia is a company of the G.E.I S.p.A. group, specialized in the production of ingredients and semi-finished products for pastry and ice cream with the main headquarters located in Strada Cebrosa 21, Settimo Torinese. With 5 different production headquarters located all around the world (Italia, Argentina, Mexico, Brazil, Turkey), Aromitalia can be categorized as a medium size multinational company made up of 200+ employees without considering commercial/sales representatives. With a gross income of 91 million euros during 2022, Aromitalia's main clientele can be traced back to Italia, Argentina, Brasil and Mexico, which together cover more than 72% of the company's sales.

Figure 8. G.E.I S.p.A clientele distribution



It is worth mentioning, that before starting the development of the thesis project, I was introduced to the entire production process, counting with different production departments and product lines. I was also introduced to the different managers of the purchasing, logistics and production department, all with the aim of getting to know the different working groups in depth. This introduction to each of the areas that make up the operation side of the company, would turn out to be of great help when developing the DDMRP as it made getting the required information and confronting the results significantly easier.

Within the company, the production department is where most of the project development took place. This particular work group is focused on the management and planning of production programs, thus serving as a bridge between the sales orders created by the commercial department and the shipments of goods created by the logistics department. In general terms, the production department performs the following tasks:

- Production planning to meet product demand.
- Management of the purchase of raw materials to carry out production.
- Control and monitoring of production orders.
- Review and analysis of the final quality of the product for sale.
- Continuous improvement of production capacity and processes.

3.3. Production Process

Aromitalia as a company produces a significantly large arrange of products, going from milk-based powders to oily dark chocolates, and even fruit based aromatic sauces that enhance and improves the ice cream final taste. In order to optimize the whole procedure and taking into account that a wide range of products requires a wide range of production processes, it was decided to create distinct product families to handle the different formulas and specialized machinery in a more accurate and clear manner. These product families are stablished by the company's research and development department, who taking into consideration the raw materials and required processes needed to obtain the final product, categorize each product code into a group of similar characteristics.

3.3.1. Products Families

AROMI: Starting with the smallest department from the plant, the "Aromas" department is responsible for preparing the base product for all the other departments, at this point of production the aroma and final color of the product is defined. This pre-processing makes it possible to facilitate and simplify the production process in other departments since they do not have to weigh or measure small components.

NUCLEI and POLVERI: These two production departments are the ones in charge of producing the "Gelato" powder milky base. The first department makes the core of the product, also known as the "Nucleo", which dictates the final flavor and consistency. The second and last department, is in charge of adding sugar, milk, or cacao in order to stabilize and obtain the desired concentrations.

OLEOSE and CIOCCOLATO: This two deeply connected departments work with oily and dense products. An example of the raw materials used in this department are chocolate, almonds paste and pistachio paste. This part of the company is in charge of transformation the cacao or almonds seeds that come in as raw materials, into chocolate sauce and creams used to decorate and add flavor to the ice cream.

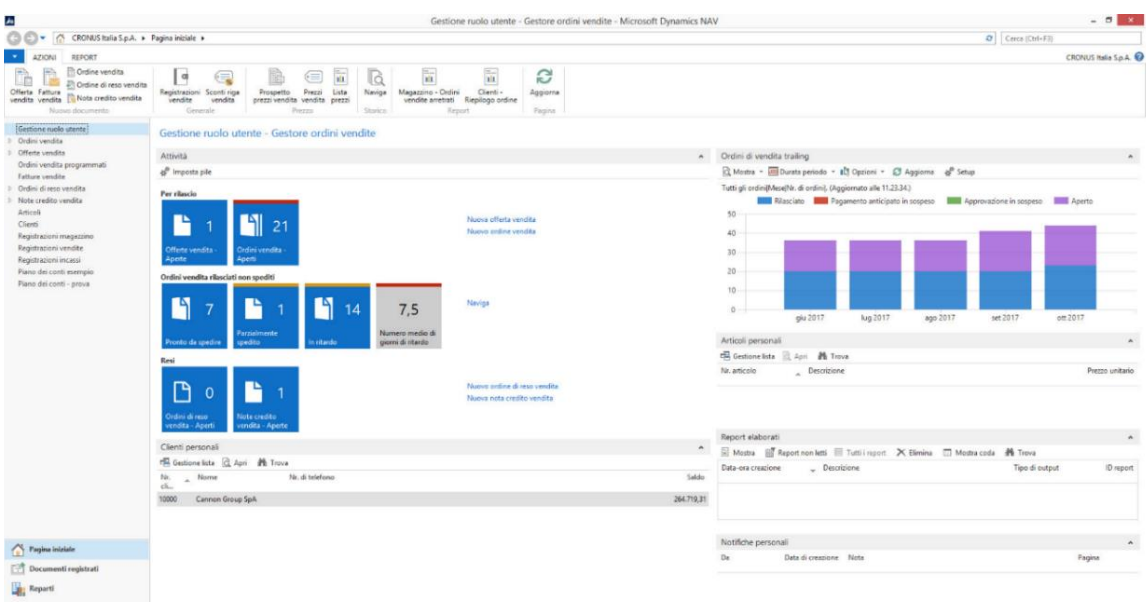
FRUTA: The fruit department oversees the production of all fruit-based products, ranging from bananas to coconut and even some egg based Italian recipes. It is one of the most complex departments as its raw materials need to be constantly refrigerated to maintain the best quality possible, therefore during the production process the product suffers constant temperature changes, going from boiling to freezing in a matter of minutes.

3.3.2.Production Program

Comprehending why products are divided into categories helps us understand how we are going to decide which product code is going to be analysed and will later participate in the simulation created to evaluate the DDMRP performance. The main operational program or ERP used in Aromitalia is called Navision by Microsoft, this tool helps the production department with the control and schedule of the production orders needed to satisfy the demand previously calculated by the commercial and sales department.

The mentioned tool helps create a production plan for each of the previously described product families, taking in consideration important factors such as: machinery capacity, number of available working hours, process time length (also called cycle time) and the most important factor related to our model development, the resources or raw materials availability.

Figure 9. ERP System used for production planning



The first part of the production planning is done in a semiautomatic manner, where NAV (short for Navision by Microsoft) gives a preliminary number of production orders to be manufactured based on the sales orders uploaded by the commercial department. The program starts by comparing the current available stock with the stablished point of reorder, if the stock goes below this threshold a flag is emitted and a production order is created. This allows the planning department to have a clearer overview of what the weekly/monthly workload is like and the criticality of certain product codes which have a closer date of expedition.

In addition to the date of the expedition, there are multiple factors that must be considered when developing the daily production schedule for each department, as seen in Figure 10. Daily production schedule for Oily department. Some of these critical factors include: allergenics, product color (as production must go from clearer to darker in order to protect the product specifications), certifications such as Ḥalāl, Kosher or gluten free, and most importantly, raw material availability. This last factor is the most important as the unavailability of a single component blocks the whole production for that specific code.

Figure 10. Daily production schedule for Oily department

						PROGRAMMA OLEOSE						
						SETTIMANA 03 DAL 17/01/22 AL 21/01/22						
LUNEDI' 17					**MARTEDI' 18**				**MERCOLEDI' 19**			
	Codice	Descrizione	N°	Dose	Codice	Descrizione	N°	Dose	Codice	Descrizione	N°	Dose
I Molteni					2362	PASTA TORTA AL LIMONE c.n. x SET	1	487.5	2986	VARIEGATO SPECULOOS x SET	2	495
II Molteni	2365	VARIEGATO TORTA AL LIMONE x SET	1	490	2365	VARIEGATO TORTA AL LIMONE x SET	1	490	2737***	PASTA NOCCIOLA	1	450
I raffinatrice	1145	PASTA CIOCCOLATO BIANCO	1	483	11152	SEMILAVORATO VARIEGATO TORTA LIMONE	1	425	11152***	SEMILAVORATO VARIEGATO TORTA LIMONE	2	425
	2985	PASTA SPECULOOS x SET	1	462					1232***	VARIEGATO GIVE ME FIVE	1	450
II raffinatrice	11152	SEMILAVORATO VARIEGATO TORTA LIMONE	1	425	11168	BASE NEUTRA X PASTA TORTA AL LIMONE	2	475				
CRM												
CONDOR									GRECI-697	CREMA TORRONCINO	2	240 pz
			4				**5**				**8**	
GIOVEDI' 20					**VENERDI' 21**				**SABATO 22**			
	Codice	Descrizione	N°	Dose	Codice	Descrizione	N°	Dose	Codice	Descrizione	N°	Dose
I Molteni	2918	VARIEGATO + BUONO	2	440	2868	VARIEGATO ORONERO	2	440				
	3088**	PASTA BROWNIE x SET	1	490								
II Molteni	2823***	PASTA NOCCIOLA SABAUDA	1	440	3090***	VARIEGATO BROWNIE	1	492				
	2823-CO-EXP-SO	PASTA NOCCIOLA SABAUDA	1	420								
I raffinatrice					11474	SEMILAVORATO PER VARIEGATO ORO NERO	2	367				
II raffinatrice					11807***	SEMILAVORATO VARIEGATO BROWNIE	1	419				
	11810***	SEMILAVORATO PASTA BROWNIE	1	477								
CRM												
CONDOR	11084	SEMILAVORATO TORTA NOCCIOLA	4	160	GRECI-697	CREMA TORRONCINO	1	240 pz				
			10				**7**					

Even though a gross production plan is created with a month in advance, a weekly control and update is carried out on the first days of the prior week. During this control, any production that needs to be brought forward in case of an expedition emergency, or pushed backwards in case any of the previously mentioned factors emerges. The problem with the present situation within the company is that the thresholds used by NAV to predict the monthly workload are not currently defined, thus they get a value of 0.

3.3.3. Material Acquisition

Having 0 as your threshold level implies for the company that your production planning is incredibly limited, as you work in a reactive manner, not allowing the production department to foresee or prepare itself for sudden rises in product demand, ultimately creating delays in delivery and unhappy clients. Additionally, this planning methodology makes it really difficult for the material acquisition department to properly prepare the warehouse for sudden consume peaks, as they are in no capacity to foresee incoming material consumption in more than a week in advance.

Figure 11. Material requirements obtained by the acquisition department.

Modifica - Prospetto pianificazione - DEFAULT - Registrazioni di default

Nr.	Messaggi o azione	Accetta messaggi o azione	Data scadenza	Data-Ora di inizio	Data-Ora di fine	Descrizione	Quantità in origine	Ordine MPS	Quantità	Tipo Ordine Rif.	Nr. ordine rif.	Stato ordine rif.	Nr. dosi lancio	Nr. DB Ricetta	Cod. di raggruppamento	Articolo gestito a Listino	Giacenza	Fabbisogno 01/12/21..30/09/22	Fabbisogno 03/10/22..16/10/22	Fabbisogno 17/10/22..31/10/22	Fabbisogno 01/11/22..30/11/22	Fabbisogno 01/12/22..31/12/22	Previsioni produzione 01/12/21..30/09/22	Previsioni produzione 03/10/22..16/10/22	Previsioni produzione 17/10/22..3
1446-SO	Crea nuov	No	01-02-22	01-02-22 22:00	01-02-22 22:00	SABORIZANTE VARI		Sì	500.00	Ordine di	OPP22-03	Pianificat	1.00	1446-RIC		No	0.00	0.00	0.00	0.00	0.00	0.00	720.00	0.00	0.0
1446-SO	Crea nuov	Sì	01-11-22	31-10-22 22:00	31-10-22 22:00	SABORIZANTE VARI		Sì	500.00	Ordine di	OPP22-03	Pianificat	1.00	1446-RIC		No	0.00	0.00	0.00	0.00	0.00	0.00	720.00	0.00	0.0
1446-SO	Crea nuov	Sì	01-11-22	31-10-22 22:00	31-10-22 22:00	SABORIZANTE VARI		Sì	500.00	Ordine di	OPP22-03	Pianificat	1.00	1446-RIC		No	0.00	0.00	0.00	0.00	0.00	0.00	720.00	0.00	0.0
1446-SO	Crea nuov	Sì	01-12-22	01-12-22 22:00	01-12-22 22:00	SABORIZANTE VARI		Sì	500.00	Ordine di	OPP22-03	Pianificat	1.00	1446-RIC		No	0.00	0.00	0.00	0.00	0.00	0.00	720.00	0.00	0.0
1446-SO	Crea nuov	Sì	01-12-22	01-12-22 22:00	01-12-22 22:00	SABORIZANTE VARI		Sì	500.00	Ordine di	OPP22-03	Pianificat	1.00	1446-RIC		No	0.00	0.00	0.00	0.00	0.00	0.00	720.00	0.00	0.0
1449-CG	Crea nuov	No	02-09-22	02-09-22 22:00	02-09-22 22:00	CAMPIONE: PASTA		No	1,420.00	Ordine di	OPP22-03	Pianificat	1.00	1449-RIC		No	4.00	20.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
1449-SO	Crea nuov	No	01-02-22	01-02-22 22:00	01-02-22 22:00	SABORIZANTE P BO		Sì	480.00	Ordine di	OPP22-03	Pianificat	1.00	1449-RIC		No	0.00	0.00	0.00	0.00	0.00	0.00	1,020.00	0.00	0.0
1449-SO	Crea nuov	No	01-02-22	01-02-22 22:00	01-02-22 22:00	SABORIZANTE P BO		Sì	480.00	Ordine di	OPP22-03	Pianificat	1.00	1449-RIC		No	0.00	0.00	0.00	0.00	0.00	0.00	1,020.00	0.00	0.0
1449-SO	Crea nuov	Sì	01-11-22	31-10-22 22:00	31-10-22 22:00	SABORIZANTE P BO		Sì	480.00	Ordine di	OPP22-03	Pianificat	1.00	1449-RIC		No	0.00	0.00	0.00	0.00	0.00	0.00	1,020.00	0.00	0.0
1449-SO	Crea nuov	Sì	01-11-22	31-10-22 22:00	31-10-22 22:00	SABORIZANTE P BO		Sì	480.00	Ordine di	OPP22-03	Pianificat	1.00	1449-RIC		No	0.00	0.00	0.00	0.00	0.00	0.00	1,020.00	0.00	0.0
1449-SO	Crea nuov	Sì	01-11-22	31-10-22 22:00	31-10-22 22:00	SABORIZANTE P BO		Sì	480.00	Ordine di	OPP22-03	Pianificat	1.00	1449-RIC		No	0.00	0.00	0.00	0.00	0.00	0.00	1,020.00	0.00	0.0
1449-SO	Crea nuov	Sì	01-11-22	31-10-22 22:00	31-10-22 22:00	SABORIZANTE P BO		Sì	480.00	Ordine di	OPP22-03	Pianificat	1.00	1449-RIC		No	0.00	0.00	0.00	0.00	0.00	0.00	1,020.00	0.00	0.0
1449-SO	Crea nuov	Sì	01-11-22	31-10-22 22:00	31-10-22 22:00	SABORIZANTE P BO		Sì	480.00	Ordine di	OPP22-03	Pianificat	1.00	1449-RIC		No	0.00	0.00	0.00	0.00	0.00	0.00	1,020.00	0.00	0.0
1449-SO	Crea nuov	Sì	01-12-22	01-12-22 22:00	01-12-22 22:00	SABORIZANTE P BO		Sì	480.00	Ordine di	OPP22-03	Pianificat	1.00	1449-RIC		No	0.00	0.00	0.00	0.00	0.00	0.00	1,020.00	0.00	0.0
1449-SO	Crea nuov	Sì	01-12-22	01-12-22 22:00	01-12-22 22:00	SABORIZANTE P BO		Sì	480.00	Ordine di	OPP22-03	Pianificat	1.00	1449-RIC		No	0.00	0.00	0.00	0.00	0.00	0.00	1,020.00	0.00	0.0
1829	Crea nuov	No	01-07-22	01-07-22 22:00	01-07-22 22:00	VARIEGATO GIANDU		Sì	897.00	Ordine di	OPP22-03	Pianificat	1.00	1829-RIC		Sì	221.00	0.00	0.00	0.00	0.00	0.00	260.00	0.00	0.0
1987-CG	Crea nuov	No	01-03-22	01-03-22 22:00	01-03-22 22:00	CAMPIONE: VARIEG		Sì	2,240.00	Ordine di	OPP22-03	Pianificat	1.00	1829-RIC		No	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.0
1988	Crea nuov	No	09-09-22	09-09-22 22:00	09-09-22 22:00	VARIEGATISSIMO S		Sì	816.00	Ordine di	OPP22-03	Pianificat	1.00	1988-RIC		Sì	1,200.00	400.00	0.00	0.00	0.00	0.00	5,384.00	0.00	0.0
1988	Crea nuov	Sì	01-11-22	31-10-22 22:00	31-10-22 22:00	VARIEGATISSIMO S		Sì	816.00	Ordine di	OPP22-03	Pianificat	1.00	1988-RIC		Sì	1,200.00	400.00	0.00	0.00	0.00	0.00	5,384.00	0.00	0.0
1988-SO	Crea nuov	Sì	01-11-22	31-10-22 22:00	31-10-22 22:00	SABORIZANTE STR		Sì	820.00	Ordine di	OPP22-03	Pianificat	1.00	1988-RIC		No	0.00	0.00	0.00	0.00	0.00	0.00	260.00	0.00	0.0
2059	Crea nuov	No	25-07-22	25-07-22 22:00	25-07-22 22:00	PASTA CIOCCOLAT		Sì	483.00	Ordine di	OPP22-03	Pianificat	1.00	2059-RIC		Sì	1,596.00	430.50	0.00	0.00	0.00	0.00	6,135.50	0.00	0.0
2059	Crea nuov	No	01-08-22	01-08-22 22:00	01-08-22 22:00	PASTA CIOCCOLAT		Sì	483.00	Ordine di	OPP22-03	Pianificat	1.00	2059-RIC		Sì	1,596.00	430.50	0.00	0.00	0.00	0.00	6,135.50	0.00	0.0
2059	Crea nuov	No	01-08-22	01-08-22 22:00	01-08-22 22:00	PASTA CIOCCOLAT		Sì	483.00	Ordine di	OPP22-03	Pianificat	1.00	2059-RIC		Sì	1,596.00	430.50	0.00	0.00	0.00	0.00	6,135.50	0.00	0.0
2059	Crea nuov	No	01-08-22	01-08-22 22:00	01-08-22 22:00	PASTA CIOCCOLAT		Sì	483.00	Ordine di	OPP22-03	Pianificat	1.00	2059-RIC		Sì	1,596.00	430.50	0.00	0.00	0.00	0.00	6,135.50	0.00	0.0
2059	Crea nuov	Sì	01-12-22	01-12-22 22:00	01-12-22 22:00	PASTA CIOCCOLAT		Sì	483.00	Ordine di	OPP22-03	Pianificat	1.00	2059-RIC		Sì	1,596.00	430.50	0.00	0.00	0.00	0.00	6,135.50	0.00	0.0
2059-IN	Crea nuov	No	16-09-22	16-09-22 22:00	16-09-22 22:00	PASTA CIOCCOLAT		Sì	210.00	Ordine di	OPP22-03	Pianificat	0.43	2059-RIC		No	0.00	210.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
2059-IN	Annulla	No	20-09-22	20-09-22 6:00	20-09-22 6:00	PASTA CI	210.00	No	0.00	Ordine di	OPR22-0E	Rilasciato	0.00			No	0.00	210.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
2716-SO	Crea nuov	Sì	01-11-22	31-10-22 22:00	31-10-22 22:00	SABORIZANTE P GI		Sì	480.00	Ordine di	OPP22-03	Pianificat	1.00	2716-RIC		No	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
2716-SO	Crea nuov	Sì	01-11-22	31-10-22 22:00	31-10-22 22:00	SABORIZANTE P GI		Sì	480.00	Ordine di	OPP22-03	Pianificat	1.00	2716-RIC		No	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
2716-SO	Crea nuov	Sì	01-12-22	01-12-22 22:00	01-12-22 22:00	SABORIZANTE P GI		Sì	480.00	Ordine di	OPP22-03	Pianificat	1.00	2716-RIC		No	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
2727-AG	Crea nuov	No	01-05-22	29-04-22 22:00	29-04-22 22:00	VARIEGATO CIOCC		Sì	848.00	Ordine di	OPP22-03	Pianificat	1.00	2727-RIC		No	0.00	0.00	0.00	496.00	0.00	304.00	2,520.00	0.00	0.0
2727-AG	Crea nuov	Sì	28-10-22	28-10-22 22:00	28-10-22 22:00	VARIEGATO CIOCC		Sì	848.00	Ordine di	OPP22-03	Pianificat	1.00	2727-RIC		No	0.00	0.00	0.00	496.00	0.00	304.00	2,520.00	0.00	0.0

On Figure 11 we can observe the typical datasheet obtained by the material acquisition department, based on the production orders created by the production scheduling team. Even though this approach allows the company to have an overview of the material consumption in the upcoming weeks, it is completely linked to the already confirmed orders and leave no room for any kind of preparation for unforeseen demand peaks, which could be instead detected when analyzing the historic demand values and their variability. Therefore, a critical need for a DDMRP model is born within the company, allowing the acquisition department to have a more proactive approach towards "Supply Chain Management" that creates a smoother reorder process and reduces the probability of running out of stock with critical product components.

The creation of strategically placed decoupling points will allow the material procurement department to have a safety net in which to relay-on in case of a sudden or unexpected variation in the market behavior, an unanticipated rise in manufacturing efforts for a trending product which may cause a demand peak for its internal components, or a random delay related with a particular supplier.

4. IMPROVEMENT PROPOSAL

4.1. Assumptions

Before starting with the model development, it is important to stablish and identify some of the assumptions and conditions that permeate the information that is going to be gathered from the company and the company's ERP system, as they will influence in one way or another the model behaviour and the obtained results. It is worth mentioning that the information gathering, and data processing activities will always be confronted with an experienced member of the production department in order to avoid erroneous data or atypical data behaviours.

The first situation to take into consideration is that even though the material or inventory movement is continuously tracked via the company's ERP system, this is not always a 100% accurate as shown in Figure 12, where due to component unavailability or a laboratory production test, an internal component its changed with an appropriate substitute. This kind of changes are not immediately recognised by the software which proceeds to assume that the raw material was just simply not consumed in this occasion.

Figure 12. Example of erroneous material consumption during a production run

G.E.I. - Gruppo Essenziero Italiano SpA

DATA 05/10/22

FOGLIO PRELIEVO MATERIALI PER ORDINE: OPR22-08231

PAG. 1

PER PRODURRE:	KG 131,250	ARTICOLO:	GRECI-775/CA NUCLEO CREMA TIRAMISU'GRECI		
NR. DOSI:		LOTTO:	221000318	DATA SCADENZA:	31/10/24
		GR. ALCOL.:	0	DATA PRODUZ.:	12/10/22

COMPONENTE	DESCRIZIONE	U.M.	QTA. X DOSE	FABBISOGNO	REPARTO
20211	GLUCOSIO DISIDRATATO D.E. 29	KG	35,350	35,350	NUCLEI
20535	LATTE MAGRO POLVERE 1%	KG	16,975	16,975	NUCLEI
21639 ~~20300~~	~~AMIDO PATATA PREGELAT.PREGEFLO PJ 20~~ [illegible] 12602	KG	32,200	32,200	NUCLEI
21333	GRASSO DI COCCO RAFFINATO FP80K	KG	14,000	14,000	NUCLEI
	Pesate reparto Aromi				
20614	GELOGEN BDC 65	GR	47,250	47,250	NUCLEI
20497	CRYOGEL 200/3 (O.BOVINA)	GR	1.099,000	1.099,000	NUCLEI
21993	DRYCELL AROMA PANNA MASCARPONE	GR	707,000	707,000	NUCLEI
21994	DRYCELL AROMA UOVO 00591.1	GR	26.302,500	26.302,500	NUCLEI
	Attenzione: Mescolare i colori con gli zuccheri utilizzando il cutter quindi setacciare				
20344	ZUCCHERO CRISTALLINO FINE	GR	350,000	350,000	NUCLEI
21426	CURCUMA 1% PW/WS/SL E100	GR	2.584,750	2.584,750	NUCLEI
21884	COLORE GIALLO ANNATTO 13-14% PW/WS	GR	666,750	666,750	NUCLEI
20211	GLUCOSIO DISIDRATATO D.E. 29	GR	1.750,000	1.750,000	NUCLEI
				132,032 KG	

Situations like the previously explained lead to a particular scenario where raw material don't end up being instantly reduced from the existing inventories and create delays and inaccuracy in the obtained information. To handle this problematic, the production department on Aromitalia dedicate a day during the week to double check the material consumption of all production orders in order to have the system data as updated as possible. As this corrections and control take place in a different time frame than what is directly registered at system, it was then decided to work with only the ERP data without considering possible inventory modifications during the simulation run.

Another critical aspect to take into account, is that even though it is considered a last resort measure, component substitution are possible if a big production run would be put on hold otherwise. In these types of cases, the R&D lab makes a prior analysis of the components that need to be replaced, and with the quality department acceptance, the production run can begin with the modified component. This practice is highly frowned upon by the company’s director as it means an extra amount of work related to laboratory analysis, quality analysis, label remanufacturing including the newly added component and production efforts as the manufacturing process needs to be closely followed to avoid any unexpected effects in the product formula.

In order to have a deeper control in the effects and results obtained during the model simulation, these type of material changes were not considered as it is essential to have a system that is as static as possible in order to identify only the changes and outcomes produced by the new model implementation and limit the variation generated by random production variables.

It is also important to mention, that even though the material procurement department has an average lead time stablished with Aromitalia’s suppliers, no company is safe from unforeseen delays or broken machinery that may cause further setbacks. During the year, many raw material orders arrive on a date which is posterior to the one agreed previously because of these unforeseen delays. In order to maintain the static environment previously mentioned, it was decided to manage the average lead times as confirmed lead times, meaning that no matter what, the raw materials will arrive the agreed day, allowing the model to run a smoother simulation.

The last considerable assumption that needs to be made before starting to develop the model is that the model will run without any strict restrictions about warehouse capacity or financial capacity. These last assumptions implies that the simulation will not take into consideration the raw material dimensions or financial effects, such as price or management costs.

4.2. Model Preparation

In order to initialize and developed an adequate DDMRP for Aromitalia, it was absolutely necessary to determine and select an individual product that would allow us to better represent the total product range for the company during the upcoming simulation. Given that at the time of the study, the company's owner asked the production department to deliver a statistical analysis of manufacturing process for each product type, it became evident that this would be an excellent opportunity to gather information and develop an ABC Pareto classification.

This classification method would allow us to segregate each product into one of three possible categories: A, B, C. The first category, the so-called A group, is composed by the most important products for the company as they represent around 70% of the total income but only around 15% of the production volume. It becomes evident that the focus of our study will be on one the codes that makes part of this group as they correspond to the company's backbone and usually guide the strategic planning and execution.

Nonetheless, the second group or group B is characterized by representing about 25% of the total income and 35% of the production volume. In this specific case of study, it was discovered that this group mostly corresponds to products that are made and tailored for specific costumers, being produced and shipped only after an order that surpasses a threshold has been made.

Lastly, the group C is composed by most of the production volume, reaching an astounding amount of almost 50% of all manufacturing efforts but only contribute to a 5% of the aggregated income. As mentioned before, guided by the plant director who has more than 25 years of experience in the role, it was decided to use a product code belonging to the A group in order to simulate the ongoing of a product that represents a pilar stone for the company gross income,

4.2.1. ABC Identification

As mentioned during the company's introduction, one of the many product types that are offered to Aromitalia's clients is the "Oleose" products. These oily based goods represent the biggest contribute to the annual income when comparing all product types and a significant amount of the manufacturing efforts. By these reasons it was then decided to focus on this product family for the scope of this project.

The first step in order to identify and obtain the ABC pareto classification was to organize each of the product codes in decreasing order based on total volume in kg and total manufacturing cost. As this information was not directly obtainable from the company's ERP, it was necessary to extrapolate the data from all production orders into an Excel worksheet, then aggregate the production orders based on the product family and discard the ones not belonging to the "Oleose" family. Once this step was concluded, it was possible to add the production volume for each single product code, removing all duplicates and making sure to record the number of times each code was sent into production.

Table 2. ABC Product Classification based on Total Manufacturing Volume.

	Descrizione	Codice	Nr. Ordini	Quantita KG
1	SEMILAVORATO STRACCIATELLA	11492	56	79,573
2	SEMILAVORATO VARIEGATO TORTA LIMO	11152	161	68,097
3	SEMILAVORATO VARIEGATO +BUONO	11530	60	56,498
4	PASTA BON BON R...	1449	44	47,945
5	VARIEGATO BON BON R...	1446	49	47,381
6	VARIEGATO BON BON R... industriale	1896-CYW	20	36,036
7	CREMA AMORETTA	3243	21	33,632
8	VARIEGATO +BUONO	2918	32	31,836
9	SEMILAVORATO PER VARIEGATO ORO NE	11474	43	28,993
10	PASTA +BUONO	2917	22	28,437
11	PASTA NOCCIOLA SABAUDA INTENSA	2737	63	25,965
12	VARIEGATO ORONERO	2868	30	22,506
13	VARIEGATO +BUONO	2918-AG	23	22,134
14	VARIEGATO TORTA AL LIMONE c.n.	60428V	40	19,320
15	PASTA BON BON R...	60415P	22	18,648
16	VARIEGATO TORTA AL LIMONE c.n.	2365-IND	38	18,590
17	PASTA BON BON R... industriale	1784-CYW	11	18,564
18	VARIEGATO BON BON R...	61014V	25	18,144
19	FAVE DI CACAO ECUADOR SPIETRATE	11783	2	17,816
20	SEMILAVORATO VARIEGATO+BUONO BIA	11768	44	17,688
21	VARIEGATO STRACCIATELLA	6028	11	16,276
22	PASTA +BUONO c.n.	2917-AG	16	16,187
23	SEMILAVORATO STRACCIATELLA BIANCA	11873	51	15,300
24	SEMILAVORATO MASSA CACAO ECUADOR	11774	12	15,145
25	FAVE DI CACAO VENEZUELA SPIETRATE	11784	1	15,058
26	PASTA COCCO MALESIA	327	35	14,143
27	BASE NEUTRA X PASTA TORTA AL LIMONE	11168	30	13,905
28	PASTA GIANDUIA SEL. SPECIALE	2736	10	13,250
29	PASTA NOCCIOLA	60402	33	13,167
30	VARIEGATO +BUONO BIANCO	3030	30	12,815

Codice		Vol. Cod	Rep. Vol
	A	12.7%	70.0%
	B	19.2%	20.0%
	C	68.1%	10.0%

Table 2 allows us to have a better picture of the number of times each product was manufactured and its aggregated volume from 1st September 2021 to 1st September 2022, which is considered to be a full season commercially wise. It can be observed that the first three codes at the top of the list are product components rather than final products, these results make sense if we considered that they are widely used in an array of final products and as such their volume represents the cumulative amount of their so-called “father” products. Additionally, it is worth mentioning that it was decided to keep them on the list as they are regularly sold to Aromitalia’s subsidiaries as a final product for their own internal production.

Table 3. ABC Product Classification based on Total Manufacturing Cost.

	Descrizione	Codice	Nr. Ordini	Quantita KG	Costo
1	SEMILAVORATO STRACCIATELLA	11492	56	79,573	235,040 €
2	VARIEGATO BON BON R...	1446	49	47,381	205,018 €
3	PASTA NOCCIOLA SABAUDA INTENSA	2737	63	25,965	179,366 €
4	PASTA BON BON R...	1449	44	47,945	177,235 €
5	SEMILAVORATO VARIEGATO TORTA LIMO	11152	161	68,097	174,881 €
6	PASTA PISTACCHIO PLATINO CN	680	24	10,500	168,012 €
7	VARIEGATO BON BON R... industriale	1896-CYW	20	36,036	167,030 €
8	PASTA +BUONO	2917	22	28,437	162,933 €
9	SEMILAVORATO VARIEGATO +BUONO	11530	60	56,498	142,765 €
10	PASTA PISTACCHIO PLATINO	2548	22	8,626	137,757 €
11	PASTA PISTACCHIO NATURA TRAD.	1197-AG	23	11,592	135,424 €
12	VARIEGATO +BUONO	2918	32	31,836	107,433 €
13	CREMA AMORETTA	3243	21	33,632	105,985 €
14	PASTA PISTAKION	2712-AG	18	8,573	100,012 €
15	PASTA NOCCIOLA	60402	33	13,167	93,729 €
16	SEMILAVORATO PER VARIEGATO ORO NE	11474	43	28,993	92,850 €
17	PASTA +BUONO c.n.	2917-AG	16	16,187	92,434 €
18	PASTA BON BON R...	60415P	22	18,648	91,404 €
19	VARIEGATO ORONERO	2868	30	22,506	89,310 €
20	VARIEGATO +BUONO	2918-AG	23	22,134	77,084 €
21	VARIEGATO BON BON R...	61014V	25	18,144	74,505 €
22	PASTA BON BON R... industriale	1784-CYW	11	18,564	74,279 €
23	PASTA NOCCIOLA SABAUDA	2823	22	9,572	68,034 €
24	PASTA PISTACCHIO NATURA TRAD.	1197/5	11	5,000	67,653 €
25	GRANELLA DI CIALDE SPEZZATE GRANDE	11805	26	9,968	66,855 €
26	PASTA GIANDUIA SEL. SPECIALE	2736	10	13,250	65,161 €
27	SEMILAVORATO VARIEGATO+BUONO BIA	11768	44	17,688	64,709 €
28	SEMILAVORATO MASSA CACAO ECUADO	11774	12	15,145	63,429 €
29	pasta NOCCIOLA PIEMONTE IGP	5061	15	5,253	61,891 €
30	VARIEGATO BON BON R... industriale	1896	34	12,012	59,943 €

		Vol. Cod	Rep. Vol
Codice	A	11.4%	70.0%
	B	17.9%	20.0%
	C	70.7%	10.0%

It was then proceeded to create Table 3 where the products were not organized based on their total volume but on their cumulative cost. Discussing with the commercial department it was discovered that the main rule for product costing and sale price is a direct marginal percentage over the product cost, which is normally a set to a fixed value for all products except for peculiar product codes that make part of product category B and are not relevant for this specific case of study. This discovery allows to treat the cumulative cost as a real indicator of the cumulative income associated to that cost.

4.2.2.Product Selection

Observing booth tables, we can notice how product 1449 “Pasta BON BON” is always on the top of the list, highlighting its importance for the company’s annual income and manufacturing efforts. After discussing it with the production department it was confirmed based on their qualifications and experience that it is a code with a high inventory rotation and that is commonly sent into production, this made it an ideal candidate for the DDMRP simulation and analysis.

Additionally, to the previously mentioned facts, the production of this good takes place at different production sectors and at different complexity levels, this means that is uses a wide variety of ingredients and components which most certainly will have different suppliers, each with their own cost, lead time and particular characteristics that will make up a good test for the solidity of the model.

4.2.3.BOM Analysis

With the help of the laboratory department and the company's ERP, the product BOM was extrapolated allowing us to see all its component, measures, and production levels. As it can be seen in Table 4, the final product is composed of by two big components (11159 and 1448/CA) that are often called semi-finished products and an array of single ingredients, going from different types of oils and sugars to packing items such as buckets, boxes or labels.

A system was created to better identify each of the product components, based on its level inside the BOM. The general format decided upon was “P(a)-(b)” where “a” would be the main level the component is located, being “1” for the finished product, “2” for semi-finished products or big components and “3” for the individual ingredients that are acquired from external suppliers. Consecutively, “b” would work as a unique and increasing number that would allow us to discriminate one ingredient from the rest.

Table 4. Product BOM

		PASTA BON BON R	1449		Total Cost	€ 7,031.47	Kg Cost	€ 3.64		
Nr.	Bloccato	Descrizione	Avviso	Quantity from Finished Product	Cod. unità di misura	Sistema di rifornimento	COD Mod	Fornitore	DLT	MOQ
1449	No	PASTA BON BON R...	No	1.00	KG	Ordine di produzione	P1-1	Produzione Interna		
22510	No	OLIO DI SEMI DI GIRASOLE LINOLEICO ALTA RAFFINAZ	No	0.01	KG	Acquisto	P3-1	SALOV S.P.A.	21	850
20687	No	CESSA POWDER-60	No	0.01	KG	Acquisto	P3-2	NATURAL IT SP z.o.o.	21	700
21023	No	LECITINA SOJA genet. NON modificata	Sì	0.00	KG	Acquisto	P3-3	A.D.E.A. S.R.L.	21	220
21625	No	OLIO DI COLZA	No	0.11	KG	Acquisto	P3-4	F.LLI RUATA S.P.A.	21	916
21401	No	OLIO DI PALMA RAFFINATO	No	0.02	KG	Acquisto	P3-5	OLFOOD S.R.L.	21	300
11159	No	PASTA NOCCIOLA SCURA PER LAVORAZIONI	No	0.17	KG	Ordine di produzione	P2-1	Produzione Interna		
20872	No	NOCCIOLE MORTARELLE SGUSCIATE calibri 12/13/14 sep	No	0.18	KG	Acquisto	P3-6	D.A.R. S.R.L.	21	700
22510	No	OLIO DI SEMI DI GIRASOLE LINOLEICO ALTA RAFFINAZ	No	0.00	KG	Acquisto	P3-7	SALOV S.P.A.	21	850
VASO-PL	No	BARATTOLO TRASPARENTE GR. 200	No	0.01	PZ	Acquisto	P3-8	ACTIPACK	21	6272
COP-VASOPL	No	COPERCHIO BARATTOLO TRASPARENTE X CONTROCAMPI	No	0.01	PZ	Acquisto	P3-9	ACTIPACK	21	6400
ET-80X105	No	ETICHETTA BIANCA PER TERZI E NUCLEI	No	0.01	PZ	Acquisto	P3-10	ALL4LABELS Italy NMS s.r.l.	21	50000
20922	No	ZUCCHERO A VELO	No	0.08	KG	Acquisto	P3-11	GRANDA ZUCCHERI S.P.A.	21	450
21088	No	CACAO BENSDORP 10/12 DZS o 10/12 SR	No	0.09	KG	Acquisto	P3-12	BARRY CALLEBAUT COCOA AG	21	750
21196	No	CACAO POLV DE ZAAN 10/12 S75	No	0.04	KG	Acquisto	P3-13	BARRY CALLEBAUT COCOA AG	21	700
21087	No	CACAO POLV DE ZAAN 10/12 S9	No	0.04	KG	Acquisto	P3-14	BARRY CALLEBAUT COCOA AG	21	750
20211	No	GLUCOSIO DISIDRATATO D.E. 29	No	0.09	KG	Acquisto	P3-15	UNIGLAD INGREDIENTI S.R.L.	21	2475
21602	No	DESTROSIO ANIDRO POLVERE	No	0.17	KG	Acquisto	P3-16	BASF ITALIA S.P.A.	21	1000
1448/CA	No	COLORAROMA PASTA BON BON R...	No	0.01	KG	Ordine di produzione	P2-2	Produzione Interna		
20270	No	AROMA NOCCIOLA LQD FA-BO7143	No	0.00	KG	Acquisto	P3-17	KERRY INGREDIENTS & FLAVOURS	44	20
20336	No	HERBALOX HTO-C (E.ROSMARINO) BIOCHIM	No	0.00	KG	Acquisto	P3-18	BIOCHIM S.R.L.	21	15
11657	No	AROMA NOCCIOLA 1075FG	No	0.01	KG	Acquisto	P3-19	KERRY INGREDIENTS & FLAVOURS	44	20
20313	No	GRANELLA DI NOCCIOLA CALIBRO 2/4 mm.	No	0.08	KG	Acquisto	P3-20	D.A.R. S.R.L.	21	1000
SEC-PG4.2	No	SECCHIELLO PG LT.4 AROMITALIA	No	0.28	PZ	Acquisto	P3-21	ACTIPACK	14	990
COP-PG	No	COPERCHIO PER TERMOSALDATURA SECCHIELLO PG	No	0.28	PZ	Acquisto	P3-22	ACTIPACK	14	990
FILM-590	No	FILM ANONIMO TERMOSALDATURA TRASPARENTE H. 615	No	0.00	KG	Acquisto	P3-23	ACTIPACK	14	202
WRAP-PG4.2	No	CARTONE 2 SECCHI PG4.2 AROMITALIA	No	0.14	PZ	Acquisto	P3-24	SMURFIT KAPPA ITALIA S.P.A.	14	1300
ET-PASTE	No	ETICHETTA PASTE ARGENTO MM. 102X246	No	0.28	PZ	Acquisto	P3-25	ALL4LABELS Italy NMS s.r.l.	14	102000
ET-80X200-AZ	No	ETICHETTA CARTONI 80x200 AZZURRA	No	0.14	PZ	Acquisto	P3-26	ALL4LABELS Italy NMS s.r.l.	14	102000

Inside Table 4 we can also observe the supplier for each one of the ingredients and its respective lead time and minimum order quantity. This information was extrapolated from the company's ERP system and confronted with the material acquisition department which shared valuable information such as that packaging items usually have the biggest MOQ as they are often sold in bulk, and components as P3-17 and P3-19 usually have the biggest DLT as they are specifically manufactured to meet Aromitalia's production needs.

It is important to mention that the BOM analysis was carried out on a three level bases, as going deeper into the production formulas and recipes would lead to unnecessary model complexity and would in the end risk having misaligned or suboptimal conclusions caused by the enormous amount of information to be evaluated. The previously mentioned levels are as follows:

- Level 1: The first or "main" level represents the finished product as a whole, including branding and packaging material, which basically constitutes the "Ready for Sale" state.
- Level 2: The second BOM level consists of the product macro-components, as mentioned in the chapter introduction, the elaborated products make up the general finished product consistency and flavour, which is why they should be carefully analysed and considered.

- Level 3: Finally, the third level consist of a regrouping effort of all the different ingredients that make up the finished product, based on their general properties and their so-called families (a few examples of these are sugars, oils, cacao or milk-based powders).

Entering the buffer positioning side of the study, in conjunction with the laboratory department and the R&D team, it was decided that the buffers should be allocated on all the components constituting the BOM third level, as these are by no means substitutable with other ingredients without sacrificing the finished product properties or entering into a health security matter as the product label should described the general properties with incredible accuracy. However, from the third level forward, some modifications and substitutions can happen between identical products from different suppliers. Moving forward, it was decided that the BOM Level 3 would be used as a study frontier in order to evaluate the model responsiveness and results without sacrificing the product quality and integrity.

The mentioned level consists of the following ingredients:

Table 5. Level 3 Components

OLIO DI SEMI DI GIRASOLE+A1:B26 LINOLEICO ALTA RAFFINAZ	P3-1`
CESSA POWDER-60	P3-2
LECITINA SOJA genet. NON modificata	P3-3
OLIO DI COLZA	P3-4
OLIO DI PALMA RAFFINATO	P3-5
NOCCIOLE MORTARELLE SGUSCIATE calibri 12/13/14 sep	P3-6
OLIO DI SEMI DI GIRASOLE LINOLEICO ALTA RAFFINAZ	P3-7
BARATTOLO TRASPARENTE GR. 200	P3-8
COPERCHIO BARATTOLO TRASPARENTE X CONTROCAMPIONI	P3-9
ETICHETTA BIANCA PER TERZI E NUCLEI	P3-10
ZUCCHERO A VELO	P3-11
CACAO BENSDORP 10/12 DZS	P3-12
CACAO POLV DE ZAAN 10/12 S75	P3-13
CACAO POLV DE ZAAN 10/12 S9	P3-14
GLUCOSIO DISIDRATATO D.E. 29	P3-15
DESTROSIO ANIDRO POLVERE	P3-16
AROMA NOCCIOLA	P3-17
HERBALOX HTO-C	P3-18
AROMA NOCCIOLA 1075FG	P3-19
GRANELLA DI NOCCIOLA CALIBRO 2/4 mm.	P3-20
SECCHIELLO PG LT.4 AROMITALIA	P3-21
COPERCHIO PER TERMOSALDATURA SECCHIELLO PG	P3-22

FILM ANONIMO TERMOSALDATURA TRASPARENTE H. 615	P3-23
CARTONE 2 SECCHI PG4.2 AROMITALIA	P3-24
ETICHETTA PASTE ARGENTO MM. 102X246	P3-25
ETICHETTA CARTONI 80x200 AZZURRA	P3-26

4.2.4. ADU Calculation

In order to continue with the development of the DDMRP simulation, it was necessary to obtain information related to the average consume for each of the product components, at this stage of the study it was decided that the first two product levels, these being P1 and P2, were not going to be taken into consideration as they represent a transformation stage of the manufacturing process and not really a material consumption process, in fact, the ingredients required for these processes are already considered at the P3 level.

Moving forward it was decided to evaluate a time frame of 8 weeks, going from 04/07/2022 to 03/09/2022 which is considered to be the "high" season for the production department, as most of the production orders arrive during these months. From the ERP system it was possible to extrapolate the total consumption for each of the ingredients during the mentioned time frame, which would later be divided into 8 consecutive weeks. This weekly based approach was selected in order to soften the consumption curve, as doing it on a day-by-day basis would result in information gaps as the company's production processes usually take more than a day to be completed, especially if we include the packaging process as well.

Table 6. Consumption Table for product ingredients

		PASTA BON BON R	Consume							
Nr.	Bloccato	Descrizione	Week -2	Week -1	Week 0	Week 1	Week 2	Week 3	Week 4	Week 5
			4/07/2022-9/07/2022	11/07/2022-16/07/2022	18/07/2022-23/07/2022	25/07/2022-30/07/2022	01/08/2022-06/08/2022	08/08/2022-13/08/2022	22/08/2022-27/08/2022	29/08/2022-03/09/2022
1449	No	PASTA BON BON R...								
22510	No	OLIO DI SEMI DI GIRASOLE LINOLEICO ALTA RAFFINAZ	2,351.7	1,718.8	399.6	3,628.6	1,528.8	1,812.5	772.9	2,179.7
20687	No	CESSA POWDER-60	171.9	447.9	9.2	221.6	62.9	26.9	29.2	108.1
21023	No	LECITINA SOJA genet. NON modificata	88.6	43.0	17.4	173.2	47.7	51.0	35.7	78.2
21625	No	OLIO DI COLZA	1,224.8	778.0	46.5	1,925.6	1,133.0	1,257.5	504.0	1,944.0
21401	No	OLIO DI PALMA RAFFINATO	364.4	160.0	26.5	299.7	266.7	203.8	118.7	294.4
11159	No	PASTA NOCCIOLA SCURA PER LAVORAZIONI								
20872	No	NOCCIOLE MORTARELLE SGUSCIATE calibri 12/13/14 sep	-	9,450.0	7,350.0	10,500.0	7,000.0	2,100.0	2,100.0	-
22510	No	OLIO DI SEMI DI GIRASOLE LINOLEICO ALTA RAFFINAZ	2,351.7	1,718.8	399.6	3,628.6	1,528.8	1,812.5	772.9	2,179.7
VASO-PL	No	BARATTOLO TRASPARENTE GR. 200	200.0	158.0	52.0	457.0	213.0	165.0	70.0	175.0
COP-VASOPL	No	COPERCHIO BARATTOLO TRASPARENTE X CONTROCAMPI	198.0	158.0	62.0	459.0	213.0	165.0	69.0	175.0
ET-80X105	No	ETICHETTA BIANCA PER TERZI E NUCLEI	3,521.0	2,422.0	1,201.0	2,464.0	2,439.0	1,287.0	3,770.0	1,801.0
20922	No	ZUCCHERO A VELO	3,973.3	3,268.5	503.1	9,417.1	4,091.6	4,116.5	1,443.3	4,700.3
21088	No	CACAO BENSDORP 10/12 DZS o 10/12 SR	996.4	206.0	1.1	2,163.0	544.9	636.0	277.5	674.8
21196	No	CACAO POLV DE ZAAN 10/12 S75	468.1	59.4	-	896.1	215.1	206.4	152.1	231.5
21087	No	CACAO POLV DE ZAAN 10/12 S9	535.3	221.8	153.0	1,133.5	251.1	340.8	152.1	298.7
20211	No	GLUCOSIO DISIDRATATO D.E. 29	1,978.3	2,548.3	1,206.7	14,699.6	5,511.9	4,087.1	2,789.9	1,930.4
21602	No	DESTROSIO ANIDRO POLVERE	896.4	-	112.4	3,075.9	-	14.1	816.8	1,424.4
1448/CA	No	COLORAROMA PASTA BON BON R...								
20270	No	AROMA NOCCIOLA LQD FA-BO7143	4.5	17.6	0.5	4.9	-	7.8	-	3.7
20336	No	HERBALOX HTO-C (E.ROSMARINO) BIOCHIM	9.6	28.9	3.6	18.6	2.8	8.1	2.7	6.5
11657	No	AROMA NOCCIOLA 1075FG	12.4	59.6	4.2	17.6	-	24.8	-	13.6
20313	No	GRANELLA DI NOCCIOLA CALIBRO 2/4 mm.	1,081.0	345.0	-	152.0	932.0	2,400.0	-	434.0
SEC-PG4.2	No	SECCHIELLO PG LT.4 AROMITALIA	4,660.0	1,768.0	381.0	11,920.0	3,975.0	3,743.0	1,914.0	6,238.0
COP-PG	No	COPERCHIO PER TERMOSALDATURA SECCHIELLO PG	8,580.0	4,447.0	1,190.0	22,140.0	6,720.0	5,018.0	4,218.0	9,913.0
FILM-590	No	FILM ANONIMO TERMOSALDATURA TRASPARENTE H. 615	97.8	67.9	11.9	223.7	67.5	48.5	49.3	109.3
WRAP-PG4.2	No	CARTONE 2 SECCHI PG4.2 AROMITALIA	2,118.0	491.0	121.0	3,934.0	2,070.0	1,835.0	904.0	4,173.0
ET-PASTE	No	ETICHETTA PASTE ARGENTO MM. 102X246	8,991.0	4,225.0	1,003.0	21,463.0	7,478.0	4,384.0	4,615.0	10,463.0
ET-80X200-AZ	No	ETICHETTA CARTONI 80x200 AZZURRA	5,729.0	4,170.0	1,326.0	22,777.0	8,280.0	3,998.0	4,205.0	7,709.0

Table 6 allows us to realize the different levels of consumption that characterize each ingredient, with codes having an average weekly consumption under 10kg and other going beyond the 5,000kg each week. This heterogenic behaviour from the ingredients will allow us to put a real test to the DDMRP model and have a more precise comparison against its more commonly used MRP counterpart.

After all the information was properly gathered, we could continue with the calculation of the Average Weekly Usage or AWU for short. Discussing with the production department, the method selected for this average calculation is a weighted average analysis, as this method would allow us to take into consideration the values of previous weeks in order to soften any abrupt changes in consumption that may be caused by a sudden demand spike, an unusually large order by one of the subsidiaries or simply an accumulated consumption caused by material shortage in the previous week.

It was then decided that the weight that would be given to the previous weeks combined would be of 70% and the remaining 30% would be covered by the actual week being calculated. This allowed us to have a clearer sight of the usual material behaviour during the selected timeframe. The results can be observed in Table 7

Table 7. AWU Calculation for each component.

Livello	Code	Week 1	Week 2	Week 3	Week 4	Week 5	AWU
PF	P1-1	Produzione Interna					
SL	P2-1	Produzione Interna					
SL	P2-2	Produzione Interna					
IN	P3-1	2131.6	1799.6	1840.4	1858.2	1613.9	**1848.7**
IN	P3-2	213.2	177.2	76.6	81.4	60.2	**121.7**
IN	P3-3	86.7	68.8	70.9	74.1	54.8	**71.1**
IN	P3-4	1055.8	981.6	1101.8	1158.3	1258.6	**1111.2**
IN	P3-5	218.5	193.5	199.5	215.3	225.8	**210.5**
IN	P3-6	7070.0	8470.0	6428.3	5203.3	2613.3	**5957.0**
IN	P3-7	2131.6	1799.6	1840.4	1858.2	1613.9	**1848.7**
IN	P3-8	232.8	219.5	218.0	215.8	157.0	**208.6**
IN	P3-9	235.2	222.3	220.8	216.0	156.8	**210.2**
IN	P3-10	2406.1	2152.0	1810.4	2575.3	2289.4	**2246.6**
IN	P3-11	4632.3	4304.8	4504.4	4545.5	3662.1	**4329.8**
IN	P3-12	929.7	716.5	822.9	863.5	542.7	**775.1**
IN	P3-13	391.9	287.5	321.2	353.1	203.3	**311.4**
IN	P3-14	552.4	427.2	461.0	448.2	263.2	**430.4**
IN	P3-15	5747.7	5959.7	6223.7	6506.6	3469.9	**5581.5**
IN	P3-16	1158.1	743.9	748.2	966.0	621.2	**847.5**
IN	P3-17	6.7	5.4	3.6	3.0	2.9	**4.3**
IN	P3-18	15.4	12.7	8.3	7.7	5.1	**9.8**
IN	P3-19	23.1	19.0	12.5	9.9	9.9	**14.9**
IN	P3-20	378.3	395.6	972.9	812.9	907.7	**693.5**
IN	P3-21	5164.8	4475.3	4920.6	5156.4	4118.9	**4767.2**
IN	P3-22	9959.3	8497.3	8517.1	9170.3	6697.0	**8568.2**
IN	P3-23	108.6	91.1	85.3	94.1	71.4	**90.1**
IN	P3-24	1817.2	1681.7	1979.7	2100.3	2374.0	**1990.6**
IN	P3-25	9756.7	8471.3	8302.1	9160.3	6983.5	**8534.8**
IN	P3-26	9452.3	9081.0	8755.4	9441.0	6158.7	**8577.7**

As mentioned previously, Table 7 not only allows us to see the difference between codes on how materials are consumed but also allows us to identify that there are certain codes which even after doing the weighted average continue to have significant spikes from one week to another, as it is the case of P3-6 which goes from 5,203kg in Week 4 to 2,613kg in Week 5. This is most certainly caused by the planning and production methods utilized at Aromitalia, which focus on trying to cover in as few production runs as possible all the demand for a product in a given season, meaning that as the list of codes being produced change every week, the ingredient consumption also follows this trend.

4.3. Buffer Calculation

The next step in the study was the calculation and development of the DDMRP Buffers that would allow us to control and verify the status of the inventory each week as the simulation progresses, DDMRP model by Ptak and Smith proposes a buffer made up of three individual zones. The red zone or critical zone where the probability of stock-out is high and would end up meaning delivering a product behind schedule, a yellow zone that serves the purpose of warning when the stock level begins to decrease below the optimal or safer level, and finally the green zone or "optimal" zone where the calculation model will try to keep the stock level in order to reduce the stock-out probability as much as possible.

Table 8. DDMRP Buffer Calculation .

Supplier	Code	ADU	DLT (days)	LT factor	Variability Factor	MOC (days)	MOQ	ADU*MOC	ADU*DLT* LTF	Green Zone	Yellow Zone	Red Base	Red Safety	Red Zone	Top of Red	Top of Yellow	Top of Green
	P1-1	INTERNAL PRODUCTION															
	P2-1																
	P2-2																
SALOV S.P.A.	P3-1	426.3	21	0.3	0.75	15	850	6,395	2,686	6,395	8,953	2,686	2,014	4,700	4,700	13,653	20,048
NATURAL IT SP z.o.o.	P3-2	42.6	21	0.3	0.75	15	700	640	269	700	896	269	202	470	470	1,366	2,066
A.D.E.A. S.R.L.	P3-3	17.3	21	0.3	0.75	15	220	260	109	260	364	109	82	191	191	555	816
F.LLI RUATA S.P.A.	P3-4	211.2	21	0.3	0.75	15	916	3,167	1,330	3,167	4,434	1,330	998	2,328	2,328	6,763	9,930
OLFOOD S.R.L.	P3-5	43.7	21	0.3	0.75	15	300	655	275	655	918	275	206	482	482	1,399	2,055
D.A.R. S.R.L.	P3-6	1414.0	21	0.3	0.75	7	700	9,898	8,908	9,898	29,694	8,908	6,681	15,589	15,589	45,283	55,181
SALOV S.P.A.	P3-7	426.3	21	0.3	0.75	15	850	6,395	2,686	6,395	8,953	2,686	2,014	4,700	4,700	13,653	20,048
ACTIPACK	P3-8	46.6	21	0.3	0.75	15	6,272	698	293	6,272	978	293	220	513	513	1,491	7,763
ACTIPACK	P3-9	47.0	21	0.3	0.75	15	6,400	706	296	6,400	988	296	222	519	519	1,507	7,907
ALL4LABELS Italy NMS s.r.l.	P3-10	481.2	21	0.3	0.75	15	50,000	7,218	3,032	50,000	10,106	3,032	2,274	5,306	5,306	15,411	65,411
GRANDA ZUCCHERI S.P.A.	P3-11	926.5	21	0.3	0.75	15	450	13,897	5,837	13,897	19,456	5,837	4,377	10,214	10,214	29,670	43,566
BARRY CALLEBAUT COCOA AG	P3-12	185.9	21	0.3	0.75	15	750	2,789	1,171	2,789	3,905	1,171	879	2,050	2,050	5,955	8,744
BARRY CALLEBAUT COCOA AG	P3-13	78.4	21	0.3	0.75	15	700	1,176	494	1,176	1,646	494	370	864	864	2,510	3,686
BARRY CALLEBAUT COCOA AG	P3-14	110.5	21	0.3	0.75	15	750	1,657	696	1,657	2,320	696	522	1,218	1,218	3,538	5,195
UNIGLAD INGREDIENTI S.R.L.	P3-15	1149.5	21	0.3	0.75	15	2,475	17,243	7,242	17,243	24,140	7,242	5,432	12,674	12,674	36,814	54,057
BASF ITALIA S.P.A.	P3-16	231.6	21	0.3	0.75	15	1,000	3,474	1,459	3,474	4,864	1,459	1,094	2,554	2,554	7,418	10,892
KERRY INGREDIENTS & FLAVOURS	P3-17	1.3	44	0.3	0.75	15	20	20	18	20	59	18	13	31	31	90	111
BIOCHIM S.R.L.	P3-18	3.1	21	0.3	0.75	15	15	46	19	46	65	19	15	34	34	99	145
KERRY INGREDIENTS & FLAVOURS	P3-19	4.6	44	0.3	0.75	15	20	69	61	69	203	61	46	107	107	310	379
D.A.R. S.R.L.	P3-20	75.7	21	0.3	0.75	7	1,000	530	477	1,000	1,589	477	358	834	834	2,423	3,423
ACTIPACK	P3-21	1033.0	14	0.5	0.5	42	990	43,384	7,231	43,384	14,461	7,231	3,615	10,846	10,846	25,307	68,691
ACTIPACK	P3-22	1991.9	14	0.5	0.5	42	990	83,658	13,943	83,658	27,886	13,943	6,972	20,915	20,915	48,801	132,459
ACTIPACK	P3-23	21.7	14	0.5	0.5	42	202	912	152	912	304	152	76	228	228	532	1,444
SMURFIT KAPPA ITALIA S.P.A.	P3-24	363.4	14	0.5	0.5	28	1,300	10,176	2,544	10,176	5,088	2,544	1,272	3,816	3,816	8,904	19,081
ALL4LABELS Italy NMS s.r.l.	P3-25	1951.3	14	0.5	0.5	56	102,000	109,275	13,659	109,275	27,319	13,659	6,830	20,489	20,489	47,808	157,082
ALL4LABELS Italy NMS s.r.l.	P3-26	1890.5	14	0.5	0.5	56	102,000	105,865	13,233	105,865	26,466	13,233	6,617	19,850	19,850	46,316	152,181

Table 8 illustrates how all the previous information captured or calculated so far was recompiled in the Excel document called "BUFFER FILE.xlsx". Additionally, to the information explained in the previous sections of this document, we can observe that a "LT Factor", "Variability Factor" and "MOC" have been added. The first column makes reference to lead time factor, which is a multiplicative value ranging from 0 to 1 that explains the characteristics of the supplier and the time it takes him to deliver an order, in this case study and based on the Ptak and Smith model it was determined that if the lead time would be inferior to 10 days, it would have a value of 0.7 assigned to it, if the lead time ranges from 11 to 25, I would have a value of 0.5, and 0.3 in the case the lead time is superior to 25 days.

The second new column makes refers to the "Variability factor", which is used as a conservative guide for planners and buyers to follow when determining the buffer size. Lastly, the minimum order cycle or MOC corresponds to the minimum amount of time that passes between two consecutive orders, this parameter is usually defined by each company based on acquisition method or supplier parameters, in this specific case it was taken as the time between two consecutive material orders, value that was latter corroborated by the acquisitions department.

4.3.1.Green Zone

Starting from the Green Zone, this is the buffer zone where the value ranges for the stock level must remain theoretically speaking, and thus it becomes the base for the number and size of the orders to be made to make sure the balance continues through time. This zone dimensionality is calculated based on three parameters: Minimum Order Cycle (In unit values), Minimum Order Quantity and Lead Time Factor. The size of this zone is then determined by a maximum value out of the three parameters. From now on, an example of the calculations made to obtain each buffer will be displayed, taking component P3-6 as a reference, given it is largely used throughout the company's catalog.

- Parameter 1: Minimum Order Cycle:

This parameter makes reference as explained before, to the number of days stablished between two consecutive purchase orders. In order to calculate the green zone based on this factor, we must multiplicate the product´s ADU by the MOC in terms of day. Taking as reference the ADU=1.414 and the MOC=7 obtained for component P3-6, the equation becomes:

Equation 1. Minimum Order Cycle

$$MOC = ADU * MOC_d$$

$$9.898 = 1.414 * 7$$

- Parameter 2: Minimum Order Quantity:

The minimum order quantity corresponds to the lowest amount of product that a supplier will agree to sale, usually defined by the production and delivery costs. This information was obtained by doing a meeting with the acquisition department were the corresponding suppliers were consulted in order to obtain the necessary information for the model development.

Equation 2. Minimum order quantity for P3-6

$$MOQ_{P3-6} = 700$$

- Parameter 3: Lead Time Factor:

Lastly, the lead time factor corresponds to the multiplication of average daily usage times the decoupled lead-time times the percentual lead time factor as seen in Equation 3. Lead Time FactorThis parameter tries to capture and explain the variability associated to the amount of product order to each individual supplier and the probability of receiving the order in the agreed date and conditions.

Equation 3. Lead Time Factor

$$LTF = ADU * DLT * \%LTF$$

$$8.908 = 1.414 * 21 * 0,3$$

Finally, as mentioned before, the green zone buffer is then defined by the maximum value out of the three analyzed parameters as seen on Equation 4.

Equation 4. Green Zone Value

$$Green\ Zone = MAX\ (\ MOC\ , MOQ_{P3-6}, LTF)$$

$$9.898 = MAX\ (\ 700, 9.898\ , 8.908)$$

4.3.2. Yellow Zone

The yellow zone corresponds to the main tool use by the warehouse department to determine the inventory coverage for a given time period. It is most often calculated as the average daily usage times the decoupled lead time , as it aims to cover the production runs while the next material purchase order arrives.

Equation 5. Yellow Zone Value

$$Yellow\ Zone = ADU * DLT$$

$$26.694 = 1.414 * 21$$

4.3.3.Red Zone

The red zone is where the embedded safety of the buffer lays, its size deeply depends on the variability associated to the component and the supplier that provides it. As they are directly proportional, a high component variability will lead to a high red zone, in order to minimize the risk of stock-out. The calculation of this zone dimensionality is based on three steps.

- Red base: This value obtained by the multiplication of the same factors used to calculate the green zone Parameter 3. This factor makes reference to the minimum or safety stock that must be guaranteed in warehouse in order to maintain a competitive production run and not create delays caused by stock-outs.

Equation 6. Red Base value

$$Red\ Base = ADU * DLT * LTF$$

$$8.908 = 1.414 * 21 * 0.3$$

- Red Safety: Calculated as a percentage of the Red base with the aim of taking into consideration the variability associated to the component, whether its high, medium or low caused by internal or external factors.

Equation 7. Red Safety value

$$Red\ Safety = Red\ Base * Variabilty\ Factor$$
$$6.681 = 8.908 * 0.75$$

- Red Zone: The last step is to add the two previously discussed factors (Red Base + Red Safety) in order to obtain a singular value for the size of this security zone of the buffer.

Equation 8. Red Zone value

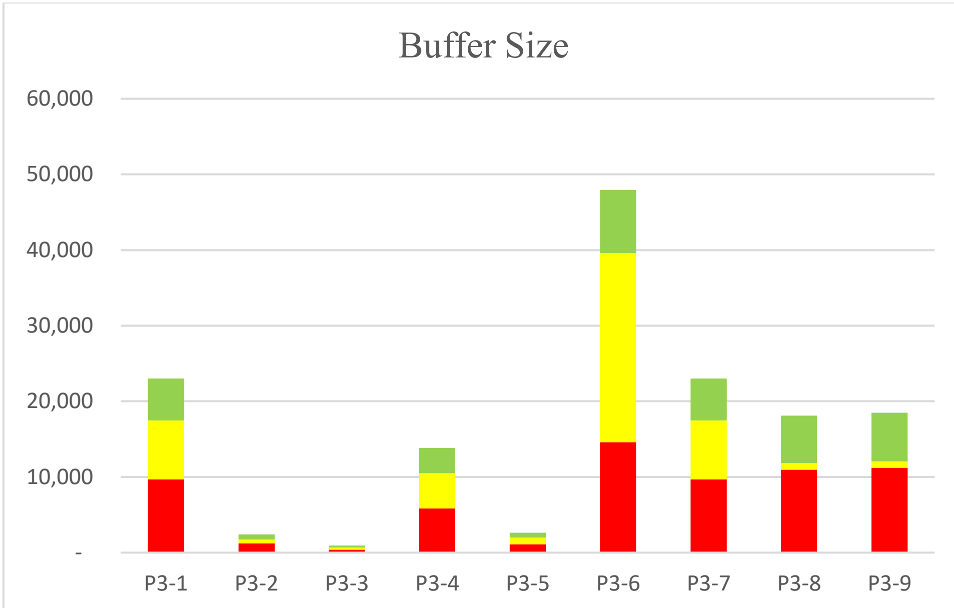
$$Red\ Zone = Red\ base + Red\ Safety$$
$$15.589 = 8.908 + 6.681$$

Once the three zones of the buffer have been calculated we can proceed to aggregate them in order to obtain the full buffer size. Figure 13 is displayed as an example of the obtained buffers for 9 of the product components. It can be observed how each code displays a different behaviour based on its initial values and supplier characteristics.

Equation 9. Buffer size value

$$Buffer\ size = Green\ zone + Yellow\ zone + Red\ zone 55.181 = 9.898 + 29.694 + 15.589$$

Figure 13. Buffer size for 9 product components.



4.4. Material Arrival Analysis

For the analysis of the component arrivals, it was necessary to extrapolate the data from the company's ERP system, obtaining this way an aggregate of the total arrival amount since 04/07/2022 to 03/09/2022. Once the gross number were obtained, an Excel datasheet was created in order to compile the data for all the product components and then segregate into the 8 weeks of the simulation run. It is important to mention that some of the materials, especially the ones that cover the packaging side of the process are not always uploaded to the system and are controlled at the warehouse in printed format, this situation made the information collection more difficult as it had to be looked up from the pile of printed arrival documents.

Table 9. Arrivals database

		Week -2	Week -1	Week 0	Week 1	Week 2	Week 3	Week 4	Week 5	
Codice	DLT (wk)	04/07/2022-09/07/2022	11/07/2022-16/07/2022	18/07/2022-23/07/2022	25/07/2022-30/07/2022	01/08/2022-06/08/2022	08/08/2022-13/08/2022	22/08/2022-27/08/2022	29/08/2022-03/09/2022	Number of Orders
P3-1	3	5526	3400	0	3790	3400		5400	3400	6
P3-2	3	0	0	520	0	0	0	520	0	2
P3-3	3	440				440				2
P3-4	3	2760	2748	2789	2776	0	0	0	2759	5
P3-5	3		1800						1800	2
P3-6	3	10500			10,500.00		10,500.00		10500	4
P3-7	3	5526	3400	0	3790	3400		5400	3400	6
P3-8	3						6272			1
P3-9	3						6400			1
P3-10	3									0
P3-11	3	0	9000	9000	9000	0	9000	0	8800	5
P3-12	3		4500			4500		4500		3
P3-13	3			1500						1
P3-14	3		4500			4500		4500		3
P3-15	3	31350	0	0	15675	0	15675	0	15675	4
P3-16	3			3000		11000				2
P3-17	6					200				1
P3-18	3					200				1
P3-19	6						100			1
P3-20	3	3,000.00				2000				2
P3-21	2	19,800.00				25,170.00				2
P3-22	2	39690	0	930	0	35910	0	71820	71820	5
P3-23	2									0
P3-24	2									0
P3-25	2									0
P3-26	2									0

For the DDMRP simulation run it was decided to only take into account the orders made with the traditional MRP system up to Week 0, after this point the arrivals would be the ones generate through the use and application of the developed model. In Table 9 we can observe the compilation of the arrival information for each of the product components. Additionally on the right it was registered the amount of order that were made during the studied timeframe, its interesting to mention how the last codes observed not a single arrival as the initial stock was high enough to cover all production demands, most likely caused by the high MOQ that characterises this components.

4.5. Material Consumption

Following a similar procedure to the one used for the arrival information, the consume data was also gathered from the company's ERP database, and compiled into an Excel datasheet where it was segregate by week of consumption. As expected a priori, the values obtained for components that are specific for that product or product family have a much lower rate than those which serve a bigger volume of product codes.

Components such as P-15 which represents a type of sugar, ingredient widely used in all Aromitalia's products, present an extraordinary rate of depletion in comparison to P-17 which is only used during the manufacturing process of P1-1. Table 10 presents an insight into the amount each component was used during a singular production week.

Table 10. Component consumption per week.

			Week -2	Week -1	Week 0	Week 1	Week 2	Week 3	Week 4	Week 5
Codice	DLT		04/07/2022-09/07/2022	11/07/2022-16/07/2022	18/07/2022-23/07/2022	25/07/2022-30/07/2022	01/08/2022-06/08/2022	08/08/2022-13/08/2022	22/08/2022-27/08/2022	29/08/2022-03/09/2022
P3-1	21		2,351.70	1,718.80	399.6	3628.6	1528.8	1812.5	772.9	2179.7
P3-2	21		171.9	447.9	9.2	221.6	62.9	26.9	29.2	108.1
P3-3	21		88.6	43	17.4	173.2	47.7	51	35.7	78.2
P3-4	21		1,224.80	778	46.5	1925.6	1133	1257.5	504	1944
P3-5	21		364.4	160	26.5	299.7	266.7	203.8	118.7	294.4
P3-6	21			9,450.00	7,350.00	10,500.00	7,000.00	2,100.00	2,100.00	
P3-7	21		2,351.70	1,718.80	399.6	3628.6	1528.8	1812.5	772.9	2179.7
P3-8	21		200	158	52	457	213	165	70	175
P3-9	21		198	158	62	459	213	165	69	175
P3-10	21		3,521.00	2,422.00	1,201.00	2,464.00	2,439.00	1,287.00	3,770.00	1,801.00
P3-11	21		3,973.30	3,268.50	503.1	9417.1	4091.6	4116.5	1443.3	4700.3
P3-12	21		996.4	206	1.1	2163	544.9	636	277.5	674.8
P3-13	21		468.1	59.4		896.1	215.1	206.4	152.1	231.5
P3-14	21		535.3	221.8	153	1133.5	251.1	340.8	152.1	298.7
P3-15	21		1,978.30	2,548.30	1,206.70	14699.6	5511.9	4087.1	2789.9	1930.4
P3-16	21		896.4		112.4	3075.9		14.1	816.8	1,424.40
P3-17	44		4.5	17.6	0.5	4.9		7.8		3.7
P3-18	21		9.6	28.9	3.6	18.6	2.8	8.1	2.7	6.5
P3-19	44		12.4	59.6	4.2	17.6		24.8		13.6
P3-20	21		1,081.00	345		152	932	2,400.00		434
P3-21	14		4,660.00	1,768.00	381	11,920.00	3,975.00	3,743.00	1,914.00	6,238.00
P3-22	14		8,580.00	4,447.00	1,190.00	22140	6720	5018	4218	9913
P3-23	14		97.8	67.9	11.9	223.7	67.5	48.5	49.3	109.3
P3-24	14		2,118.00	491	121	3,934.00	2,070.00	1,835.00	904	4,173.00
P3-25	14		8,991.00	4,225.00	1,003.00	21,463.00	7,478.00	4,384.00	4,615.00	10,463.00
P3-26	14		5,729.00	4,170.00	1,326.00	22,777.00	8,280.00	3,998.00	4,205.00	7,709.00

4.6. MRP Execution

For the sake of evaluating the DDMRP model performance and results, it was decided to replicate the behaviour of a normal MRP, which is in fact the method currently used by the company to manage the purchase orders and the warehouse stock levels. As so, the first step was to calculate the inventory or On-hand level for each single component on a weekly basis, this would be calculated based on the following formula:

$$On\ Hand(t) = On\ Hand_{(t-1)} + Arrivals_t - Consume_t$$

On Table 11 we can observe the obtained results for the On-hand values for each component after applying the formula to the previously gathered information. This datasheet represents the actual and regular functioning of the inventory controlling systems applied by the company at this moment. When we compare this table to the one mentioned in the component consume section, we can observe somewhat of a contradictory situation. While some of the components exhibit a consumption rate decrease, the MRP system is unable to react to this and continues to create orders based on the historic performance.

Table 11. On-Hand levels for MRP

		Week T0	Week -2	Week -1	Week 0	Week 1	Week 2	Week 3	Week 4	Week 5
Codice	DLT (wk)	Initial Inventori	04/07/2022-09/07/2022	11/07/2022-16/07/2022	18/07/2022-23/07/2022	25/07/2022-30/07/2022	01/08/2022-06/08/2022	08/08/2022-13/08/2022	22/08/2022-27/08/2022	29/08/2022-03/09/2022
P3-1	3	8,623	11,797	13,479	13,079	13240.3	15111.5	13299	17926.1	19146.4
P3-2	3	1,245	1,073	625	1,136	914.4	851.5	824.6	1315.4	1207.3
P3-3	3	259	610	567	550	376.8	769.1	718.1	682.4	604.2
P3-4	3	702	2,237	4,207	6,950	7800.1	6667.1	5409.6	4905.6	5720.6
P3-5	3	489	125	1,765	1,738	1438.4	1171.7	967.9	849.2	2354.8
P3-6	3	20,801	31,301	21,851	14,501	14501	7501	15901	13801	24301
P3-7	3	8,623	11,797	13,479	13,079	13240.3	15111.5	13299	17926.1	19146.4
P3-8	3	987	787	629	577	120	-93	6014	5944	5769
P3-9	3	1,522	1,324	1,166	1,104	645	432	6667	6598	6423
P3-10	3	19,221	15,700	13,278	12,077	9613	7174	5887	2117	316
P3-11	3	5,231	1,258	6,989	15,486	15069	10977.4	15860.9	14417.6	18517.3
P3-12	3	3,208	2,212	6,506	6,505	4341.5	8296.6	7660.6	11883.1	11208.3
P3-13	3	1,257	789	730	2,230	1333.4	1118.3	911.9	759.8	528.3
P3-14	3	3,012	2,477	6,755	6,602	5468.4	9717.3	9376.5	13724.4	13425.7
P3-15	3	5,231	34,603	32,054	30,848	31823.1	26311.2	37899.1	35109.2	48853.8
P3-16	3	3,876	2,980	2,980	5,867	2791.3	13791.3	13777.2	12960.4	11536
P3-17	6	52	48	30	29	24.5	224.5	216.7	216.7	213
P3-18	3	80	70	42	38	19.3	216.5	208.4	205.7	199.2
P3-19	6	252	240	180	176	158.2	158.2	233.4	233.4	219.8
P3-20	3	1,863	3,782	3,437	3,437	3285	4353	1953	1953	1519
P3-21	2	896	16,036	14,268	13,887	1967	23162	19419	17505	11267
P3-22	2	1,307	32,417	27,970	27,710	5570	34760	29742	97344	159251
P3-23	2	931	833	765	753	529.7	462.2	413.7	364.4	255.1
P3-24	2	22,803	20,685	20,194	20,073	16139	14069	12234	11330	7157
P3-25	2	103,820	94,829	90,604	89,601	68138	60660	56276	51661	41198
P3-26	2	105,931	100,202	96,032	94,706	71929	63649	59651	55446	47737

After all On-hand calculations have been made, a summary table was created using the global average for each component over the 5 Week time period. From Table 12 we can observe some interesting results, one example of this is how the components with the highest average on hand value do not correspond directly with the components with the highest total stock value. A clear case of this effect are components P3-25 and P3-26 which on aggregate take about 38% of the global inventory value wise, but when looking at the ranking based on cost, they are one of the weaker contributors to the whole inventory cost.

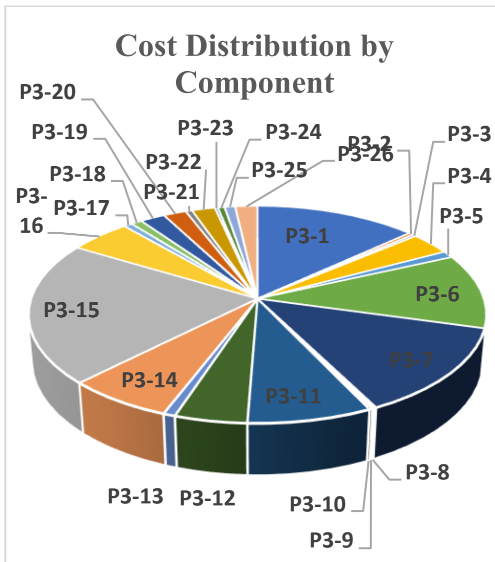
This effect can be explained because of the significant difference between the unit cost for each of the evaluated components, while base ingredients that make part of the final product (such as oils, sugars and dry fruits) have a higher unit cost, packaging and wrapping components have an inexpensive cost in comparison.

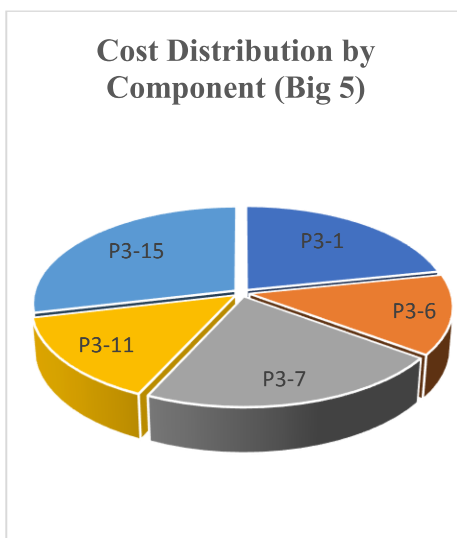
Table 12. MRP Results

Code	Avg. On-Hand Value	Unit Measure Type	Quantity from Finished Product	Unit Value	Total Stock Value	
P3-1	14,634.75	KG	0.01	€ 5.23	€ 76,539.74	
P3-2	993.44	KG	0.01	€ 2.16	€ 2,145.83	
P3-3	609.80	KG	0.00	€ 2.98	€ 1,817.20	
P3-4	5,487.14	KG	0.11	€ 3.55	€ 19,454.40	
P3-5	1,301.16	KG	0.02	€ 4.50	€ 5,855.23	
P3-6	17,957.25	KG	0.18	€ 3.61	€ 64,845.63	
P3-7	14,634.75	KG	0.00	€ 5.23	€ 76,539.74	
P3-8	2,468.38	PZ	0.01	€ 0.25	€ 617.09	
P3-9	3,044.88	PZ	0.01	€ 0.25	€ 761.22	
P3-10	8,270.25	PZ	0.01	€ 0.15	€ 1,240.54	
P3-11	12,321.90	KG	0.08	€ 3.63	€ 44,666.89	
P3-12	7,326.48	KG	0.09	€ 3.56	€ 26,049.69	
P3-13	1,049.95	KG	0.04	€ 4.12	€ 4,325.79	
P3-14	8,443.23	KG	0.04	€ 4.55	€ 38,416.67	
P3-15	34,687.65	KG	0.09	€ 3.56	€ 123,333.87	
P3-16	8,335.33	KG	0.17	€ 3.53	€ 29,418.79	
P3-17	125.28	KG	2.01	€ 32.00	€ 4,008.80	
P3-18	124.86	KG	0.47	€ 42.00	€ 5,244.23	
P3-19	199.80	KG	6.42	€ 59.00	€ 11,788.20	
P3-20	2,964.88	KG	0.08	€ 3.63	€ 10,747.67	
P3-21	14,688.88	PZ	0.28	€ 0.21	€ 3,084.66	
P3-22	51,845.50	PZ	0.28	€ 0.21	€ 10,887.56	
P3-23	547.13	KG	0.00	€ 2.50	€ 1,367.81	
P3-24	15,235.13	PZ	0.14	€ 0.21	€ 3,264.67	
P3-25	69,120.88	PZ	0.28	€ 0.07	€ 4,937.21	
P3-26	73,669.00	PZ	0.14	€ 0.14	€ 10,524.14	
					ADDED STOCK VALUE	€ 581,883.27

Another interesting conclusion from this MRP run is how most of the final stock value is concentrated in 5 main components, these main contributors make up almost 53% of the global stock value. Seeing Figure 14 it becomes clear how the packaging and wrapping components make up only for a small percentage of the inventory value, and how when making strategic decisions about supplier contracts and inventory management the "Big 5" cost contributor must become a priority for impact analysis.

Figure 14. Value contribution by component





5. DDMRP SIMULATION

5.1. Model Simulation

Being the main reason of this case study, which is to determine and evaluate the performance obtained by an DDMRP model used in the context of a company in the Food Industry, the simulation feeds from all the data obtained on the previous sections. The "DDMRP Simulation.xlsx" file contains the simulation and results obtained for each single product component during all the weeks taken into consideration during the project. The factors taken into consideration can be categorized as follows:

- Supplier Dependant: in this group we find MOQ and LT as they are information that is not model dependant but are previously agreed with each supplier

- Buffer Zones: the buffer zones used in the DDMRP simulation are calculated as the average value obtained during the evaluated weeks in the "BUFFER FILE.xlsx" file.

- Inventory Status: In this category we found information about the ongoing inventory levels for each component. On-Hand(t-1): represents the availability of the component in inventory on the previous time frame, in this case the previous week. On-Order(t-1): indicates the amount that is yet to arrive for a particular component in the previous timeframe. Sales Order(t): indicates the amount of that component that is being solicited by the production department.

- Model control mechanisms: In this group we find a series of values that allow us to comprehend how the model works and how it makes its decisions. The Netflow column serves as a signal to create a new order as the inventory levels start to decline, the formula used to obtain this value is the following:

$$NetFlow\ (t) = On\ Hand_{(t-1)} + On\ Order_t - Consume_t$$

  As most of the companies are not able to fully commit to the orders created by the model, probably because they might generate an unmanageable clustering in the warehouse if the space and conditions are not adequate, a parameter called Planning Priority is necessary. This parameter allows the user to discriminate between all the possible orders that are generated by the model and does this by stablishing a percentage value that defines how critical the situation is for every component evaluated. As the percentage starts to decrease the criticality of ordering that specific component arises. In this model a limit of 5 orders per week were stablished in order to guarantee the correct functioning of the warehouse and material arrival.

- Order Information: Starting with the Gross Order column, this value lets us know the theoretical amount of material to be ordered to fulfil the gap between the TOG and the current NetFlow. However, if we take into consideration the MOQ that won't allow us to order any particular quantity at will, we obtain the Effective Order, which is nothing but an approximation to the Gross Order in MOQ magnitudes and represents the actual order sizes to be registered. Arrival Date gives us an insight of the possible date of material arrival given the suppliers LT and Percentual Difference lets us identify how misaligned the Effective order is in comparison to the theorical optimal order.

Table 13. DDMRP Simulation (Week -2)

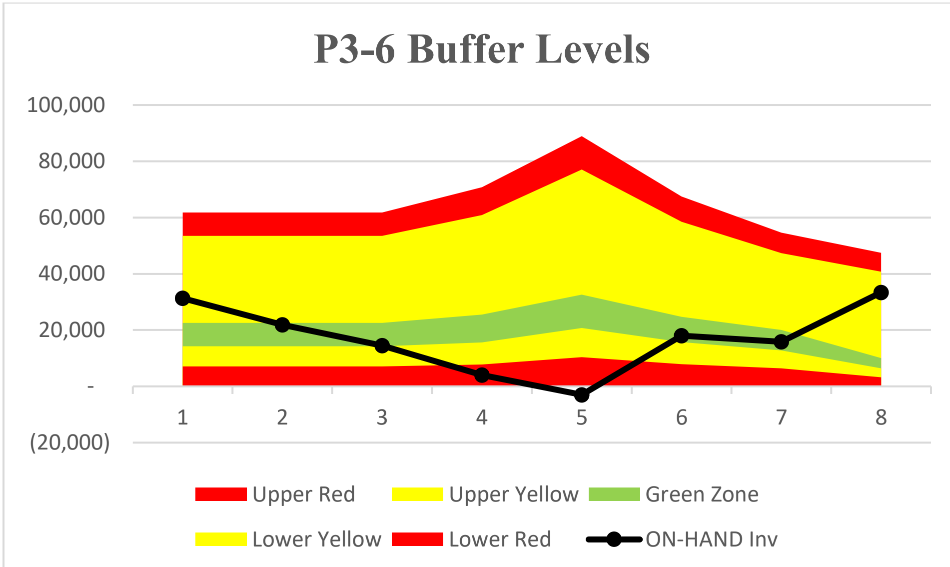
COD Mod	MOQ	Red Zone	Yellow Zone	Green Zone	DLT (days)	TOR	TOY	TOG	ON HAND (t-1)	ON ORDER (t-1)	SALES ORDER (t)	Net Flow	On Hand	Order Priority	Gross Order	Effective Order	Arrival Date	Percentual diferrence
P3-1	850	9,706	7,765	5,546	21	9,706	17,471	23,017	13,079	7,190	3,629	16,640	9,450.3	72%	6,376	6,800	Week 4	93.77%
P3-2	700	1,225	511	700	21	1,225	1,736	2,436	1,136	1,400	222	2,314	914.4	95%				
P3-3	220	400	298	229	21	400	698	927	550	440	173	817	376.8	88%				
P3-4	916	5,834	4,667	3,334	21	5,834	10,501	13,835	6,950	2,776	1,926	7,800	5,024.1	56%	6,034	6,412	Week 4	94.11%
P3-5	300	1,105	884	632	21	1,105	1,989	2,621	1,738	0	300	1,438	1,438.4	55%	1,182	1,200	Week 4	98.53%
P3-6	700	14,595	25,019	8,340	21	14,595	39,614	47,954	14,501	44,100	10,500	48,101	4,001.0	100%				
P3-7	850	9,706	7,765	5,546	21	9,706	17,471	23,017	13,079	7,190	3,629	16,640	9,450.3	72%	6,376	6,800	Week 4	93.77%
P3-8	6,272	10,976	876	6,272	21	10,976	11,852	18,124	577	25,088	457	25,208	18,936.0	139%				
P3-9	6,400	11,200	883	6,400	21	11,200	12,083	18,483	1,104	25,600	459	26,245	19,845.0	142%				
P3-10	50,000	87,500	9,436	50,000	21	87,500	96,936	146,936	12,077	150,000	2,464	159,613	159,613.0	109%				
P3-11	450	22,731	18,185	12,989	21	22,731	40,917	53,906	15,486	49,500	9,417	55,569	6,069.0	103%				
P3-12	750	4,069	3,255	2,325	21	4,069	7,324	9,650	6,505	4,500	2,163	8,842	4,341.5	92%				
P3-13	700	1,666	1,308	952	21	1,666	2,974	3,926	2,230	2,100	896	3,433	1,333.4	87%				
P3-14	750	2,260	1,808	1,291	21	2,260	4,067	5,359	6,602	4,500	1,134	9,968	5,468.4	186%				
P3-15	2,475	29,303	23,442	16,745	21	29,303	52,745	69,490	30,848	31,350	14,700	47,498	16,148.1	68%	21,992	34,650	Week 4	63.47%
P3-16	1,000	4,449	3,560	2,543	21	4,449	8,009	10,551	5,867	11,000	3,076	13,791	2,791.3	131%				
P3-17	20	35	38	20	44	35	73	93	29	200	5	225	24.5	241%				
P3-18	15	52	41	30	21	52	93	123	38	290	19	309	19.3	252%				
P3-19	20	78	131	45	44	78	209	254	176	100	18	258	158.2	102%				
P3-20	1,000	2,020	2,913	1,154	21	2,020	4,932	6,087	3,437	2,000	152	5,285	3,285.0	87%				
P3-21	990	60,067	13,348	40,044	14	60,067	73,415	113,459	13,887	132,090	11,920	134,057	108,887.0	118%				
P3-22	990	107,959	23,991	71,973	14	107,959	131,950	203,923	27,710	239,850	22,140	245,420	209,510.0	120%				
P3-23	202	1,135	252	757	14	1,135	1,387	2,144	753	1,414	224	1,944	529.7	91%				
P3-24	1,300	16,721	5,574	11,147	14	16,721	22,294	33,442	20,073	20,800	3,934	36,939	16,139.0	110%				
P3-25	102,000	155,361	23,897	103,574	14	155,361	179,259	282,833	89,601	204,000	21,463	272,138	68,138.0	96%				
P3-26	102,000	155,281	24,018	103,521	14	155,281	179,299	282,820	94,706	204,000	22,777	275,929	71,929.0	98%				

5.2. Buffer Level Analysis

An important part of the simulation results are the variations that can be observed in the component buffers as time passes and the On-Hand inventory levels change. As the parameters taken into consideration for the buffer calculation vary, the overall sizes of the zones (Upper Red, Upper Yellow, Green Zone or Optimal Zone, Lower Yellow, and Lower Red) are modified from timeframe to timeframe.

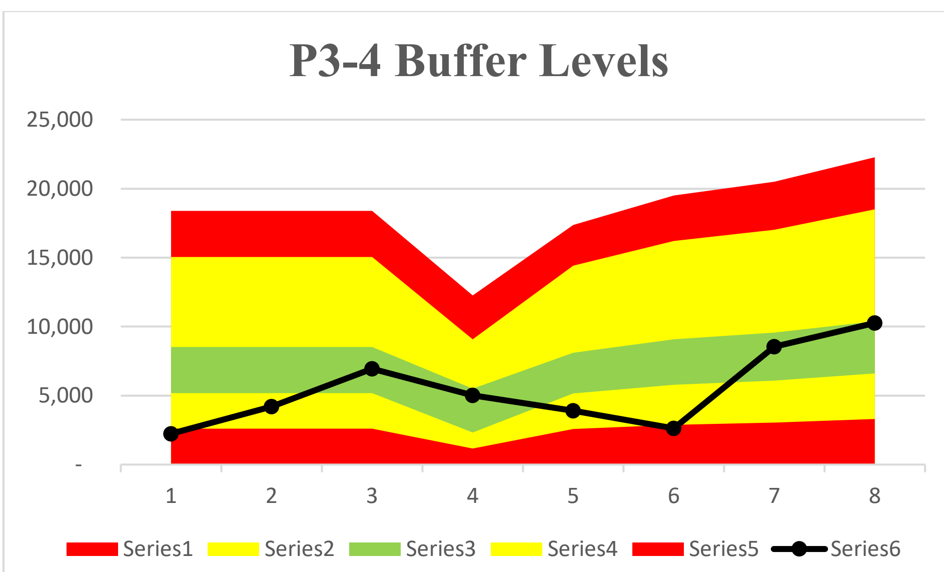
Starting with component P3-6 as an example, in Figure 15, we can observe how the buffer levels suffer distinct changes as the timeframe progresses. During the first three periods, we can observe how the On-Hand values remain stable and more or less appropriate in relation to the Optimal Zone. As we go into the fourth time period and the inventory level decreases to a critical point, a procurement order is generated and a purchase order is transmitted to the raw material supplier, unfortunately, due to the unusually high component demand and the long lead time for the material arrival, during period number 5 we observe a stock-out of the said component.

Figure 15. P3-6 Buffer levels throughout the simulation.



Entering into time period 6, with the arrival of the procurement order, we can see how the On-Hand inventory level raises and stablish itself right in the middle of the Optimal zone. On the next period, period number 7, we can observe that the inventory level continues optimal territory which leads us to believe that the amount order was the adequate one. On the last period, we can observe the arrival of the last procurement order, which raises the inventory levels above the optimal zone probably trying to prevent a possible stock-out.

Figure 16. P3-4 Buffer levels throughout the simulation.



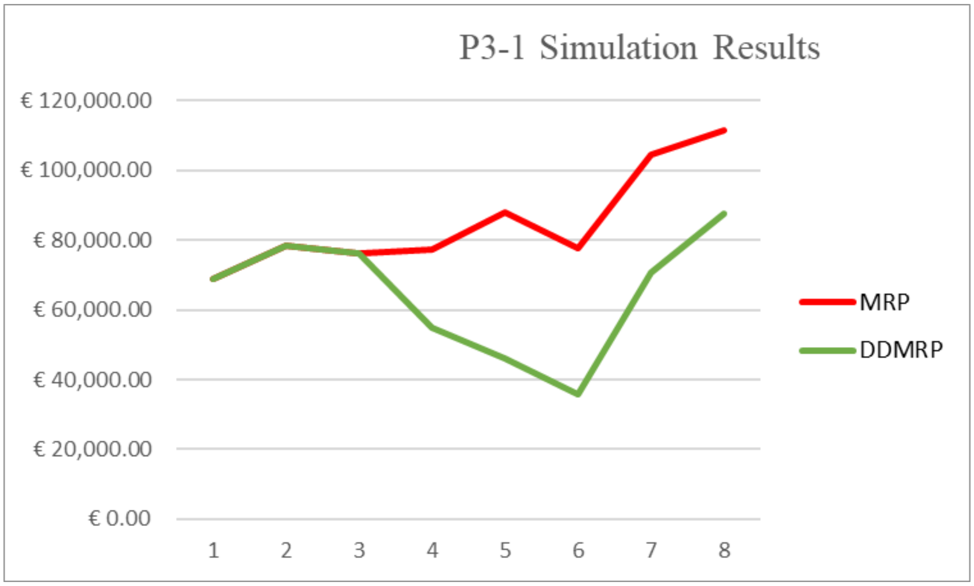
It was then decided to recreate the same analysis with another of the product components, in this case component number P3-4. We can observe from Figure 16 that at the beginning procurement orders are put in place in order to reach the optimal level defined by the buffers, however, as time progresses we see how due to component demand the available inventory falls into the lower yellow zone triggering a procurement order that arrives around the seventh period, putting the On-Hand levels back into optimal values.

6. MRP vs DDMRP COMPARISON

6.1. Stock level for "Big 5"

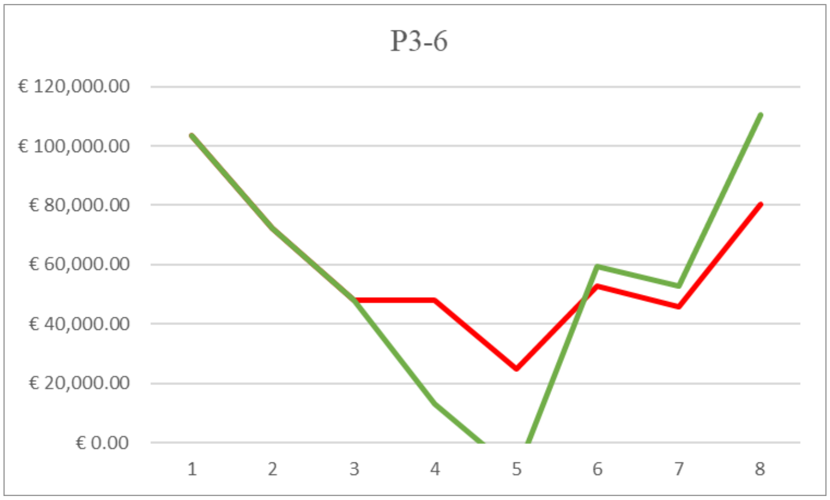
In order to furtherly evaluate the performance of the model, a series of graphs were developed confronting the results obtained per week by the MRP and the new DDMRP. For the P3-1 component, this being the biggest contributor to the total inventory cost, a clear increase in performance is observable as from the third period onward (the point from which the DDMRP starts working autonomously) the average stock cost decreases significantly with a trend that leads to believe it will continue that way.

Figure 17. P3-1 MRP vs DDMRP Results.



In the case of product component P3-6 we can observe something interesting happening, even though after the separation point on the third week the results appear to be favourable, the inventory level decreases to an alarming point until it falls into stock-out, after reviewing the data it was discovered that this is caused by the adaptation time it takes to the model to catch up with the purchase orders that need to be made in order to properly satisfy demand. As the order was made on the first week the DDMRP model takes control, the lead time associated to the component is too large and during the final week prior to the material arrival the warehouse runs into a stock-out. Even though this is a negative event, the association can be made to the set-up time and not to a fail from the proposed model.

Figure 18. P3-6 MRP vs DDMRP Results.

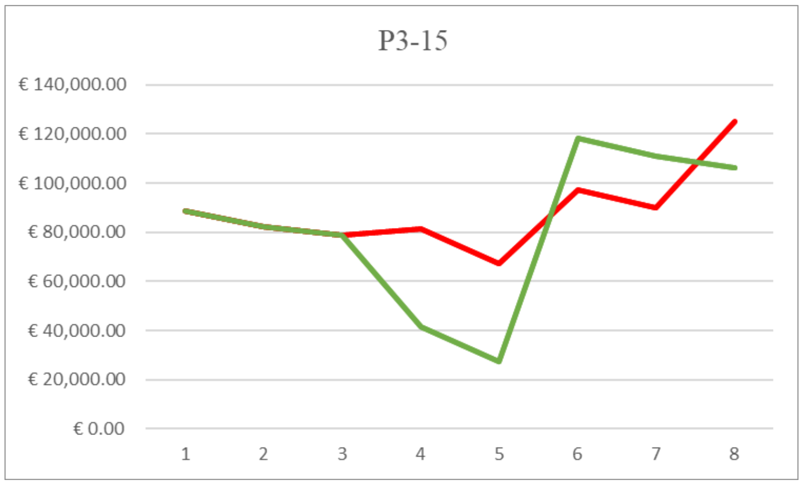


Another interesting event occurs when evaluating the performance for the P3-11 component, as seen on Figure 19, the model presents a sudden improvement with respect to its classic MRP counterpart during the first two weeks after separation. However, when the inventory value arrives to its lowest point on the fifth week, a large purchase order is placed, increasing the inventory cost way above the MRP levels. It is up to further evaluation to determine is this value continues to be higher in the DDMRP during the long run or we are just observing a local spike.

Figure 19. P3-11 MRP vs DDMRP Results.

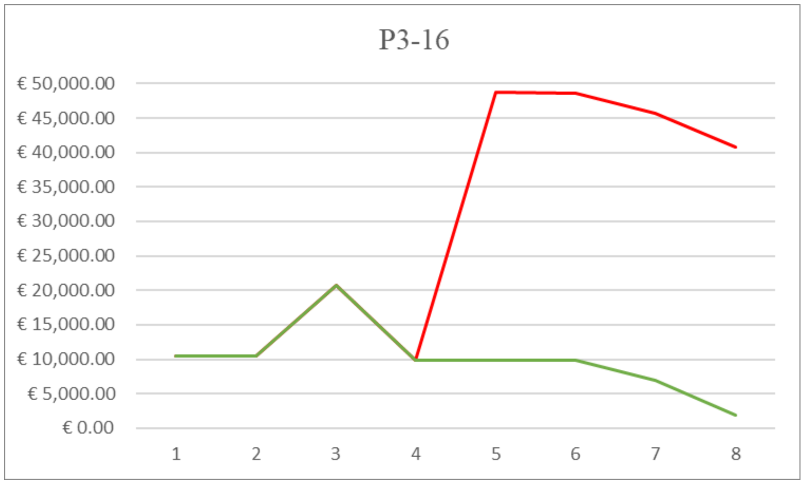
When looking at Figure 20 which depicts component P3-15 behaviour during the simulation, there are a couple things worth mentioning. At Week 5, just after the first orders made by the DDMRP model arrive an expected increase in inventory cost arises. Nonetheless, as weeks continue to go by, we can start to notice a trend that leads to believe that in the long run the results obtained for this component will be beneficial when being managed by the newer model, as at the last week we can observe that the cost function goes under the value obtain by the MRP model.

Figure 20. P3-15 MRP vs DDMRP Results



Lastly, component P3-16 shows promising results as right after the separation point the associated cost remain to be lower during the remaining weeks, and even though a significant order is to be expected on Week 9 as the inventory value continues to reach its lower limit, it will more than likely continue to remain under the MRP cost curve. A closer examination with the acquisition department revealed that the huge ordered amount presented by the MRP responds to an acquisition made based on last year's prognostics that unfortunately are not aligned to the current market and production situation.

Figure 21. P3-16 MRP vs DDMRP Results



6.2. Warehouse Level Analysis

Even though the graph analysis for the biggest cost contributors shows promising results, it was decided to do an aggregated analysis of the On-Hand inventory levels for every single component, in order to determine the full impact of the proposed model and determine if the application of a DDMRP model would be suitable for Aromitalia. As shown in Figure 22, most of the inventory levels remain similar in the grand scale even after changing the model, however some key aspects are worth highlighting.

Starting with P3-6 and P3-7, we see that in the DDMRP the level for both codes is almost identical, a reasonable explanation for this is that these two components usually make part of the BOM for the same products, meaning that a consumption of one will likely be followed by a consumption of the other, and thus lead to having similar buffer zones and ultimately On-hand levels. Another interesting case occurs with P-10, where on the DDMRP model the inventory level is significantly higher, an effect most likely caused by an effort made by the model in order to reduce the probability of stock-out.

Perhaps the clearest example of the benefits of this newer model and its adaptiveness to the changes in consume levels can be seen with component P-16. As it can be seen on the right-hand side of the Figure 22, the On-Hand inventory levels with the DDMRP model are remarkably lower when compared to the traditional MRP. When investigating the reason for this occurrence with the production department, it was discovered that the laboratory has been successfully running a series of tests by changing the P3-16 with a cheaper and newly discovered substitute. This changes to the product's BOM have led to a considerable reduction in the consume of P3-16 for the evaluated timeframe, the DDMRP model reactiveness allows it to adapt to these changes quickly reducing the value of Effective Orders as the weeks go by. On the contrary, the company's MRP that calculates its coverage based on the previous year prognostics, is unable to detect these changes and continues to order P3-16 even though it's not immediately needed.

Figure 22. Inventory levels for MRP and DDMRP models.

	MRP (Sim Avg)					
Codice	**Week 1**	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**AVG**
P3-1	13,240	15,112	13,299	17,926	19,146	15,745
P3-2	339	315	306	487	447	379
P3-3	193	393	367	349	309	322
P3-4	4,750	4,060	3,294	2,987	3,483	3,715
P3-5	1,110	904	747	655	1,818	1,047
P3-6	8,233	4,259	9,028	7,836	13,797	8,630
P3-7	13,240	15,112	13,299	17,926	19,146	15,745
P3-8	5	(4)	258	255	247	152
P3-9	28	19	286	283	275	178
P3-10	247	185	151	54	8	129
P3-11	9,383	6,835	9,876	8,977	11,530	9,320
P3-12	2,651	5,066	4,678	7,256	6,844	5,299
P3-13	942	790	644	537	373	657
P3-14	4,268	7,584	7,318	10,711	10,478	8,072
P3-15	13,974	11,553	16,642	15,417	21,452	15,808
P3-16	1,690	8,350	8,342	7,847	6,985	6,643
P3-17	134	1,232	1,189	1,189	1,169	983
P3-18	139	1,560	1,501	1,482	1,435	1,223
P3-19	1,601	1,601	2,362	2,362	2,224	2,030
P3-20	2,045	2,710	1,216	1,216	946	1,627
P3-21	71	834	699	631	406	528
P3-22	201	1,252	1,071	3,506	5,736	2,353
P3-23	227	198	177	156	109	174
P3-24	581	507	441	408	258	439
P3-25	818	728	676	620	495	667
P3-26	864	764	716	666	573	717

	DDMRP (Sim Avg)					
Codice	**Week 1**	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**AVG**
P3-1	9,450	7,922	6,109	12,136	15,056	10,135
P3-2	339	315	824	813	773	613
P3-3	193	168	142	124	84	142
P3-4	3,059	2,369	1,604	5,201	6,248	3,696
P3-5	1,110	904	747	1,582	1,354	1,140
P3-6	2,272	(1,703)	10,220	9,028	18,964	10,121
P3-7	9,450	7,922	6,109	12,136	15,056	10,135
P3-8	812	803	796	793	785	798
P3-9	851	842	835	832	824	837
P3-10	4,107	4,044	4,011	3,914	3,867	3,989
P3-11	3,779	1,231	17,161	16,262	21,741	12,035
P3-12	2,651	2,318	1,930	5,424	5,012	3,467
P3-13	942	790	2,128	2,021	1,857	1,548
P3-14	4,268	4,072	3,806	3,687	3,454	3,857
P3-15	7,091	4,670	20,264	19,039	18,192	13,851
P3-16	1,690	1,690	1,682	1,187	325	1,315
P3-17	134	574	531	531	510	456
P3-18	139	767	709	689	643	589
P3-19	1,601	1,601	1,350	1,350	1,212	1,423
P3-20	2,045	1,465	(29)	(29)	946	1,485
P3-21	3,922	3,779	3,644	3,575	3,351	3,654
P3-22	7,547	7,305	7,124	6,972	6,615	7,112
P3-23	227	805	784	763	716	659
P3-24	581	507	441	1,064	913	701
P3-25	818	3,178	3,125	3,070	2,944	2,627
P3-26	864	3,214	3,166	3,115	3,023	2,676

6.3. Cost Analysis

Probably one of the most telling tools for measuring the model performance during the simulation, besides the graphs discussed a priori, is an analysis of the stock value obtained with each model. Following this train of thought, it was decided to create a summary table where the average stock value for each of the evaluated weeks was displayed. Additionally, the number of total orders per component was also calculated, as a reduction of this value could determine an improvement in factors such as transportation costs, inbound logistics and warehouse management.

The overall improvement obtained by the use of the DDMRP over the traditional MRP, when talking only in monetary terms, would be of an average reduction of €20,530 in stock value for the analysed components. Considering that we are talking about a company in the food industry, the inventory rotation is an important factor to take into account. Given company's policies, the expected period before expiration or obsolescence for the raw materials that enter the warehouse is of about 5-6 months. This low level of permanence of raw materials in storage surges as a policy to guarantee that the final products will have an expiration date of 2 years after the date of production. Decreasing the overall inventory cost directly decreases the possibility of losing resources with raw materials that will not end up being use as their expiration date is not long enough to cover the 2-year policy.

After discussing with the accounting department, it has been informed that an estimate of about 15% of all incoming material will not end up being used, generating a cost not only at the moment of the acquisition but also latter when these components must be properly discarded. Furthermore, there is also a cost associated with the insurance policy that covers the warehouse, the financial risk of an unforeseen disaster like event and simply a handling cost that altogether sums up to about a 7% of the total inventory cost.

Table 14. MRP vs DDMRP Cost Analysis

SIMULATION RISULTS (Week 1-5)							
Codice	**MRP**	**Num. Ord**	**DDMRP**	**Num. Ord**	**Difference (Cost)**	**Difference (Orders)**	
P3-1	€ 91,791	4	€ 59,085	3	€ 32,706	1	
P3-2	€ 2,209	1	€ 3,574	0	€ (1,365)	1	
P3-3	€ 1,878	1	€ 829	1	€ 1,049	0	
P3-4	€ 21,657	2	€ 21,550	2	€ 107	0	
P3-5	€ 6,104	1	€ 6,644	2	€ (540)	-1	
P3-6	€ 50,315	3	€ 59,004	1	€ (8,689)	2	
P3-7	€ 91,791	4	€ 59,085	3	€ 32,706	1	
P3-8	€ 888	1	€ 4,651	0	€ (3,763)	1	
P3-9	€ 1,038	1	€ 4,878	0	€ (3,840)	1	
P3-10	€ 753	0	€ 23,253	0	€ (22,500)	0	
P3-11	€ 54,335	3	€ 70,162	3	€ (15,827)	0	
P3-12	€ 30,894	2	€ 20,214	2	€ 10,680	0	
P3-13	€ 3,833	0	€ 9,024	1	€ (5,191)	-1	
P3-14	€ 47,058	2	€ 22,488	0	€ 24,570	2	
P3-15	€ 92,158	3	€ 80,753	1	€ 11,405	2	
P3-16	€ 38,728	1	€ 7,664	2	€ 31,064	-1	
P3-17	€ 5,731	1	€ 2,659	0	€ 3,072	1	
P3-18	€ 7,132	1	€ 3,436	0	€ 3,696	1	
P3-19	€ 11,835	1	€ 8,295	1	€ 3,540	0	
P3-20	€ 9,484	1	€ 8,660	2	€ 824	-1	
P3-21	€ 3,079	1	€ 21,304	0	€ (18,225)	1	
P3-22	€ 13,720	3	€ 41,465	0	€ (27,745)	3	
P3-23	€ 1,013	0	€ 3,841	0	€ (2,828)	0	
P3-24	€ 2,559	0	€ 4,088	1	€ (1,529)	-1	
P3-25	€ 3,891	0	€ 15,315	0	€ (11,424)	0	**TOTAL IMPROVEMENT**
P3-26	€ 4,178	0	€ 15,602	0	€ (11,424)	0	**€ 20,530**

If we extrapolate this newly received information and use it to evaluate the MRP vs DDMRP performance, we obtain that during the simulation run we can observe a decrease in inventory associated costs of approximately €4,516 just for this final product alone. These promising results lead to believe that if the model were to be applied to a larger amount of codes, such as a product family or even the whole warehouse a very significant cost reduction is to be expected.

6.4. Unfulfilled Order Analysis

One relevant analysis to make is the evaluation of the economical impact of going into stock-out for one of the product components. In the case of this project in particular, we can evaluate this effect by analysing component number P3-6 which in one of the periods, more specifically Period 5, arrives to an inventory of almost negative three thousand kilograms. Given that this situation if critical enough could lead to cancelled orders or client penalties, it was decided to calculate real economical impact if a situation like this were to occur.

In order to properly evaluate the impact of this situation the following formula was designed and posteriorly consulted with the company's director, who gave his insight into the veracity of the economic impact. It is important before stating the formula to understand a series of factor that influence the formula results based on the company's working methodology and clients contractual relationships:

- Given the company's three-week production planning lead time and the stated contractual obligations, any setback inferior to a three-week period will not result in an order cancelation but rather an unforeseen order delay.
- In the case of a delay inferior to the three-week period, the resulting economical impact will not be 100% of the client order but rather an overhead cost of approximately 20% to cover for container and delivery reprogramming, customs penalties and possible remanufacturing costs (labels and packaging).

Once this criterion has been clarified, we can proceed to evaluate the EI (short for economic impact) formula:

Equation 10. Economic Impact Value

$$EI = S_p * M_p * P_t * C_p * R$$

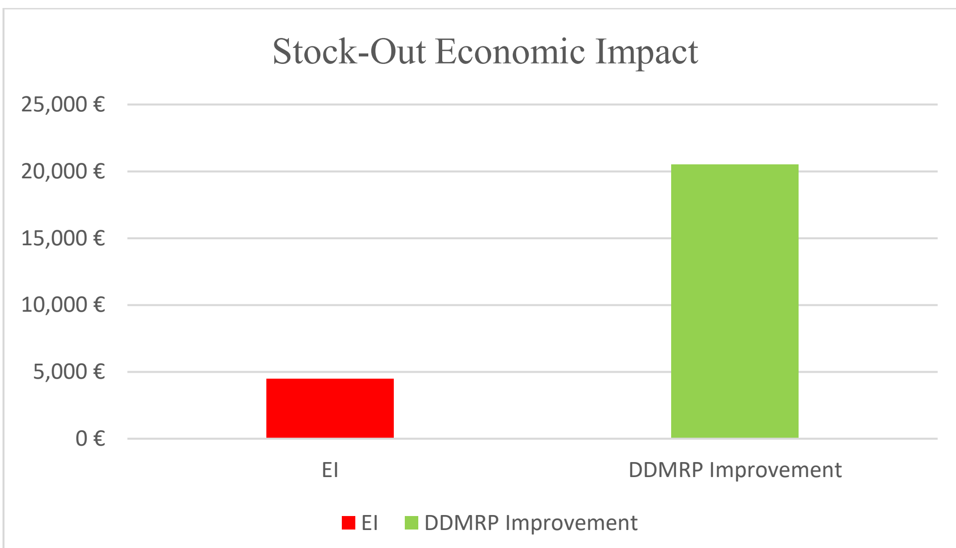
Where Sp is the sale price for the given product, in this case its assumed that all the raw material in stock-out was going to be used in the same product, Mp is the income margin related to the product in question, Pt is the cost percentage related to the amount of delay in the order (100% if the delay is superior to the three-week period or 20% otherwise), Cp is the conversion rate from raw material to product or in simpler terms, how much product P can be produced with the missing raw material. Lastly, R represents the total amount of raw material that goes into stock-out.

Having product P1 as our base product for calculations and given that the stock-out period is inferior to three-weeks, we obtain the following formula:

$$€4.486 = 4.8 * 0,34 * 0,2 * 5,5 * 2.999$$

Once we compare this newly obtained value with the economical improvement obtained with the DDMRP implementation, as seen on Figure 23, we can conclude that even though with the lastly mentioned model we run into stockout during one period of the simulation, as it is only during a single timeframe, the economic impact does not obscure the improvement obtained by implementing the DDMRP.

Figure 23. Economic Impact comparison with DDMRP improvement



7. CONCLUSIONS

Entering into this project, there was the doubt if the selected material procurement model would adapt accordingly to Aromitalia's business processes, production planning and raw material purchasing methodologies. Even though the model its designed in its majority for production processes with high inventory rotations and short procurement lead times, and Aromitalia's manufacturing practices fit perfectly into this description, each company has a unique set of traits and characteristics that make a 100% flawless application impossible.

One of the critical aspects that is worth further analysing, is the occurrence of the stock out during one of the periods of the simulation. Even though this eventuality creates an array of problems related to order delay and logistics reprogramming, after analysing the economic impact that this situation might have, it was discovered that the improvements obtained through the model usage, greatly surpassed the cost consequences of the potential production setback caused by material unavailability.

Another aspect of considerable importance when talking about the implementation of a new procurement methodology is the aspect of personnel training and "set-up" times. It is vital for the correct deployment of the new model, to understand the importance of a well-defined integration process, that leads to a smooth transition between the older methodology and the newer one. Additionally, is expected that the DDMRP system provides worst results in comparison to the current MRP system during the initial stages of the implementation, as the personal adapts and get familiar with the newer concepts and tools at their disposal.

An added aspect that brings complexity to the model incorporation it's the integration between the newly defined model and currently used ERP system "Navision". A meeting with the system consultant revealed that the two systems are compatible with one another, however, a series of thorough procedures and data recollection is due before the complete modification and implementation of the newer model into Aromitalia's ERP.

Even though the complete integration of a DDMRP system into Aromitalia's business processes brings a series of challenges and required procedures as previously mentioned, the model seems to make up to these tasks when evaluating the potential benefits, both operational and financial wise. Starting with the financial aspects, as mentioned during the result analysis, an improvement of approximately €20.500 euros was perceived during the two-month simulation period, leading to believe that the cost reduction could be considerably high when taking into account that only one of Aromitalia's hundreds of product codes was analysed.

In addition to the improvement obtained in the financial KPIs, it is important to considered the potential improvements to the overall company's operation with the implementation of the new material procurement model. One of the observed benefits from this model was the reduction of overall inventory levels, which ends up helping in great extent the warehouse management team as they have more free space in which to manoeuvre and in which to prepare the outgoing product on the delivery bay.

Finally, a not so commonly recognized benefit of the implementation of this type of models, is the use that the material procurement team give to the newly freed up time, which they can now dedicate to activities different from the day-to-day planning and emergency control. This time and effort can now be devoted to optimizing the model parameters or researching new ways of enhancing the current work procedures with amazing ideas that weren't looked upon until this moment due to lack of time.

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