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SUPERMARKET SIZING IN PRODUCTION FLOW SYSTEMS BASED ON LEAN PRINCIPLES

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DISSERTAÇÃO DE MESTRADO APRESENTADA
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Supermarket Sizing in Production Flow Systems Based On Lean Principles

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Abstract

The main objective of this thesis is to design a software tool that allows to size supermarkets in a Production Flow System, based on Lean principles. The sizing process occurs according to a set of inputs supplied by a database that contains information on the components and products such as lead times, economic order quantity, rework and scrap amounts, pallet size and length, bill of materials, packaging lines and demand information such as order dates, amounts, etc.

The tool should be capable of dealing with demand and lead time variations and a different variety of components and products. It should also be able to size the supermarket by measuring the reorder point, the safety stock, maximum stock and number of *kanbans* to consider, etc for each reference.

The supermarket to be analyzed is placed at the end of a Production Line and right before a Packaging Line and it's a part of a push-pull system. The Production Line works as a pull system. When the amount of a certain reference is lower that the respective reorder point, *kanbans* of that same reference are launched into production until the reorder point is replenished once again. The Packaging Line operates as a push system. The orders to withdrawn components from the supermarket are satisfied as long as this last one possesses the necessary resources. If it does, the orders go through a sequencing process that minimize setup times and are pushed through the Packaging Line.

To develop this tool, the modeling software used was Anylogic 7.1.2, a simulation program that supports System Dynamics, Discrete Event and Agent Based modeling using java. The model development was made using Anylogic's Personal Learning Edition while for the simulation part an Educational Edition was needed due to restrictions to the first one.

Acknowledgments

Firstly, I would like to thank the two institutions involved in this Master's thesis, both FEUP and INESC for providing the necessary conditions to the realization of this project, without them it wouldn't have been possible.

I'm grateful for all the support and wise counsel supplied by my supervisor Américo Azevedo, and second supervisor Rui Diogo Rebelo whom have set an example of excellence as a researcher, mentor, instructor, and role model.

To all the professors and colleagues who crossed my path and somehow helped in this course completion.

To my parents and sisters for all the support and kind words throughout the years.

Pedro Martins

"When you want to know how things really work,
study them when they're coming apart.."

William Gibson

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Abbreviations

FEUP	Faculdade de Engenharia da Universidade do Porto
INESC	Instituto de Engenharia de Sistemas e Computadores
JIT	Just In Time
TPS	Toyota Production System
WIP	Work In Progress
SS	Safety Stock
Q	Economic Order Quantity
μ_{LT}	Lead Time Average
σ_{LT}	Lead Time Standard Deviation
μ_{DD}	Demand Average
σ_{DD}	Demand Standard Deviation
K	Fixed Cost Per Order
h	Inventory Carrying Cost
Z	Service Level
PLE	Personal Learning Edition
FIFO	First In First Out
LIFO	Last In First Out
SMED	Single Minute Exchange of Die
VSM	Value Stream Mapping
MTM	Methods Time Measurement
TPM	Total Productive Maintenance

Chapter 1

Introduction

The project, in which this thesis is based, was proposed by INESC and its main objective was to develop a tool that through a set of inputs, was capable to generate an output that could support the sizing of a supermarket for a furniture company.

In this chapter is presented the motivation and context for this project, followed by the structure and organization of this document.

1.1 Problem and Context

In today's world, competitiveness is the key to survival in markets that are characterized by the demand of high quality products, in high quantities and with low production costs and short delivery times. In order to maintain its competitiveness, one has to constantly improve itself.

This project, proposed by INESC, intends to do exactly this. Its objective is to develop a tool that allows sizing a supermarket that will be placed at the end of a production line, right before a packaging line and guarantee lower stocks while optimizing product delivery, by having the necessary products at the right time, in the right place, in the correct quantities.

The furniture company, to whom this simulation was intended, produces furniture for kitchens, living rooms, gardens, bathrooms, etc. The seasonality for these products is very high which, consequently, makes the variability on its demand equally high. This variability implies that stock maintenance is a hard problem to deal with. To add to that, a lot of processes, especially the painting one, are very complex and also introduce high variability both in lead time and rework rates.

The main objective of this simulation is to determine, from different scenarios that were created, which one would be the best suited for the data input used in this project and best fits a supermarket with around 1200m.

1.2 Methodology

This project took place in INESC, in a six months period, where the first and last months were set aside for a literature review and the thesis writing respectively. This project was conducted following a method with five different main steps: Literature Review, Design and Implementation, Result Analysis and a Conclusion.

Firstly a Literature Review was made. This stage has the intent of understanding all the concepts regarding lean manufacturing, along with some history of where it was first created. This is a crucial stage since we are studying how to accurately apply these lean principles and also which of those are more beneficial for the furniture industry by analyzing different articles regarding lean implementation in this industry. JIT, Pull strategy and *kanbans* were some of the key lean tools, procedures and techniques utilized.

Secondly, a simulation tool that was able to simulate an entire year and could turn components and demand information inputs into supermarket's size outputs was developed in order to help decision making. A set of different scenarios of simulation were created and simulated.

Finally, the achieved results were analyzed, comparing advantages and disadvantages of each one. Improvement opportunities were investigated and solutions to reach those improvements suggested.

1.3 Thesis Structure

Besides this introduction, this thesis has 4 more chapters. In chapter **??**, the state of the art is described and some related works are presented. In chapter 3, an introduction to Anylogic is made and the simulation model used for the supermarket's dimensioning is explained. In chapter 4, the results provided by the simulation model are analysed and discussed. In chapter 5 5, the conclusions and future work for this thesis are enunciated.

Chapter 2

Technical review

A lot has been developed concerning the Lean philosophy since the concept was introduced for the first time. In this chapter some of the major theoretical concepts that were relevant in the making of this dissertation are analyzed. Besides that, some similar projects that were already approached will be discussed.

2.1 Lean

The term Lean was introduced for the first time by James Womack, Daniel Jones and Daniel Roos in their book "The Machine that Changed the World" [4]. After the 1st World War, Henry Ford started the age of mass production. He was the first to understand the importance of process speed and the hazards caused by inventory. He is considered to be the first to implement the concepts of Just In Time (JIT) and Lean Manufacturing, although he failed by not satisfying all of his customers' needs since he only produced one product.

With Europe still using craft production, the USA had no real competitors and their domination years of the global economy started. But it was only Toyota, when their sales were collapsing, who understood and pioneered the real concept of Lean production a few years later.

But what is Lean anyway? Lean is a systemic method for the elimination of "*muda*" (Japanese word for waste), any human activity, which spends time and resources, but doesn't add value. Taiichi Ohno identified 7 types of waste, to be studied further ahead. Lean also takes into account the excessive work ("*muri*"), given to employees due to a poor organization structure or bad working conditions, and unevenness workloads ("*mura*"), variation and inconsistency in quality and volume of both products and human conditions. Lean is essentially based on making obvious what ads value by reducing everything else.

2.1.1 Lean Thinking

Lean Thinking is the way to fight "*muda*", since it provides methods to transform waste into value [5]. Those methods optimize processes to improve efficiency and minimize production time in order to eliminate waste.

Some authors describe Lean as a philosophy to create value and eliminate waste. Five main principles were associated to it:

1. **Value.** This is the starting point for Lean Manufacturing. The company should place itself in the customers' perspective and identify which processes are value adding to it;
2. **Value Stream Mapping.** To fully understand value the activities in the value stream must be mapped. The objective of value stream mapping is to represent the flow and dependency between processes. Identifying and connecting this processes correctly is crucial;
3. **Flow.** In order to make the product flow smoothly make the value-creating processes occur in tight sequence, which means that, between these processes should exist as least non-value-added processes as possible. This flow should be as short as it can be whilst having high quality and low cost;
4. **Let customers pull.** A pull system, where the downstream processes only pull materials into production when they are needed, is a crucial element of a JIT system;
5. **Perfection**. After value is identified and mapped, flow is created and pull is applied, repeat the previous steps until a state of perfection with no waste, only value adding processes.

Burton and Boeder, in "The Lean Extended Enterprise: Moving Beyond the Four Walls to Value Stream Excellence", came to the conclusion that from applying Lean Thinking philosophies, companies can expect major improvements in their results, such as [6]:

Table 2.1: Lean Benefits

Element	Benefit
Capacity	10 to 20% gains in capacity by optimizing bottlenecks
Inventory	Reductions of 30 to 40% in inventory
Cycle time	Throughput time reduced by 50 to 75%
Lead time	Reduction of 50% in order fulfillment
Product development time	Reductions of 35 to 50% in development time
Space	35 to 50% space reduction
First-pass yield	5 to 15% in first-pass yield
Service	Delivery performance of 99%

2.1.2 Toyota Production System

After the 2^{nd} World War, Japan was struggling with major financial problems especially concerning the auto industry and Toyota, specifically, was nearly bankrupt. It was back then, with their minds set on changing their company's fate, that Eiji Toyoda, Toyota's President, and Taiichi Ohno, Toyota's Chief Engineer, visited Henry Ford's factory, in Detroit, USA, to understand the production model used there. In their journey, Toyoda and Ohno noticed several factors that lead them to conclude that this model could be extensively improved. They also had the opportunity to analyze the supermarket chain Piggly Wiggly which, with a much better production system implemented, served them as an inspiration.

Back in Japan, Ohno decided to create his own system, The Toyota Production System (TPS). “The main goal of the Toyota Production System is to identify and eliminate waste and reduce costs” providing products at world class quality levels [7]. Figure 2.1 represents the TPS “House”.

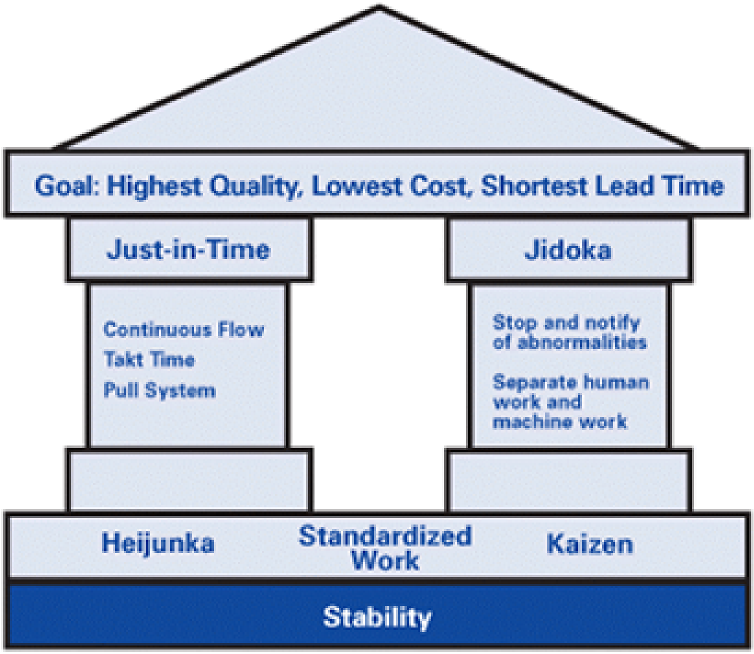

Figure 2.1: TPS House [1]

The TPS has JIT and Automation (*Jidoka*) as its main pillars. JIT is the ability to produce right parts or products in the right quantity, at the right time, in order to not create any stocks or delays. “The term *jidoka* used in the TPS can be defined as "automation with a human touch."[8] *Jidoka* intends to create conditions to achieve the perfection of the processes by allowing machines to stop in case any abnormal situation occurs.

In the base of the TPS “House” is stability, as every regular house the base must be stable. The three points that guarantee this stability are: *Heijunka*, Standardized Work and *Kaizen*.

Heijunka is the Japanese word for leveling or smoothing the production. “In most lean references, the meaning is to level the product mix over a specific time period, with the objective of producing every part every day”[2]. *Heijunka* guarantees a continuous flow of production and the satisfaction of the customers’ demands timewise and qualitywise.

Standardizing work forms the baseline for *kaizen*. By doing it, the processes will be easily understood and, therefore, easier to predict and improve. “As the standard is improved, the new standard becomes the baseline for further improvements, and so on.”[9].

Finally, *kaizen* is the Japanese word for continuous improvement of the value stream to create even more value with less waste.

2.1.2.1 Seven Types of Waste

"Real success comes from an improvement process for identifying waste"[2]. By understanding the root causes of a problem and implementing the right countermeasures to diminish it, or even put an end to it, is the way to succeed.

Toyota identified seven major types of non-value-adding activities:

1. **Overproduction**. Producing items in larger quantities than the required by the costumers and also producing before the customers' needs. This waste is the fundamental one since it causes other wastes;
2. **Waiting**. All the time a worker spends waiting for something, like waiting for a machine to end processing, a tool or a supply that isn't ready. This non-value-adding-time is created by bottlenecks, stock ruptures, lot processing delays, etc;
3. **Transportation or conveyance**. Transporting work in process (WIP) from a working station to another does not add value, even if it's for a short distance. Or moving parts, materials, or finished products into or out of storage or between processes;
4. **Inventory**. Excess of inventory, be it in the form of raw materials, WIP, or finished goods causes longer lead times, obsolescence, transportation, damaged goods, storage costs and delays. It also hides production imbalances, redundancies, defects, paperwork, downtime and long setup times;
5. **Overprocessing or incorrect processing**. Unneeded parts processing. This waste is caused by poor tool and product design. Sometimes, instead of waiting, extra "work" is done to hide it;
6. **Unnecessary movement**. Motion that isn't specifically to add value to the product is waste. Reaching for, looking for, stacking or even walking is unnecessary movement;
7. **Defects**. Whenever a defect occurs, time and workforce is wasted on the correction of that defect, that is, repair, scrap replacement, rework and inspection.

Liker and Meier identified an eighth type of waste.

8 **Unused employee creativity**. By not taking the time to listen to the employees' feedback the company will be losing ideas, skills and improvements.

2.1.2.2 The 5S

Toyota has identified five related terms, starting with an S, describing workplace practices conducive to visual control and lean production to eliminate waste.

J. Michalska and D. Szewieczek, in "The 5S methodology as a tool for improving the organization" define the 5S as [10]:

1. ***Seiri* (sorting, organization of the workplace).** Keeping only essential items at hand. Everything that can be discard should be in order to diminish the hazards and obstacles to the productive work.
2. ***Seiton* (set in order).** Every tool, equipment and material must have a specific place and everything must be in its place. This will make access easier and more efficient.

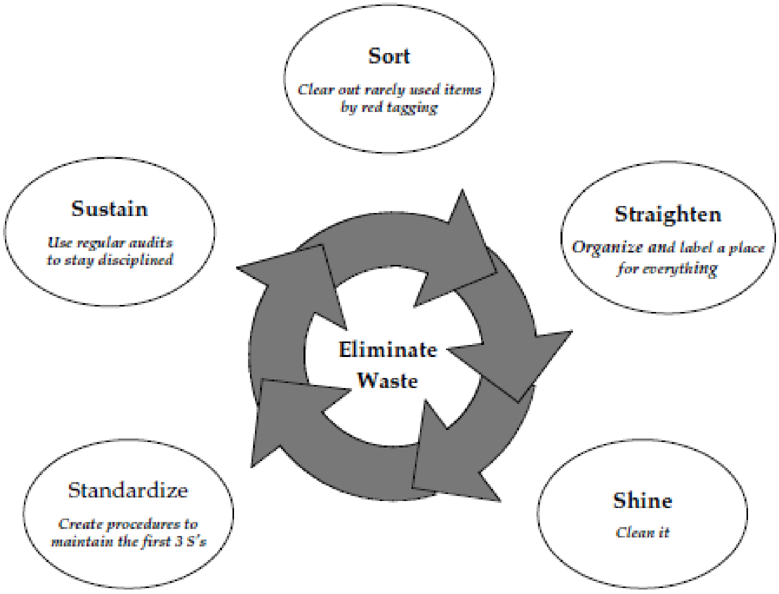

Figure 2.2: The 5S [2]

3. ***Seiso* (shine, cleaning and removing waste).** Cleaning and maintaining the workplace neat must be a daily activity. At the end of a shift everything is cleaned and rearranged to its correct place.
4. ***Seikestsu* (standardize, constant place and rules for everything).** Everyone should know what his /her responsibilities are. This will create consistency and allow for control.
5. ***Shitsuke* (sustain, maintaining what has already been achieved).** As standards are achieved, they must be held and pushed further.

2.1.2.3 Just In Time

The major objective of the JIT is to purchase and produce items shortly before they're needed. In other words, to have only the right item, at the right place, at the right time. This practice will not only reduce working capital requirements, it will also reduce the need for floor space and shorten the flow through time because material spends very little time in queues.

In places where JIT methods are used, the following elements can frequently be found (only the first four will be discussed):

1. **Uniform production rate.** "An objective of JIT is to achieve a smooth flow of materials from the company's suppliers to the company's customers with no delays or interruptions beyond the very minimum that result from the necessary production processes" [11]. A smooth and synchronized (with the customers' needs) flow of small lots of materials produced at a uniform rate will set the WIP to a minimum level.

2. **Coordination by pull.** Pull method of production instead of a push method (Discussed thoroughly further ahead).
3. **Small lots.** The production lots are kept to a minimum in order to maintain the WIP and inventory as low as possible. With small production lots, the quantities of raw material needed at a time from the supplier will also be small. Instead of big vendor deliveries, there will be a high amount of deliveries in small quantities.
4. **Quick and inexpensive setups.** Producing in small lots forces the need of setups. Well, if the setups are long and expensive this wouldn't be possible. It is necessary, therefore, to make them quick and inexpensive by having frequent setups, to which the workers will eventually get used and good at.
5. **Multiskilled works and flexible facilities**
6. **High quality levels**
7. **Preventive maintenance**
8. **Continuous improvement**

2.1.3 Information and Material Flow

The flow of information and material in the value stream is strongly related to the methods applied in it. It is a fundamental part in the process of knowing how much and when to produce something.

2.1.3.1 Push Strategy

Push manufacturing is a Make To Stock type of producing. It basically means that the production will not correspond to the demand but to a forecast. Materials will be pushed further down the supply chain according to estimated delivery dates and stocked until they are withdrawn. This strategy generates numerous problems such as:

- Incapacity to respond to frequent and unpredictable changes in demand;
- High stocks;
- Bullwhip effect.

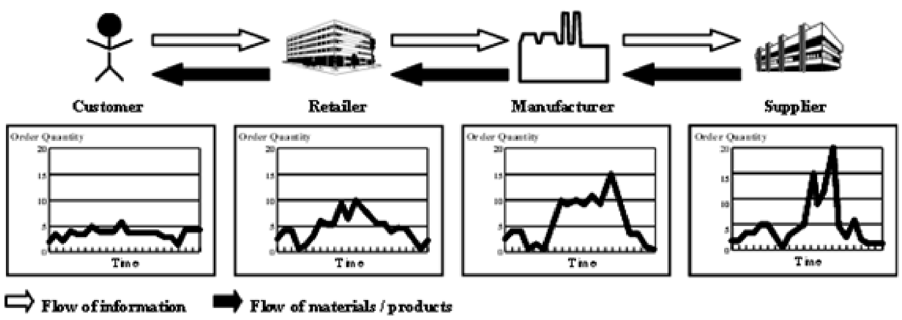

Figure 2.3: Bullwhip Effect

This effect is emphasized by:

1. **Demand forecast updating.** When the demand increases or decreases downstream there is a predisposition to increase/decrease safety stocks. This increase/decrease downstream will generate an excessive upstream increase/decrease;
2. **Order batching.** Sometimes, demands come in but the company may not immediately place the order with its supplier. It often batches or accumulates demands before issuing an order. While the company is waiting to place an order it will create moments of very low demand and when the order is finally placed the demand will suddenly increase starting the Bullwhip Effect;
3. **Price fluctuation.** Promotions, discounts, deals, etc. can all be very expensive to the supply chain since they cause significant changes in demand;
4. **Early purchase of seasonal products.** This is impossible or at least very difficult to forecast and therefore causes stock shortages.

The major problem with the push strategy is the fact that the production orders are usually generated according to forecasts. Whenever there is a slight deviation of the actual demand to from the forecasts there will always be an overproduction or underproduction.

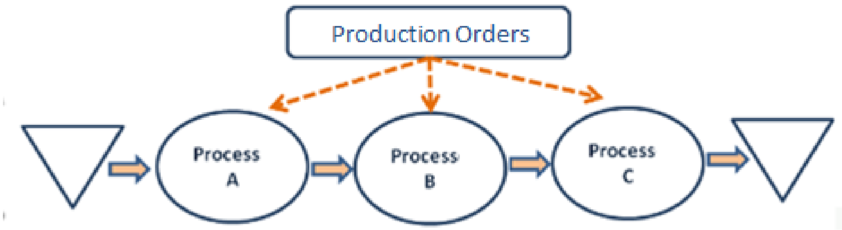

Figure 2.4: Push Strategy. Adapted from [3]

2.1.3.2 Pull Strategy

The pull strategy is the opposite of the push one and is related to the just-in-time methodology of inventory management that minimizes stock on hand, focusing on last-second deliveries. In this case the production orders are set according to the downstream demand. No forecasts are needed. Production is based in real needs. This will result in:

1. Elimination of the bullwhip effect and consequently low stocks;
2. Lower lead times;
3. Increased capacity to respond to fluctuating demands;
4. Synchronization of the processes.

To this strategy is always connected a *kanban* system that will be studied thoroughly further ahead.

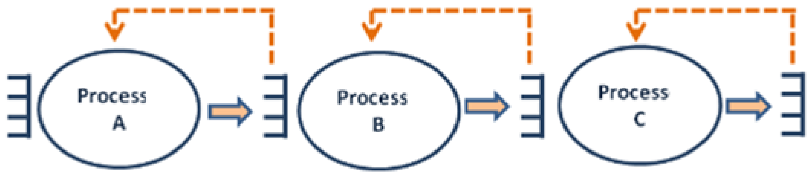

Figure 2.5: Pull Strategy. Adapted from [3]

2.1.3.3 Push/Pull Comparison

In the work of Zheng and Lu a system based on Anylogic compares and analyzes the inventory levels and order completion times a push and a pull system by establishing a simulation model under the same customer needs [12]. Data analysis showed push-type production system provided high occupancy cost of capital and declining of capital turnover rate. The pull-type production system allowed to process resources more efficiently, high flexibility and low inventory, but it would made impossible for an enterprise to adopt this type of production and develop economies of scale.

When in a scenario where production was higher than the demand, the push-type system showed much higher inventory levels and, due to mass production, a much lower order completion time. When subjected to the opposite scenario, production lower than demand, both systems revealed very similar results. When production and demand meet, inventory levels were very similar, with order completion time of the pull system being slightly higher.

Both systems have their own advantages and choosing one should be a decision that takes into consideration business goals and location in the supply chain.

2.1.3.4 *Kanban*

Kanban is the Japanese word for card. A *kanban* allows information to flow from a consumer to a supplier and its objective is to maintain a continuous flow of the production materials (WIP) and eliminate stocks. It is what keeps the pull system working.

Let's take Fig. 13 as the level of stock of a supermarket. At a determined moment of time there's a corresponding amount of stock. As materials are consumed that level of stock will decrease until it reaches the replenishment level. When it does, a *kanban* leaves that supermarket and is taken to its supplier that now as the confirmation to start the production of a certain reference. The replenishment level must be set in order to fulfill the downstream needs until the next supply. The *kanban* cards have information on the materials references, customers, suppliers and quantity to produce.

To better understand this concept let's focus on the next example.

In each green/yellow/red box there's a *kanban*. Every time a component goes into production a *kanban* is withdrawn from the board and attached to that same component. The number of empty boxes represents the number of parts in production or in stock. When all the *kanbans* are

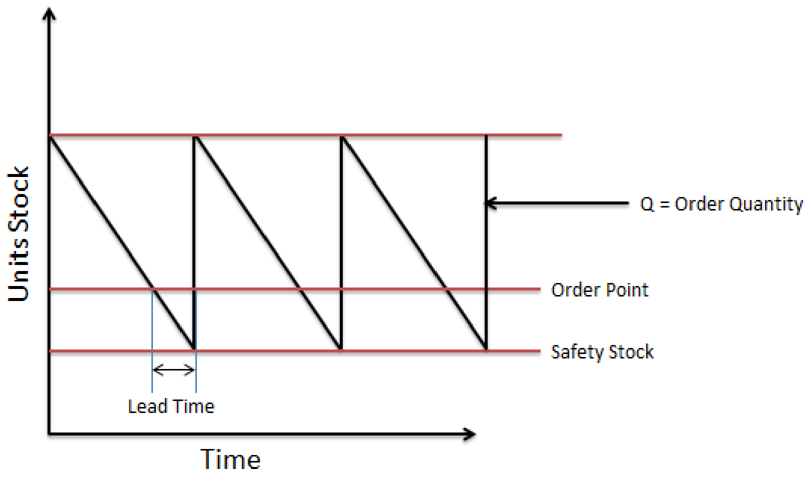

Figure 2.6: Stock Fluctuation

in the board it means there's an urgent need to produce. When the red box is empty the need for production is high but not as high as before. When only the two green boxes have *kanbans* there's no need to produce and finally when only one of the green boxes has a *kanban* the production must be stopped because the stock is full.

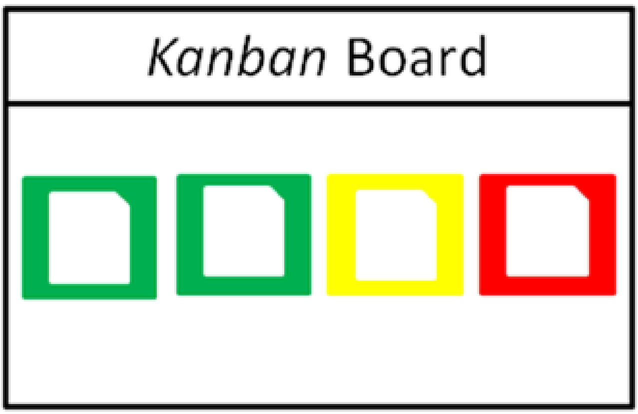

Figure 2.7: *Kanban* Board

After the products leave the stock, the *kanban* returns to the board and the process starts all over again.

2.1.3.5 Leveling Box

The leveling box is a logistic tool that supports the production planning. It contains all the *kanban* cards of finished product distributed through time accordingly to the production planning.

It typically has the duration of one day, which means it represents the production planning of one day, and it should only be applied at the end of the production line or close to it, in other words, it should only be applied to the pacemaker processes.

Each time period of the leveling box is associated to the replenishment time of the final lines. Every kanban has a corresponding production time that equals the time of the material supplier. This characteristic sets a production pace that sets a synchronism between the consumption and the replenishment of material at the end of the production lines and guarantees the pulling process.

2.2 Supermarkets

Independently on the type of production (custom job shops or repetitive manufacture) the work flow can benefit from using a supermarket. In fact, the secret for an effective manufacturing operation is to align production capacity to customers' demand.

A zero inventory strategy would be ideal but the concept is utopic since the supplier's deliveries are not always regular, quality control is inevitable and batch size is variable in each production line. A right size inventory strategy is, therefore, crucial. It employs the use of supermarkets located at specific points of the production process. Supermarkets are incredibly helpful in businesses with wide variations in customers demand and when the production lead time is longer than the takt time.

According to Chaneski there are two questions to answer when establishing supermarkets [13]; where should it be located and how large should it be?

To answer the first one the following should be considered: If there are shared resources that can cause bottlenecks, a supermarket should be placed immediately before the processes that can cause such bottlenecks. Another supermarket right after each of these processes should also be considered in order to provide a small number of parts that can be used until the machine is once again available to run that item.

The last supermarket should be placed in a location where its downstream lead time is smaller than the established delivery time to the next client. For example, if the established delivery time is 5 days, the last supermarket has to be somewhere in the production line where it's possible to make its products arrive to the customer in 5 days. It should also be as upstream as possible in the production line. This will allow a lower product differentiation and therefore least references to stock, which contributes to the reduction of supermarkets dimensions and costs of stocking due to lower transformation of the product.

For the second question the reorder point, average stock and maximum stock should be measured. These three will be studied further ahead.

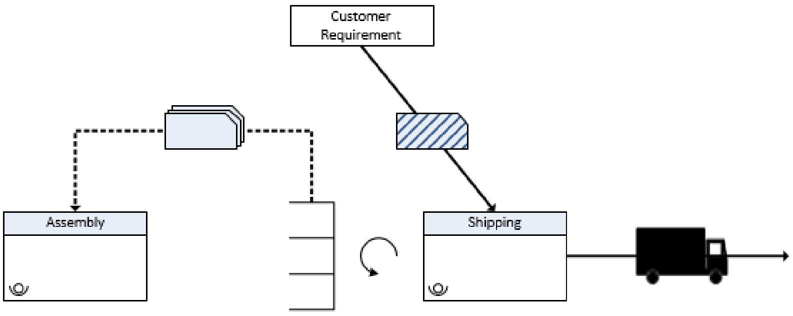

Figure 2.8: Supermarket

2.2.1 Safety Stock

If the production process would run always smoothly and with no unpredicted events, the replenishment of a supermarket would happen right before the consumption of its last item. Unfortunately this is not always the case due to sudden increases in demand, supplier's delays and variations in lead time which cause stock ruptures. That's why safety stocks are necessary. When these events occur, the safety stock allows to keep the production flowing. It should, however, as any other type of stock, be kept as low as possible by reducing production lead time, leveling the production and demand, implement a standardized transportation of materials and increase efficacy and efficiency of the processes.

It is common to find oversized safety stocks due to comfort and security they provide in what comes to service level. Despite that it should be minimized to reduce inventory levels and improve the production process itself. In order to do that, Simchi-Levi took into account that the lead time to the warehouse is variable and is normally distributed with average lead time and standard deviation of lead time denoted by μ_{LT} and σ_{LT} respectively and defined safety stock (SS) as[14]:

$$SS = max(Q, \mu_{LT}) + Z\sqrt{\mu_{LT} * \sigma_{LT}^2 + \mu_{DD}^2 * \sigma_{DD}^2} \tag{2.1}$$

where,

- SS is the Safety Stock
- Q is the economic order quantity: where,

$$Q = \sqrt{\frac{2\mu_{DD} * K}{h}} \tag{2.2}$$

  - K is the fixed cost per order;
  - h is the inventory carrying cost.
- μ_{DD} is the average daily demand;

- σDD is the standard deviation of daily demand;
- Z is the Service Level and is defined according to Table 2.2:

Table 2.2: Service Level

Service Level	90%	91%	92%	93%	94%	95%	96%	97%	98%	99%	99.9%
Z	1.29	1.34	1.41	1.48	1.56	1.65	1.75	1.88	2.05	2.33	3.08

2.2.2 Supermarket Sizing

The supermarket to size will be placed between the production line and the packaging line. It will be, therefore an almost finished goods supermarket. To size this supermarket we will need to determine its reorder level (the moment when a new production order is placed), average stock and maximum stock for each reference, i. For the reorder level, the following formulas were used.

$$ReorderPoint_i = LeadTime_i * \mu_{DDi} + SS_i \tag{2.3}$$

Although this formula works, it must be held into account that not just the demand is variable, but so it is the lead time due to machine malfunctions, human errors, supplier's delays, etc. To include that uncertainty in the calculations the next formula should be used:

$$ReorderPoint_i = \mu_{LTi} * \mu_{DDi} + SS_i \tag{2.4}$$

It should be taken into consideration that the Reorder Point should be rounded to the lot size of the reference.

Having calculated the Reorder Point, the Average Stock for each reference can be measured as:

$$AverageStock_i = SS_i * \frac{ReorderPoint_i}{2} \tag{2.5}$$

And at last, the Maximum Stock for each reference:

$$MaximumStock_i = ReorderPoint_i + LotSize_i \tag{2.6}$$

The number of *kanbans* to be used the production line and the supermarket is:

$$NumberOfKanbans_i = \frac{MaximumStock_i}{LotSize_i} \tag{2.7}$$

2.3 Simulation Modeling

"Simulation modeling is a common paradigm for analyzing complex systems" [15]. The modeling of production systems, in particular, is a research area that has been under constant development and has increasingly significance in the optimization of these systems. The simulation approach is extremely useful since it allows activities like production planning and the study of complex processes in a very short period of time and at a very low cost. Simulation has become a standard procedure when a new system is being implemented or a modification is under investigation.

The simulation processes has some advantages and disadvantages:

Advantages:

- Simulation allows the evaluation systems that haven't been implemented yet;
- It makes possible to subject an already existing system to extreme conditions and avoid dangerous situations.
- It can be used as an educational tool to teach workers how the system operates;
- It forces the an inspection of the physical system in order to gather information on processes and parameters;
- Long period events can be simulated in a short period of time at a very low cost.

Disadvantages:

- Because it's an approximation of a real system some errors are inevitable;
- Input gathering can be a costly and long lasting activity;
- The construction of the model is a hard and thorough work;
- A perfect solution for the simulation is not granted.

2.3.1 Simulation Platforms

There are three main simulation platforms on the market: Arena, Simio and Anylogic.

Simio is a simulation modeling framework based on intelligent objects. These objects are built by modelers and may be used in multiple modeling projects. It supports not only object-based modeling but event, object and agent-based modeling as well. The object oriented approach allows for a simulation and 3D animation development of the models that is very simple [16].

The Arena software has been developed by Rokwell Arena and is based on the SIMAN simulation language. It allows the simulation of discrete and continuous systems, manufacturing, supply chain management, logistics, sorting and other processes. It assures high flexibility and various facilities for models of any level [17].

In this project, the simulation software to be used is Anylogic. There is an Academic Partnership Program that provides a free Personal Learning Edition (PLE), the version to be used in the developing of this project. For the testing and validation of results, a temporary license of Anylogic's Univerisity Edition must be utilized due to a limited number of dynamically created agents of the previous version.

AnyLogic is a programming and simulation environment, with a graphical interface and it's the only simulation tool that has the ability of modeling Discrete Events, Agent Based and System Dynamics, and allows the user to extend simulation models with Java code. It also allows the creation of Java applets that can be opened in a browser. The combination of the three latter makes it a very interesting tool for simulation of complex systems.

To deal with continuous processes, the system dynamics approach should be used whereas discrete events and agent based models deal mostly with discrete time.

The abstraction level should also be taken into account in the modeling process [18]. The highest abstraction level is the one with less detail, with all the macro activities and strategic operations, followed by the middle abstraction level, where tactical activities are and the processes have average detail. Finally, the low abstraction level is a very detailed level, explored to micro activities and it's also called operational level. System Dynamics has, obviously, the highest abstraction level. At the low and medium level of the three is Discrete Events modeling. Agent Based modeling is used through all the abstraction levels (low, medium and high) as agents can be of different complexities.

2.3.2 Discrete Event Modeling

Although the great majority of the processes we observe in the world consist of continuous changes, when trying to analyze these processes it is possible to simplify them by dividing the continuous process into discrete parts. This analysis is called discrete event modeling.

In discrete event modeling, the movement and processing of a component in a factory, from raw material to its final state, can be represented by two events, namely the launch of the component to production and the storage of that component. The actual movement and processing of that component would be modeled as a time delay between the launch into production and storage. Despite this fact, Anylogic can produce continuous animations for logically discrete events.

An Anylogic event has a null execution time, doesn't interfere with other existing events, can change the model when is executed and schedule other events. If any events are scheduled to happen at the same time, they will be ordered according an intern sequence and executed one after the other.

2.3.3 Agent Based Modeling

Agent based modeling can be defined as an essentially decentralized, individual-centric approach to model design.

In this type of modeling, one needs to identify the active entities, in other words, the agents, define their characteristics and behavior, put them in a certain environment where connections are established between the agents and run the simulation. These agents can then simply interact between them or run through a discrete model or a dynamic model.

2.3.4 System Dynamic Simulation

The System Dynamics is a methodology typically used in strategic models and therefore assumes a high level of aggregation of objects being modeled. It focuses on the study of systems feedbacks. Here, agents lose their individual properties and can be represented by their quantities.

This type of modeling was not implemented in this project.

Chapter 3

Simulation modeling for supermarket dimensioning

In this chapter the simulation model used to support the dimensioning of the supermarket is presented.

A presentation of the software used in this project is followed by the simulation model construction and its respective development steps.

3.1 Modeling - Anylogic

3.1.1 Elements used in this project

3.1.1.1 Process Modeling Library

Anylogic has a Process Modeling Library which supports modeling based in processes. Previously called Entreprise Library, this library incorporates many objects that are commonly found in enterprise environments. It contains a set of objects that allow the modeling of processes in form of fluxograms that are object oriented and grant the simulation of highly complex systems. All objects are highly customizable and their parameters can be changed dynamically and their actions may depend on the entity's attributes. Objects can perform personalized Java actions when an agent is inserted or removed. This library allows the creation of sophisticated process animation by working closely with Anylogic's presentation/animation framework.

Next, some of the objects used in this project are presented:

Enter: inserts already existing agents in a particular point of the process. While a Source creates agents of a single type and with the same properties, Enter allows the insertion of specific agents previously created.

Queue: a buffer of agents waiting to be accepted by the next object. It can also be used as a general-purpose storage for the agents.

Various queueing methods can be applied such as FIFO (default), LIFO, or priority based. Despite this, it is possible to remove agents from any position in the queue.

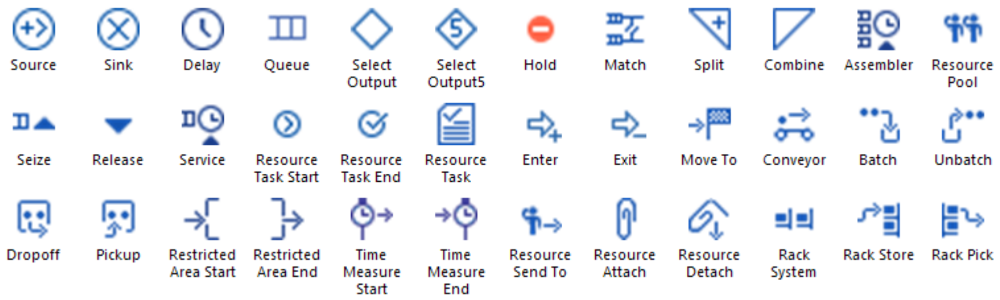

Figure 3.1: Process Modeling Library

Delay: Delays agents for a given amount of time. This time can be evaluated dynamically or can have a stochastic nature. Multiple agents can be delayed simultaneously and independently. It can also be defined accordingly to the agent's properties. It was used to simulate the supermarket.

Hold: blocks the agent flow, temporarily or permanently, in the connection where it is placed. It was used to apply both lead times and cycle times.

Seize: Seizes a given number of resource units from a Resource Pool. It is possible to associate a schedule to the Resource Pool and this property was used to implement the shifts in the packaging line.

Release: Releases the units seized by the Seize block.

3.1.1.2 Agents

An agent is an entity that can have behaviour, memory, timing contacts, etc. It may represent very different things such as vehicles, projects, people, organizations, ideas, etc.

In an agent it is possible to define variables, events, statecharts, system dynamic models, process flow charts or even other agents. In this project, only variables were used.

Two types of agents were identified:

Product: this agent contemplates both the components of the system as the finished products that have already been through production. It has information on the id and name of the component/Product, the pallet length, the amount of rework and its variability, minimum lot size, reorder point, lead time and its variation, amount of scrap, price, current stock and initial stock, demand and its variation, packaging line, ABC class and bill of materials. Besides this ones, it also has an "holdFor" variable that is used to allocate components in the supermarket to specific orders. It also has am "increaseROP" and "amountOrders" that were used to adjust reorder points, as it will be explained further ahead.

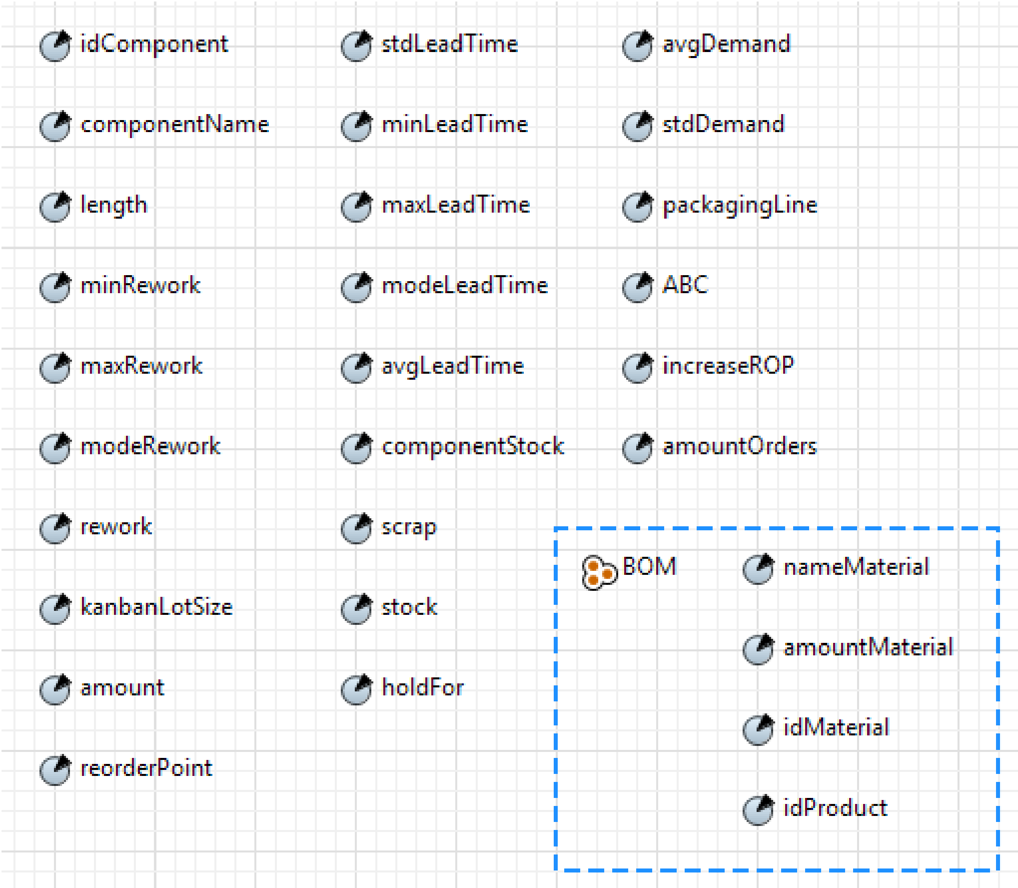

Figure 3.2: Agent Product

Order: this agent represents the orders placed at the packaging line for products to withdrawn from the supermarket. It has information on order id, id and name of the component to withdraw, release date, amount, line where the order will be packaged, and status of the order.

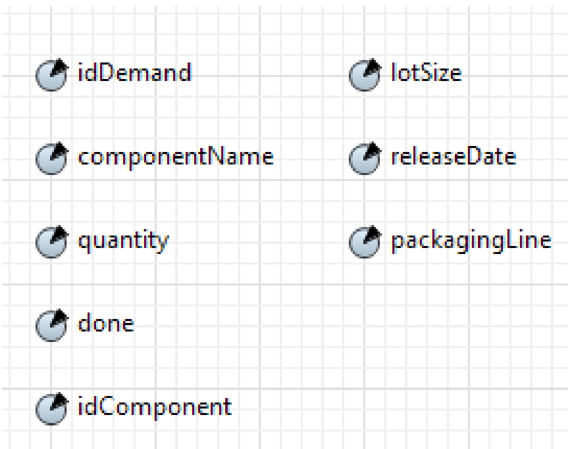

Figure 3.3: Agent Order

3.2 Description of the Simulation Model

In this project will be studied a system that can be divided in two parts: A production line that works as a pull system and a packaging line that works as a push system.

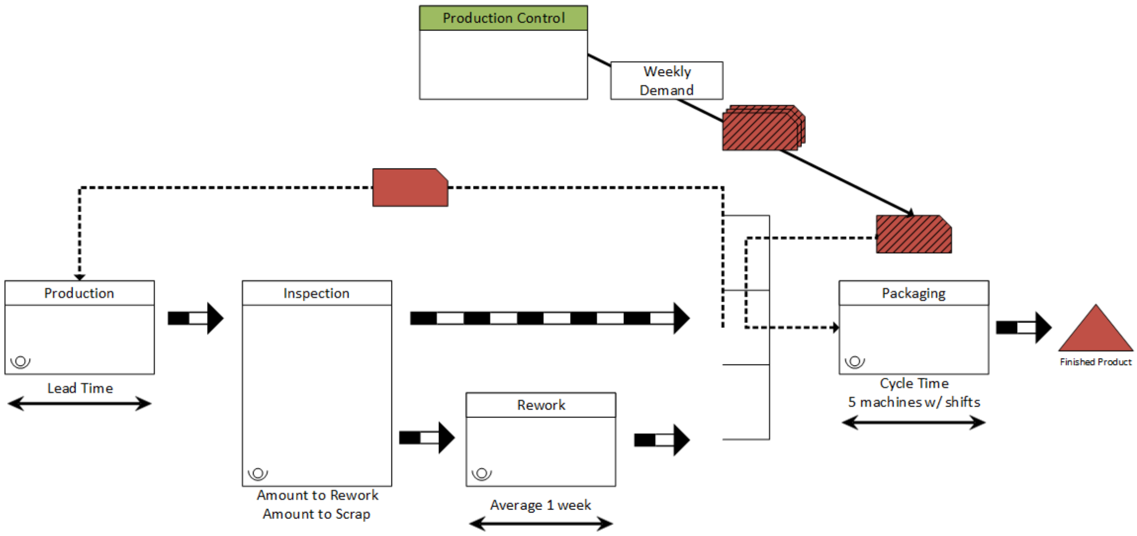

Figure 3.4: System's Schematics

A supermarket that is placed between the production line and the packaging line, receives the weekly orders to be pushed down the packaging line. If the supermarket doesn't have enough components to satisfy that order or, if after satisfying that order the reorder point is triggered, a kanban is released to start production for the components needed. When the supermarket has a number of components that is sufficient to serve that order, those components are sent to be packaged.

The production line produces 10 different families of products. Each family has different production routes and production technologies although there was no interest in this project to approach them thoroughly so they are simulated simply using a lead time for each family.

After going through the production line, components are subjected to an inspection. After that inspection, part of the components is subjected to rework and another part to scrap. Rework and scrap rates are considerable, causing significant perturbation in the output line. This phenomenon implies that decisions related to the amount of components to launch into production or send to package are difficult to make.

The packaging line consists in 5 machines, one for each line. Each of this line works according to a predetermined schedule. Three machines work from 8pm to 16am, every day of the week except Sunday, while the other two are active during the same days 24 hours a day. Before being sent to the packaging line the products go through a sequencing process that minimizes the setup time.

All the parameters used in this project, such as average and standard deviation of lead time, rework and scrap rates, were estimated from data captured in the production line and from existing

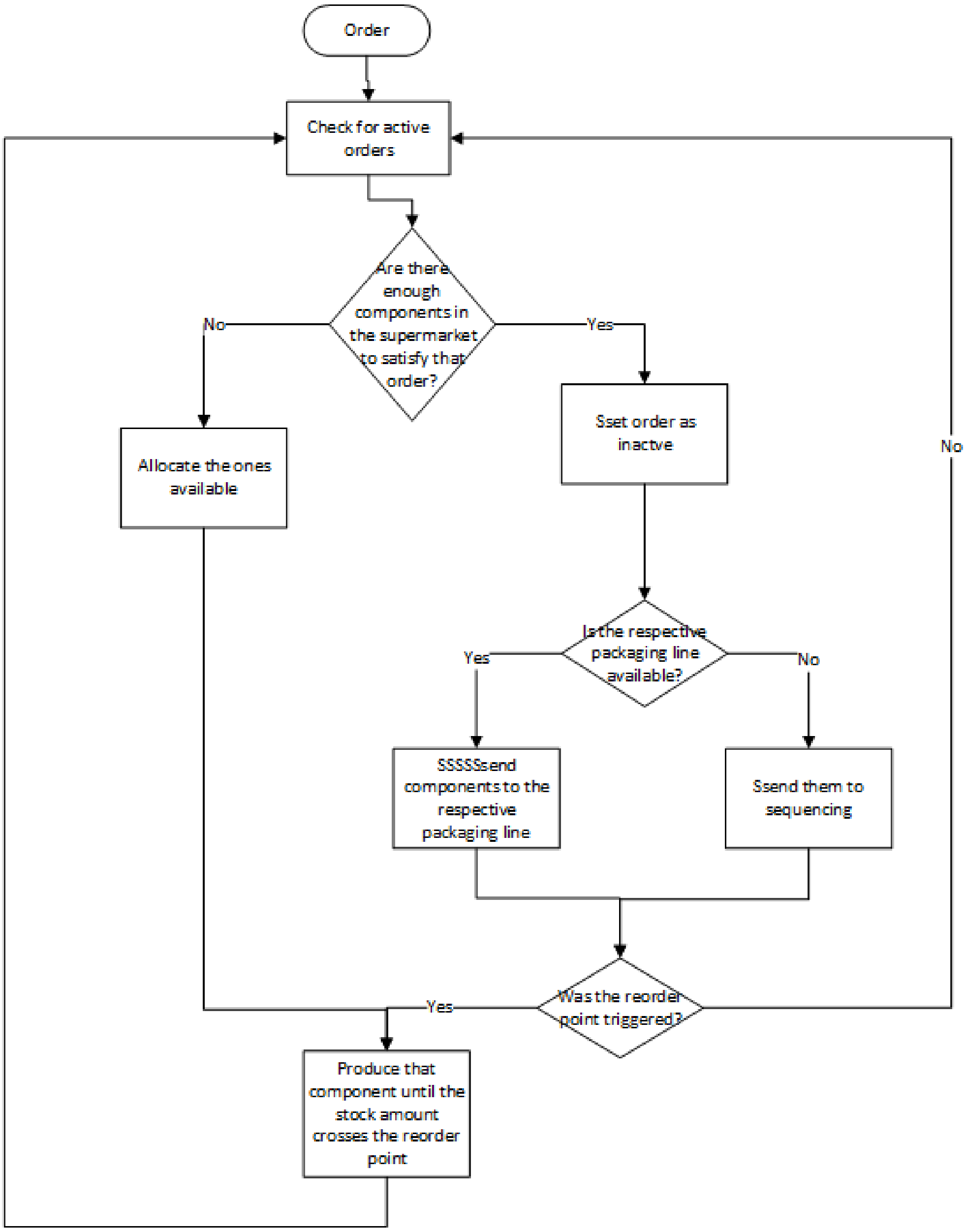

Figure 3.5: System's Flow Chart

quality reports. Because there was no information on how much time did components spent in rework, it was estimated 1 week for all of them.

Table 3.1: Families Description

Family	Annual Production (pcs) (%)	Lead Time (days)	Lead Time Standard Deviation (days)	Rework (%)	Rework Standard Deviation (%)	Pallet Size
1	134.510 2.5%	16,62	8,58	19,3%	21,0%	1.1
	283.812 5.2%	5,54	4,53	11,0%	8,6%	2.3
3	502.812 9.2%	2,72	1,63	11,8%	12,1%	1.0
4	37.628 0.7%	4,83	3,02	19,8%	11,6%	2.4
5	631.726 11.5%	8,29	6,34	14,7%	13,2%	1.0
6	211.804 3.9%	21,00	11,19	21,9%	21,4%	1.0
7	1.179.905 21.5%	15,33	13,34	17,5%	34,5%	1.0
8	1.041.280 19.0%	5,13	2,72	10,7%	6,7%	1.0
9	390.432 7,1%	15,64	7,67	9,3%	7,4%	1.0
10	1.067.757 19.5%	12,05	4,29	14,5%	8,9%	1.0

3.3 Approach Strategy

The steps taken to approach this problem were the following:

1. Development of the simulation model;
2. ABC analysis of the input components;
3. Scenario definition;
4. Results analysis and improvements suggestions.

3.3.1 Simulation model

The simulation model needed to be capable of dealing with an input of over 300 components and over 300 products. Every single component/product had information on its identification with an id number and component name, average and standard deviation of lead time and rework, amount to go to scrap, length of a pallet, bill of materials and minimum production lot size. There was also information on demand containing information on the product, amount, release date and packaging line.

With this set of inputs, the model had to be able to simulate the production and packaging of the system during an entire year and provide information on WIP values, number of packaged products and their delays, production amounts and supermarket dimensions such as length and number of components.

Next, the steps of the creation and behavior of the model will be briefly explained:

1. **Upload of the inputs to the model.** Microsoft Excel was used as a database to support the model. All the components/products characteristics are uploaded to a collection that holds that information during the entire simulation. The same process occurs with demand. This procedure takes place right when the simulation begins.
   Besides uploading all the information to the collections, it also generates some new information from the previous one. It generates a setup matrix for every single component. This numbers are randomly created by the model and they can take values from around 7 to 30 minutes. It also calculates the reorder points for each component using the formulas presented in chapter 2, the number of orders for each product and finally, injects in the supermarket the initial stock for each component, which is set to be the reorder point plus a pallet rounded to the minimum production lot size;
2. **The production line/pull system.** Orders are set to active by an event that occurs daily. After an order is set to active, a function named "checkStock" will check the supermarket for the necessary components to satisfy all the active orders. If the supermarket has enough components to satisfy that order the components are either removed from the supermarket by a function named "removeSupermarket" or sent to a sequenced waiting list that minimizes setup times. If the supermarket doesn't have enough components to satisfy an active order those components are marked as reserved. In any of the cases, a function with the name "checkROP" will check if any of the reorder points was triggered. When evaluating if the reorder point should be triggered or not, this function only takes into consideration the available components in the supermarket and in WIP, which means that, for example, the stock in the supermarket might be higher than the reorder point but trigger it anyway if all the components are reserved.
   After triggering the reorder point the kanbans are released to production. Because all the lead times include processing time and setup time, the production block has maximum capacity, which means it can handle has many kanbans has necessary. After production, products go through an inspection where some of them make it through to the supermarket, others to rework and other go to scrap. The rework block is similar to the production block but here the lead time is the same for every component (1 week) and all of them go to the supermarket when finished.

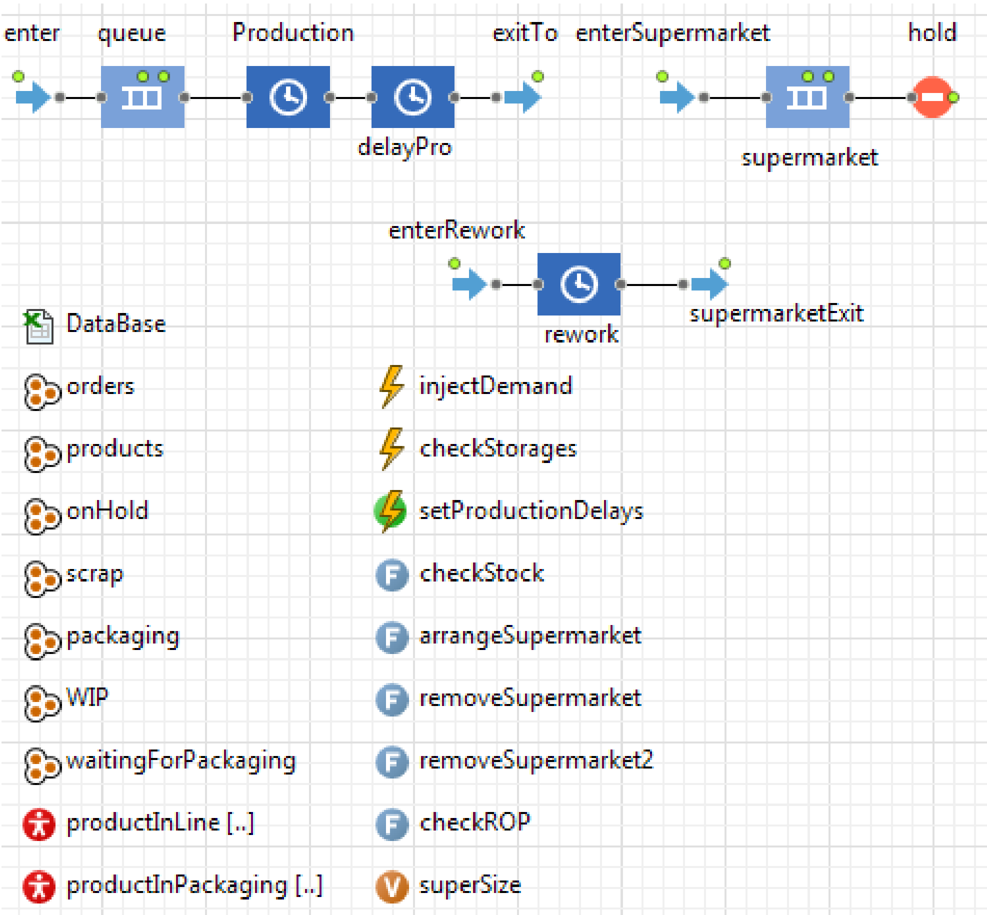

Figure 3.6: Production Line

3. **The packaging line/push system.** The packaging line is composed by 5 machines. The components can either be sent directly to the packaging line if this one is available or, in case it's not, orders are sequenced in the sequencing functions, using a nearest neighbor algorithm, in order to minimize setup time. They are then stored in an ordered array list, that will serve as a plan of execution. When the packaging line is once again available, the necessary setup is applied and the packaging process occurs followed by the destruction of the agents.

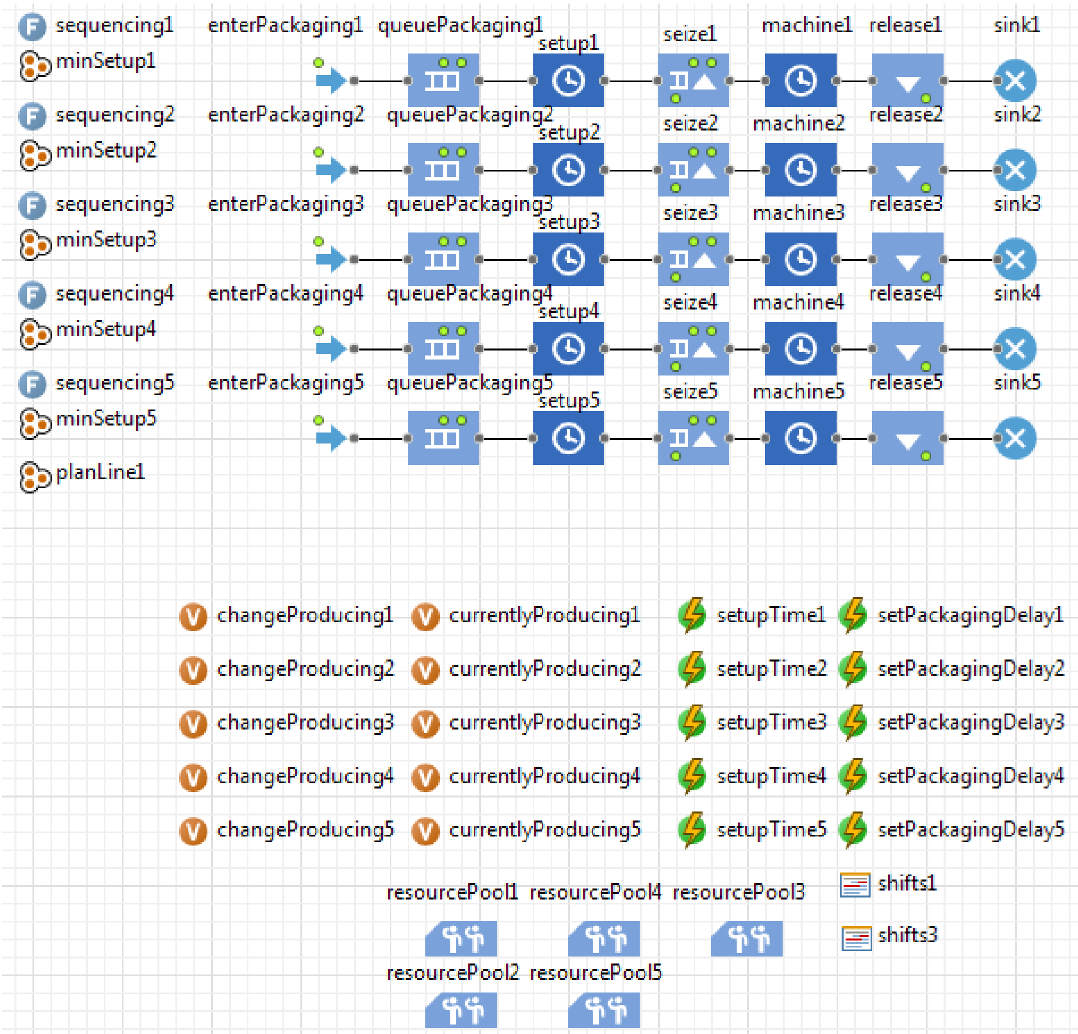

Figure 3.7: Packaging Line

4. **Reorder points adjustment.** Because the formulas used to calculate reorder points didn't take into consideration rework and scrap, the results needed to be adjusted to the reality. For that reason a process to evaluate them was created. A routine that recalculated the reorder points was introduced. This routine made the program run cyclically and increase the reorder points of each component at the end of each program cycle by 50% if any stock out was registered. The same process was made to decrease the reorder points. For every program cycle that ran without stock out, the respective component's reorder point was decreased by 10%. This procedure ran for all components (except those with less than two orders per year) until no stock outs were registered and it was no longer possible to reduce reorder points without causing one. Once this stage was done, it was possible to observe increases in the original reorder points of around 250%.

3.3.2 ABC analysis

ABC analysis is an inventory categorization technique. It categorizes an inventory as A, B or C items. A items, also known as high runners, are the ones that are ordered frequently (almost weekly) and therefore, represent a very high percentage of the demand. B items, also known as medium runners, are products that are ordered frequently but not as frequently as the A items. Finally, C items, also known as low runners, are products that are ordered infrequently and in highly variable amounts.

The classification of the items in this project was made according to the next parameters:

- A items – 80% of annual demand;
- B items – 15% of annual demand;
- C items – 5% of annual demand;

The results obtained according to this classification are displayed in the following graph.

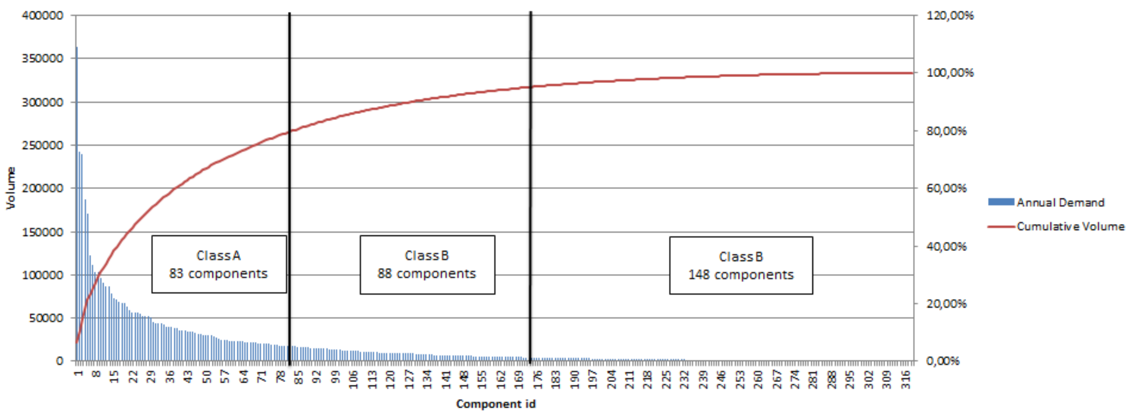

Figure 3.8: ABC Analysis

In Creating Level pull a list of solutions on which components to hold in finished goods and which to make-to-order is provided and presented in Table 3.2 [19].

Table 3.2: Rropoposed Scenarios

Option	Pros	Cons
1. Hold finished-goods inventory of all products – replenishment pull system	Ready to ship all items on short notice.	Very high finished-goods storage dimensions.
2. Hold no finished-goods inventory and make all to order – sequential pull system	Less inventory and associated waste.	Longer delivery dates.
3. Hold only C's in inventory and make A and B products to order daily – mixed pull system	Less inventory.	Requires mixed production control and daily stability.
4. Hold A and B products in finished-good s and make C's to order from semifinished-goods - mixed pull system	Moderate inventory.	Moderate inventory.

3.3.3 Scenarios Definition

The scenarios presented ahead were based in Table 3.2 and the columns of each scenario depict the following (from left to right):

- The scenario name. Between brackets is the number of weekly delivery frequency of the products that are considered for the supermarket;
- The volume in components, the percentage of the yearly demand and the weekly demand in components;
- The number, percentage and class of the components that are stored in the supermarket;
- The number of the different families that the supermarket will store;
- The average and standard deviation of the lead time in weeks;
- The average and standard deviation of the rework rate;
- The average pallet size in meters and number of components.

Scenarios description:

- **Scenario 1:** All products All products are kept in the supermarket no matter their family. The production system would work entirely under a pull system.

Table 3.3: Scenario 1

Name	**Volume (pcs) (% yearly demand) (weekly demand)**	**Products (number) (%pcs) (class ABC)**	**Families (#)**	**Lead time (weeks)**	**Rework (%)**	**Pallet size (m) Pallet lot (pcs)**
All products	5.481.666 95% 140.000	319 100% Class A-83 Class B-88 Class C-148	10	μ 1.9 σ 1.3	μ 17% σ 22%	1.2 194

- **Scenario 2.1:** High variability The family of products with highest average and standard deviation of lead time and rework are kept in the supermarket and work under a pull strategy while the other families have no space reserved in the supermarket and, therefore, are produced according to a push strategy.

Table 3.4: Scenario 2.1

Name	**Volume (pcs) (% yearly demand) (weekly demand)**	**Products (number) (%pcs) (class ABC)**	**Families (#)**	**Lead time (weeks)**	**Rework (%)**	**Pallet size (m) Pallet lot (pcs)**
Higher variability Family 6	211.804 4% 5.042	33 10% Class A-4 Class B-10 Class C-19	1	μ 3 σ 1.6	μ 19% σ 13%	1.0 112

- **Scenario 2.2:** High variability This scenario is very similar to the previous but in this case the two families with highest average and standard deviation of lead time and rework are kept in the supermarket instead of just one and, from those two families, only the components that were order at least every two or three weeks were considered.

Table 3.5: Scenario 2.2

Name	**Volume (pcs) (% yearly demand) (weekly demand)**	**Products (number) (%pcs) (class ABC)**	**Families (#)**	**Lead time (weeks)**	**Rework (%)**	**Pallet size (m) Pallet lot (pcs)**
Higher variability Families 6&7 (2,3)	696.153 12% 16.575	21 7% Class A-14 Class B-2 Class C-5	2	μ 2.3 σ 1.8	μ 18% σ 32%	1.0 99

- **Scenario 3:** High rotation The supermarket only holds products that are delivered every two weeks (at maximum).

Table 3.6: Scenario 3

Name	**Volume (pcs) (% yearly demand) (weekly demand)**	**Products (number) (%pcs) (class ABC)**	**Families (#)**	**Lead time (weeks)**	**Rework (%)**	**Pallet size (m) Pallet lot (pcs)**
High rotation (2)	2.108.280 36% 50.210	41 13% Class A-34 Class B-3 Class C-4	9	μ 1.3 σ 0.8	μ 14% σ 14%	1.1 198

- **Scenario 4:** Single family The supermarket holds only one family. Family 8 is the one of the most significants in terms of production volume and, from those, the one with higher variability and, for those reasons, it was chosen to be the one to be kept in the supermarket.

Table 3.7: Scenario 4

Name	**Volume (pcs) (% yearly demand) (weekly demand)**	**Products (number) (%pcs) (class ABC)**	**Families (#)**	**Lead time (weeks)**	**Rework (%)**	**Pallet size (m) Pallet lot (pcs)**
Single family Family 8	1.041.280 18% 24.700	20 6% Class A-15 Class B-4 Class C-1	1	μ 0.7 σ 0.4	μ 11% σ 7%	1.2 124

Chapter 4

Results Analysis

In this Chapter, the simulation model outputs will be analyzed. Parameters such as weekly demand, packaged components, weekly production, supermarket length, number of components in the supermarket and WIP will be taken into consideration in order to draw some conclusions.

First of all, the supermarket will be simulated using the values that were obtained using the formulas exhibited in chapter 2. In this simulation rework and scrap will not be activated since the formulas don't take them into consideration. This test will allow judging the efficacy of the formulas and to do it Scenario 1 (All products) will be applied since it grants a broader number of examples.

Next, all the scenarios depicted in chapter 3 will be simulated and analyzed (with the reorder points optimized).

4.1 Scenario 1: All products (no rework/no scrap)

In order to evaluate the quality of the supermarket sizing formulas. Rework and scrap will not be taken into consideration in this section because they are also not in the formulas.

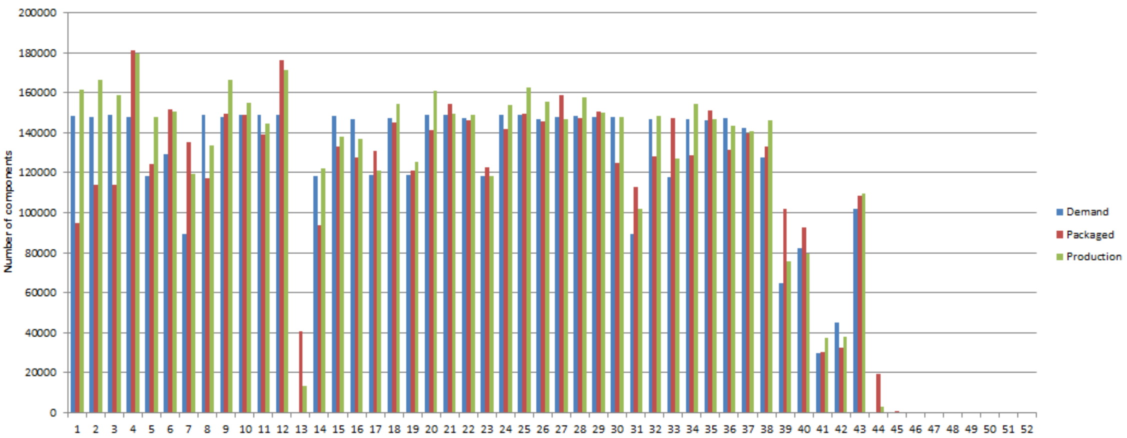

Figure 4.1: Demand, Packaging and Production Comparison for Scenario 1

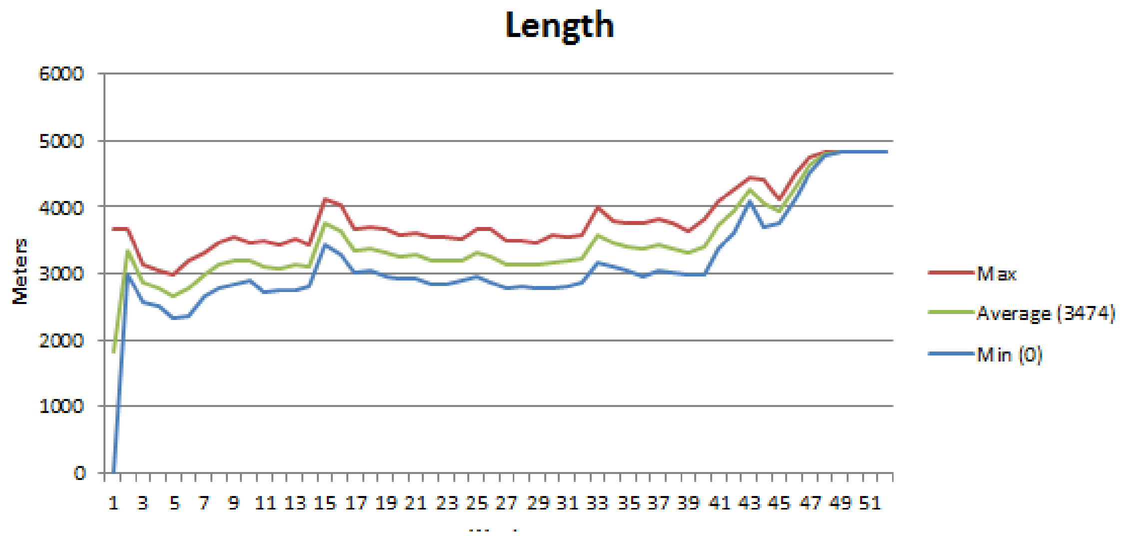

Figure 4.2: Supermarket Length for Scenario 1

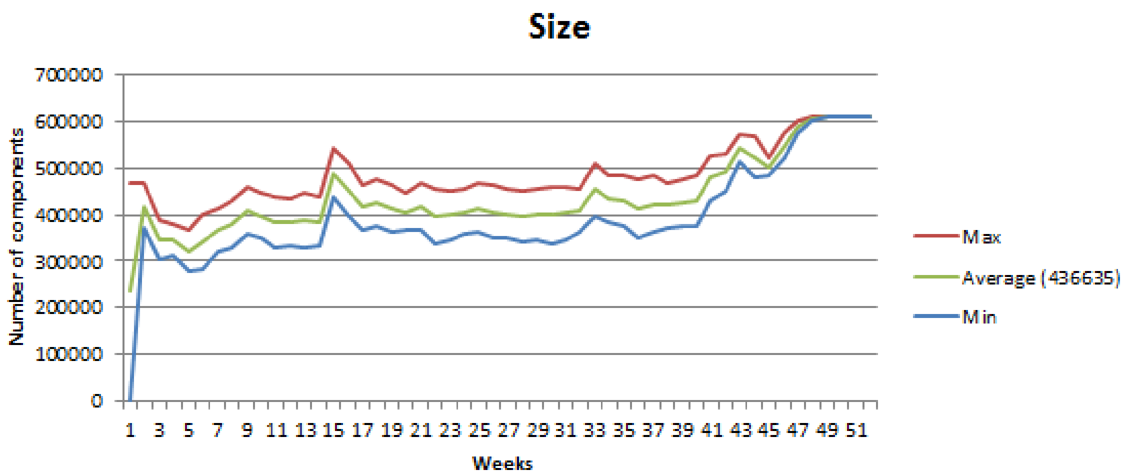

Figure 4.3: Supermarket Size for Scenario 1

It is possible to observe that the supermarket struggles really hard and ultimately fails to keep up with the demand. Despite its length and components number are kept low, it is always trying to follow demand but can never actually keep up with it, being the times where it achieves demand similar levels very rare.

This led to the conclusion that, although the formulas consider lead time and demand variations they were not producing viable results, and therefore the reorder points needed to be optimized. This optimization was realized using the simulation model by running it cyclically and increasing or decreasing reorder point until almost no stockouts were registered. The optimization took into consideration rework and scrap levels.

4.2 Scenario 1: All products

This scenario represents the ideal scenario according to Lean principles. All the products are kept in the supermarket and are, therefore, ready for packaging immediately, as long as no stock out is registered of course. As a result of keeping all the products in the supermarket the production line would be entirely regulated by a pull strategy.

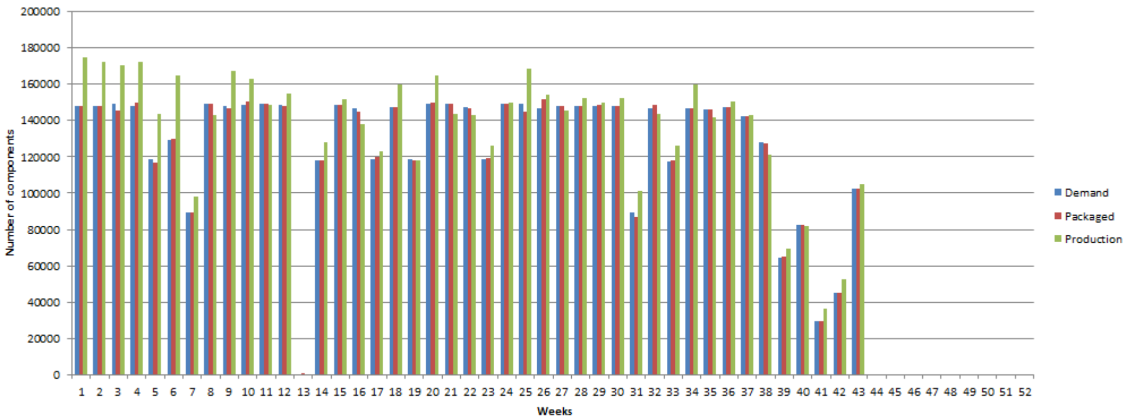

Figure 4.4: Demand, Packaging and Production Comparison for Scenario 1

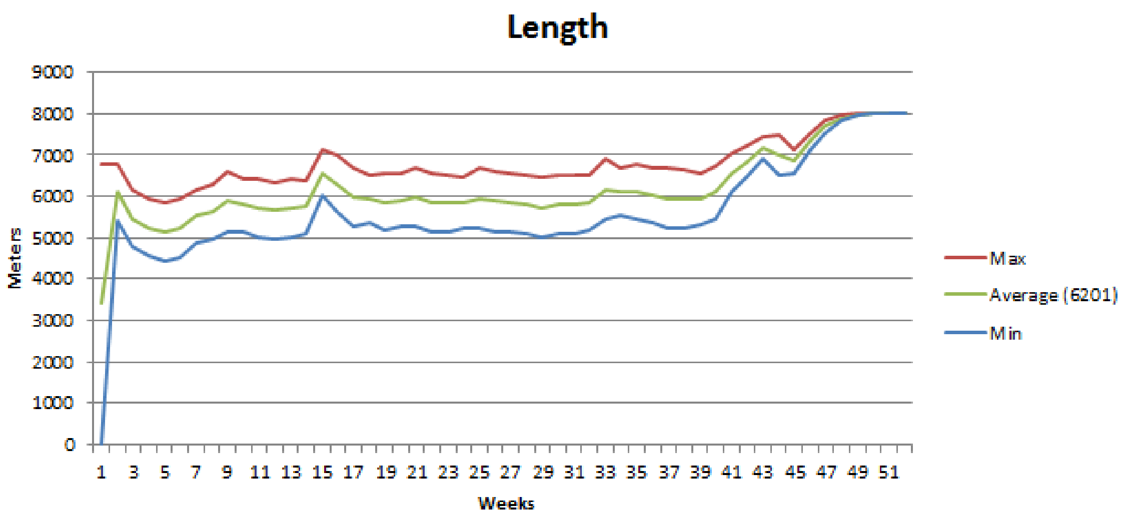

Figure 4.5: Supermarket Length for Scenario 1

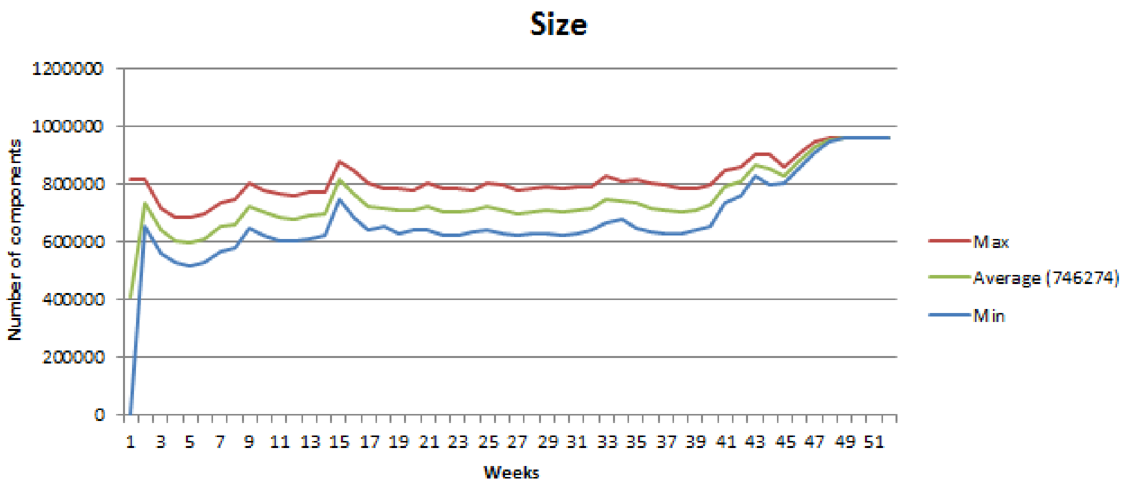

Figure 4.6: Supermarket Size for Scenario 1

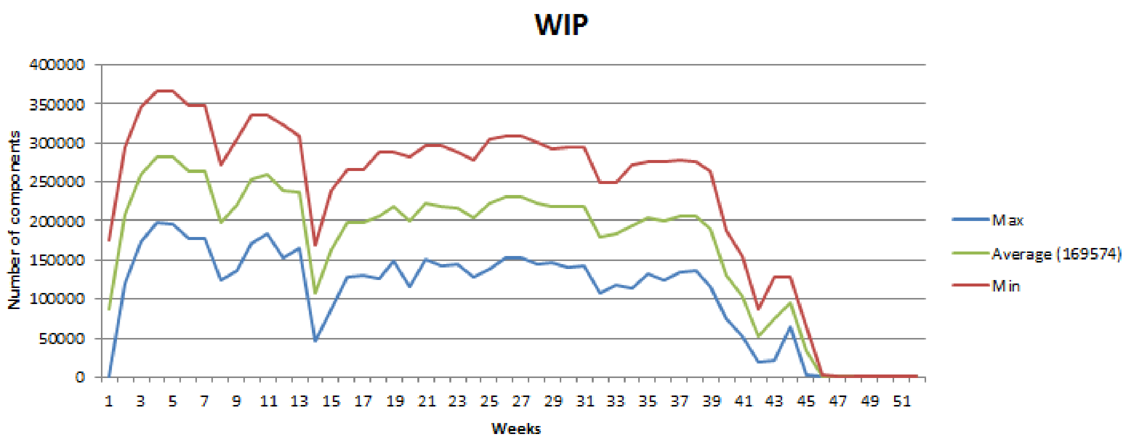

Figure 4.7: WIP for Scenario 1

It is now possible to observe that, with the optimization of the reorder points, and consequente increase of length and size of the supermarket, it was able to deal with demand much better, responding almost every week, with the correct amount of components to the respective orders. The supermarket can now hold approximately 3 weeks of packaging.

Scenario's pros:

- Products can immediately start in the packaging line and then be shipped;
- Production line entirely regulated by pull strategy, being the production orders triggered by reorder points.

Scenario's cons:

- Supermarket size;

4.3 Scenario 2.1: Higher variability - Family 6

The product family with highest variability is held in the supermarket. This scenario intends to reduce the unpredictability introduced by the high variability of lead time and rework rates. This entire family would work under a pull strategy.

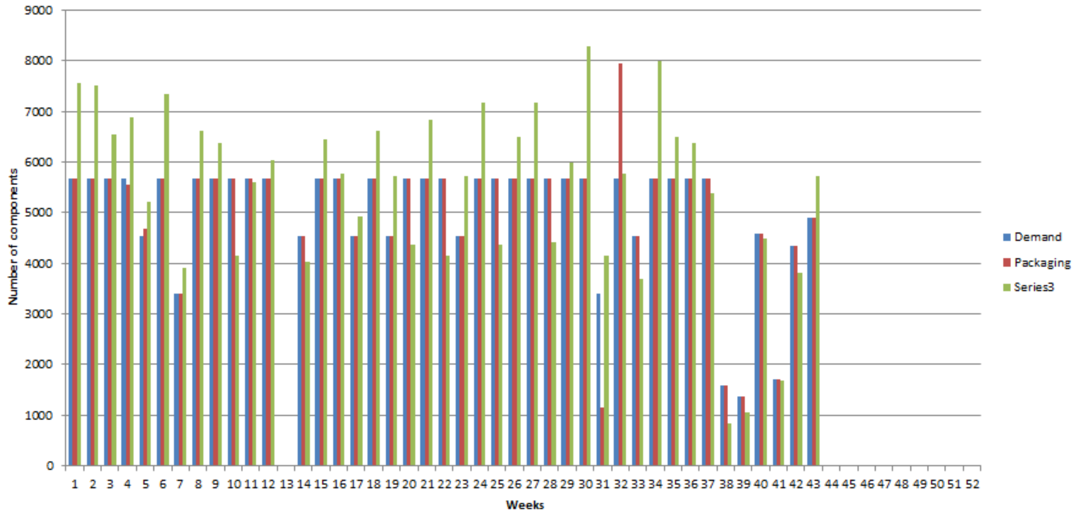

Figure 4.8: Demand, Packaging and Production Comparison for Scenario 2.1

By observing Figure 4.8 it is possible to observe that apart from week 31, the demand can be matched in every week. The mismatch in week 31, is most likely due to a component or more that because they are ordered so few times in the year, their reorder points haven't been optimized and therefore a compensation in the next week is necessary. Plus, because it's the highest variability scenario, the prodiction is always much higher than demand to make up for that variability.

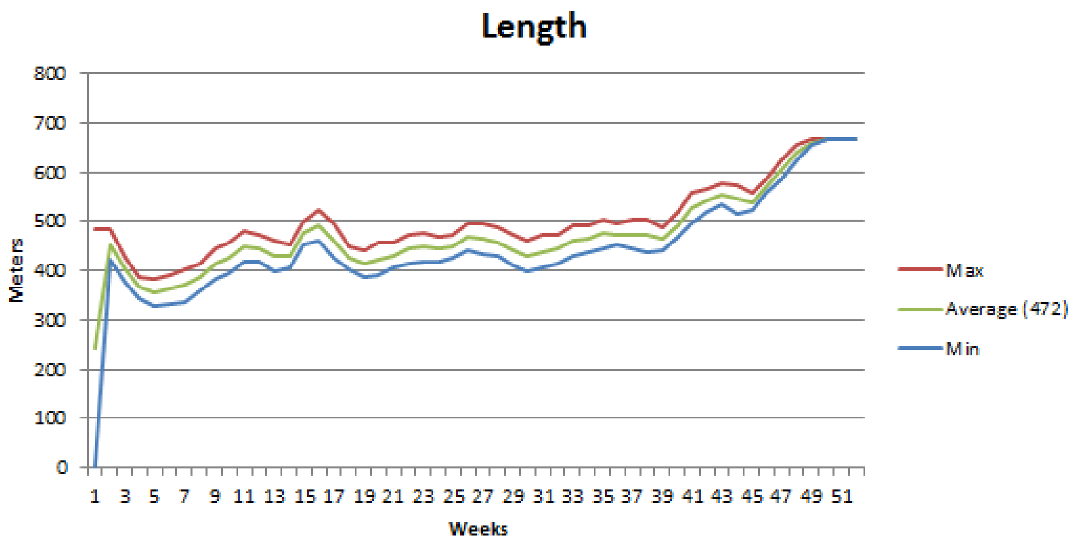

Figure 4.9: Supermarket Length for Scenario 2.1

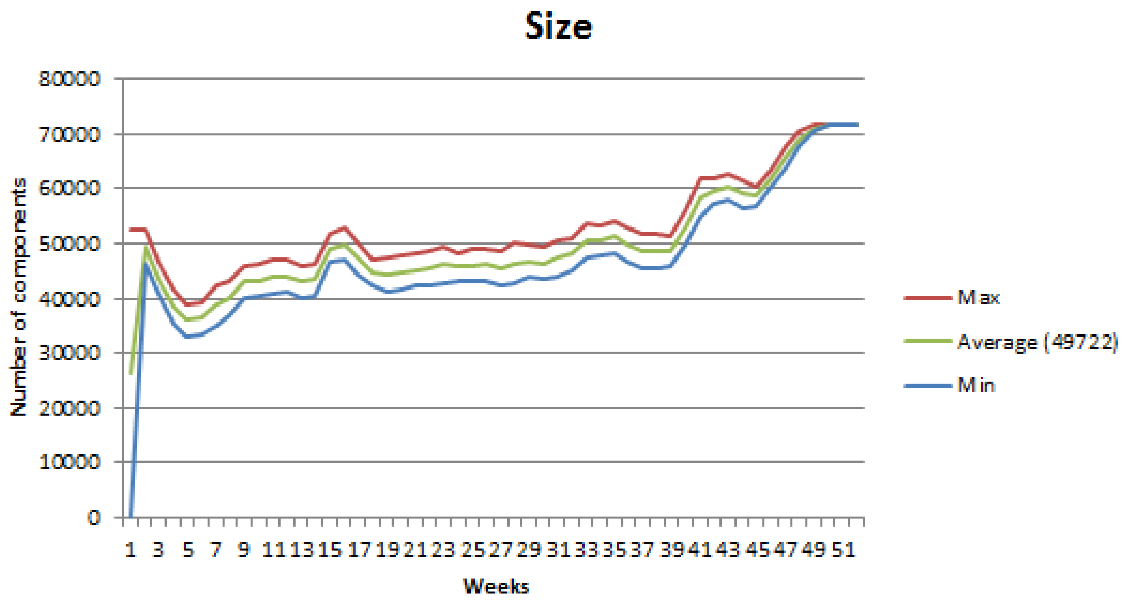

Figure 4.10: Supermarket Size for Scenario 2.1

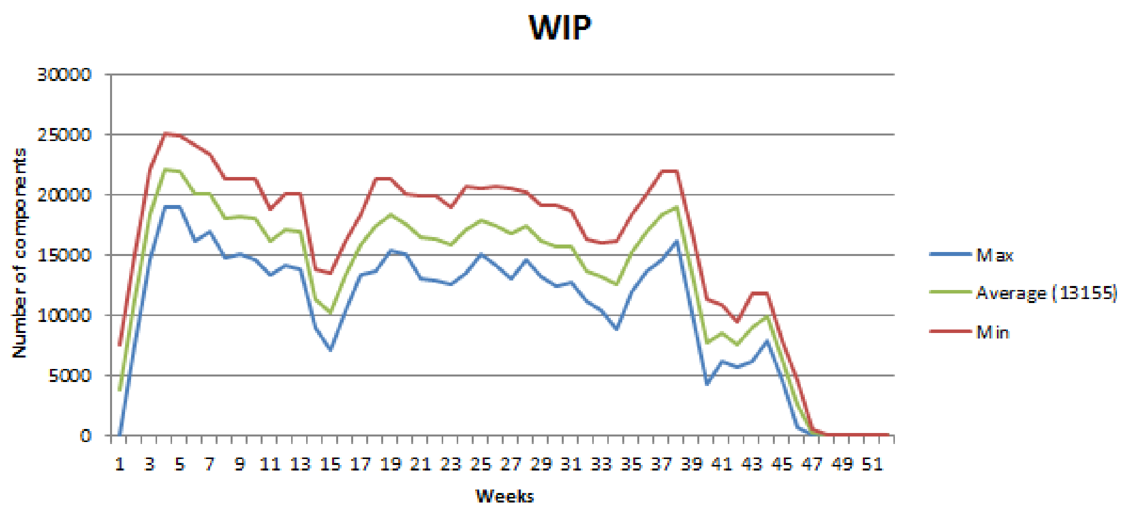

Figure 4.11: Supermarket WIP for Scenario 2.1

Scenario's pros:

- Reduced unpredictability;
- Reduced stock requirements and space for the supermarket;
- High variability products managed by pull strategy;
- The supermarket can hold approximately 4 weeks of packaging.

Scenario's cons:

- Low utilization of the supermarket space (the supermarket holds only 4% of the production volume);
- Most of the production works under a push strategy since most of it doesn't go into the supermarket.

4.4 Scenario 2.2: Higher variability - Family 6 & 7

Most like the previous scenario, this one intends to reduce the unpredictability introduced by the high variability of lead time and rework rate by holding the two families with higher variability. Besides that, it also only takes into consideration, from those families, the components that are ordered every two or three weeks to try and combine the reduction of unpredictability with high rotation components (which are the ones that are originally supposed to go in the supermarket).

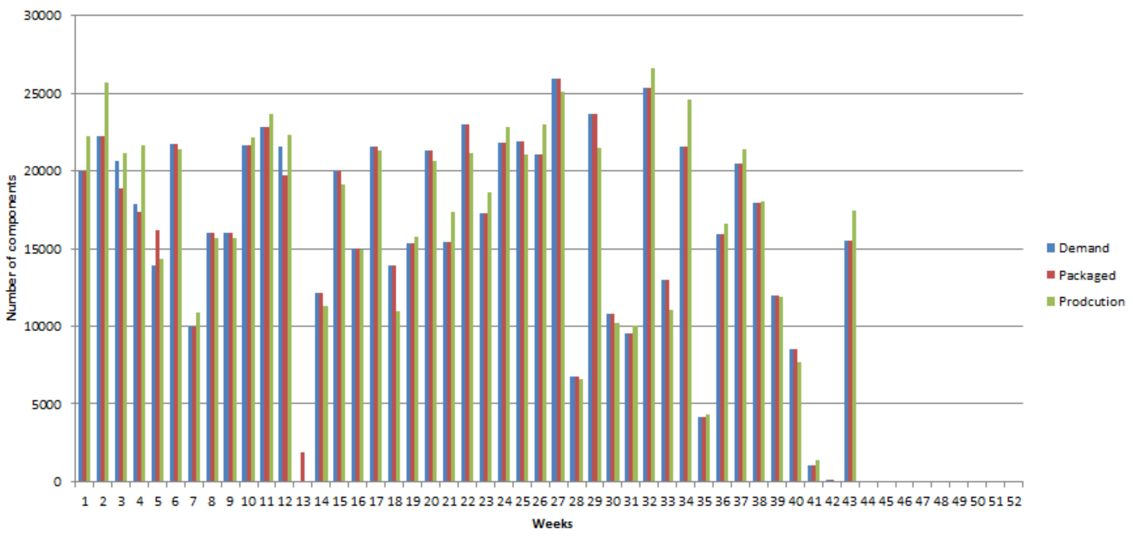

Figure 4.12: Demand, Packaging and Production Comparison for Scenario 2.2

The pros and cons of this scenario are similar to the previous one and won't, therefore, be repeated. It is important to add however, that despite the production volume has increased from 4% to 12% relatively to the previous scenario, it is still a very low figure.

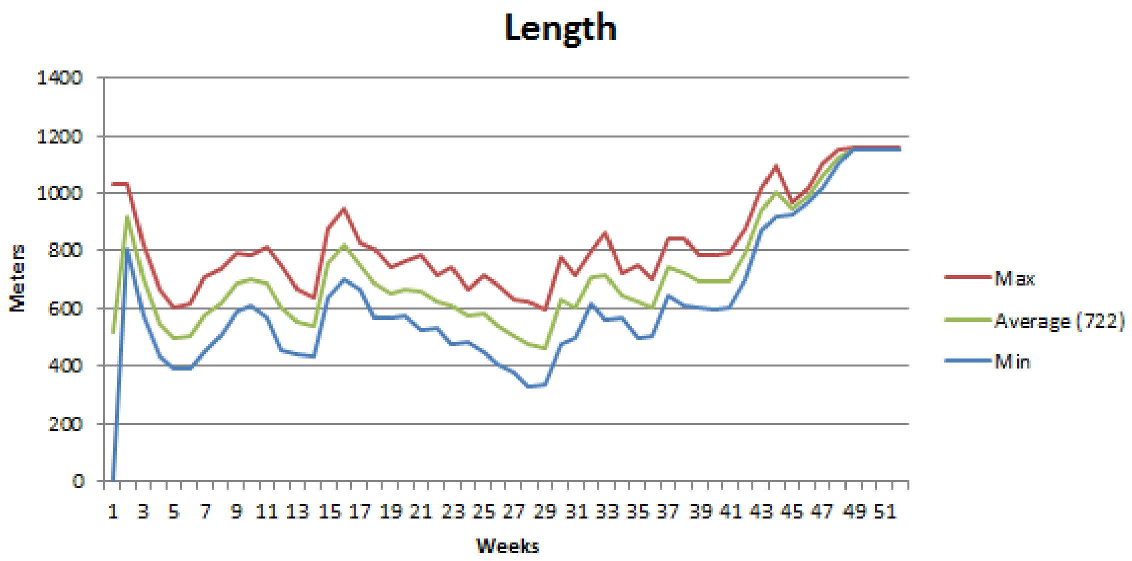

Figure 4.13: Supermarket Length for Scenario 2.2

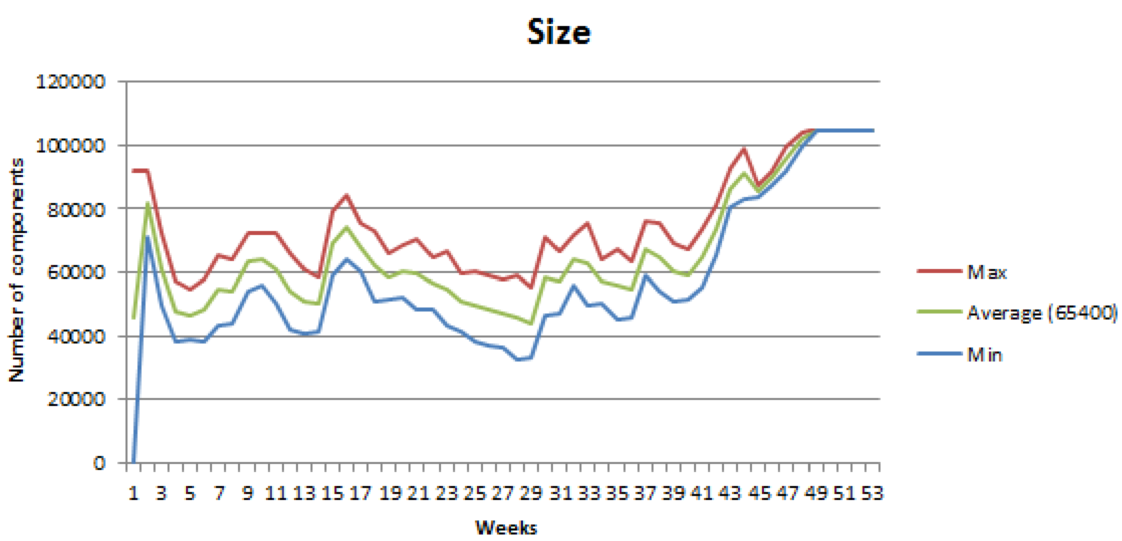

Figure 4.14: Supermarket Size for Scenario 2.2

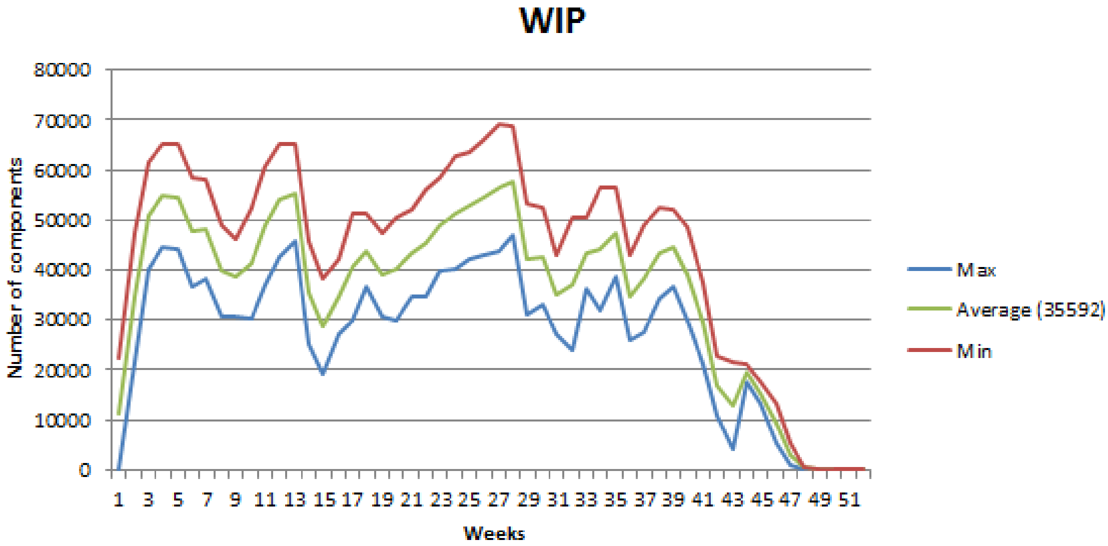

Figure 4.15: Supermarket WIP for Scenario 2.2

4.5 Scenario 3: High Rotation

The supermarket will hold components that are ordered every two weeks (at maximum). The components held in the supermarket will mostly be the ones with low variability due, probably, to the large amount of times they're produced during the year and consequent improvement in their production. By holding these components, those with high variability will be left out of the supermarket and managed by a push strategy, which will increase the unpredictability.

This scenario represents the purpose of the supermarket, holding high rotation products. This doesn't mean, however, that this will be the best solution.

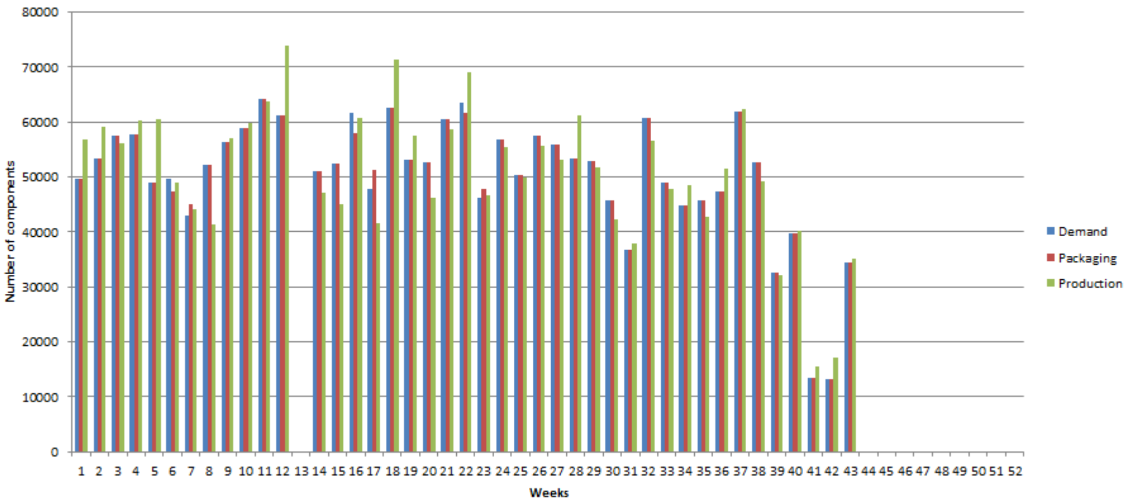

Figure 4.16: Demand, Packaging and Production Comparison for Scenario 3

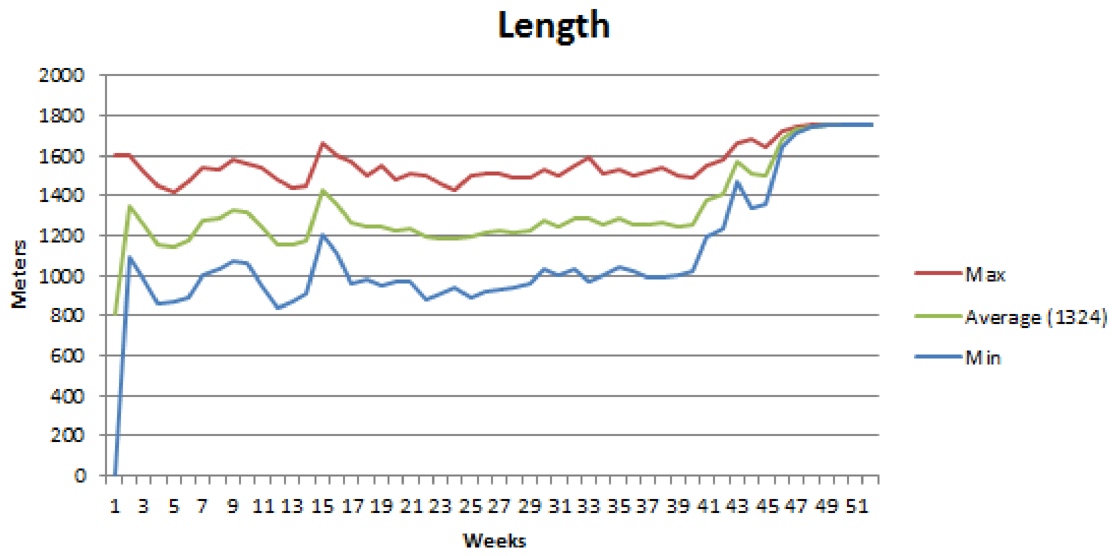

Figure 4.17: Supermarket Length for Scenario 3

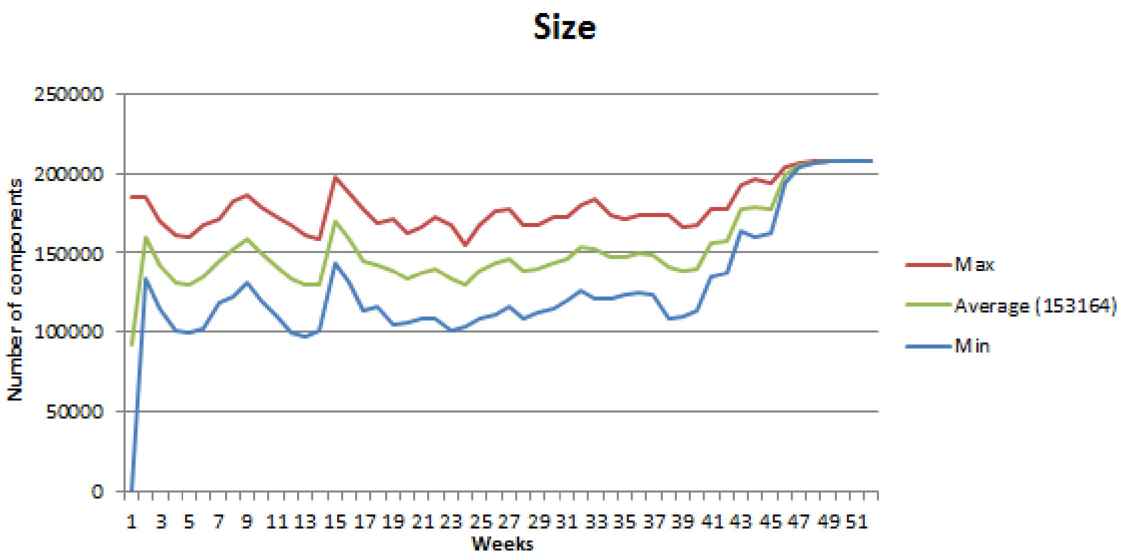

Figure 4.18: Supermarket Size for Scenario 3

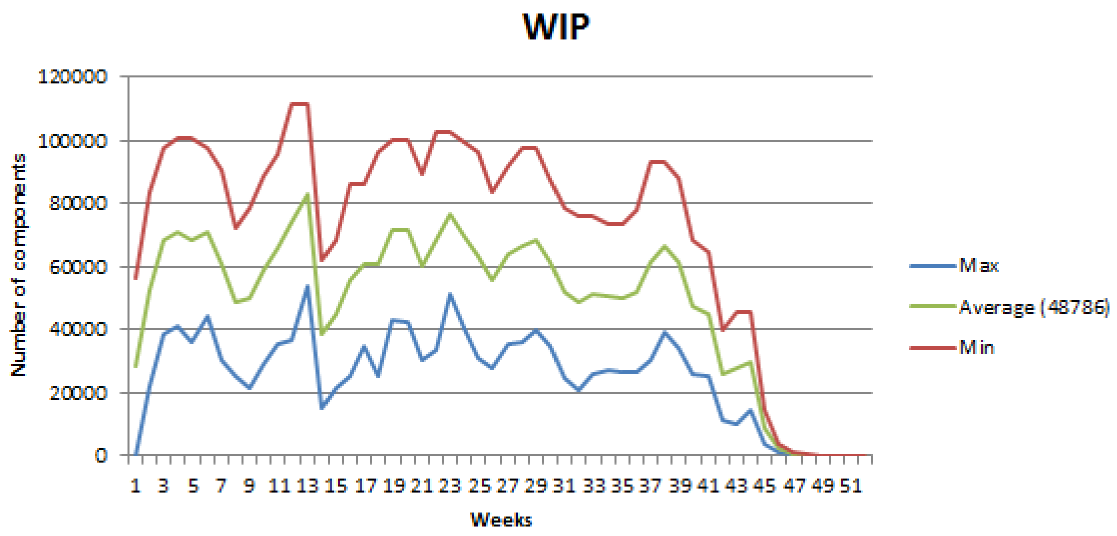

Figure 4.19: Supermarket WIP for Scenario 3

Scenario's pros:

- Supermarket holds components that are ordered frequently and therefore, the delays on delivering this components will be reduced or even eliminated;
- Supermarket can hold until 36% of the production volume.

Scenario's cons:

- Requires a push-pull production strategy;
- Some components with high rework rates may cause perturbations in the replenishment of the supermarket;
- The supermarket can only hold approximately 1 week of packaging.

4.6 Scenario 4: Family 8

This scenario keeps in the supermarket the most representative family in terms of production volume: family 8. This would allow having an entire product technology managed by pull strategy.

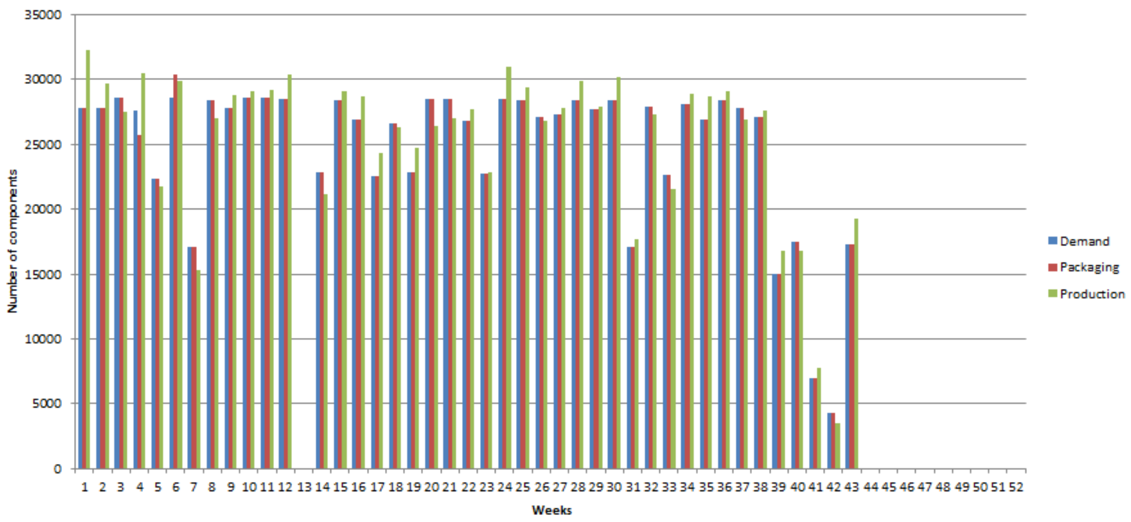

Figure 4.20: Demand, Packaging and Production Comparison for Scenario 4

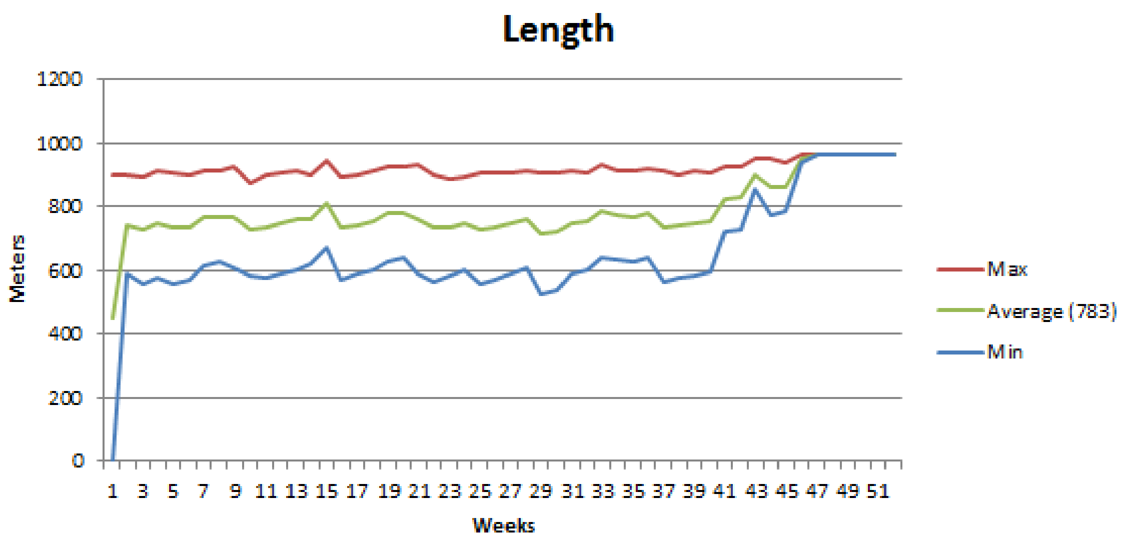

Figure 4.21: Supermarket Length for Scenario 4

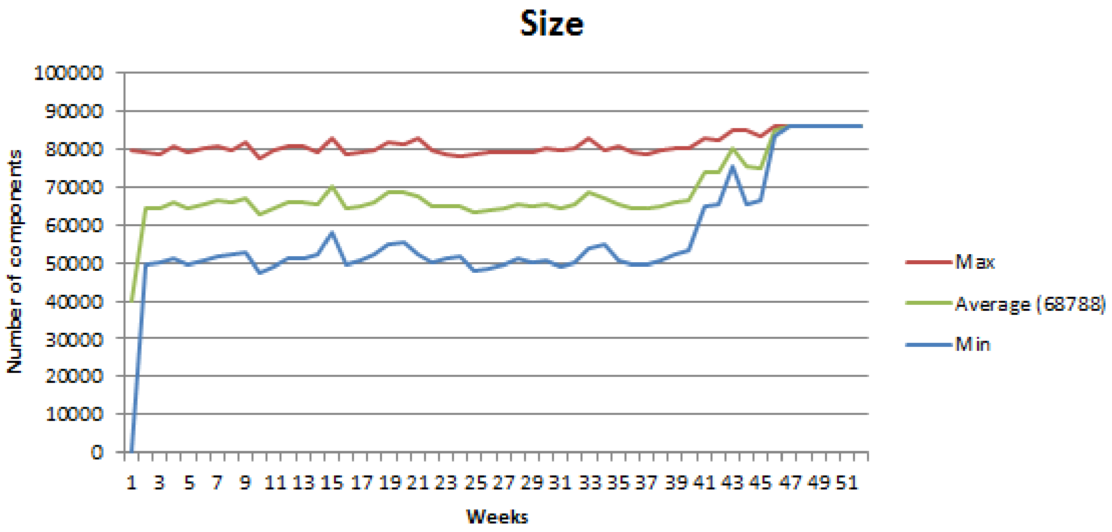

Figure 4.22: Supermarket Size for Scenario 4

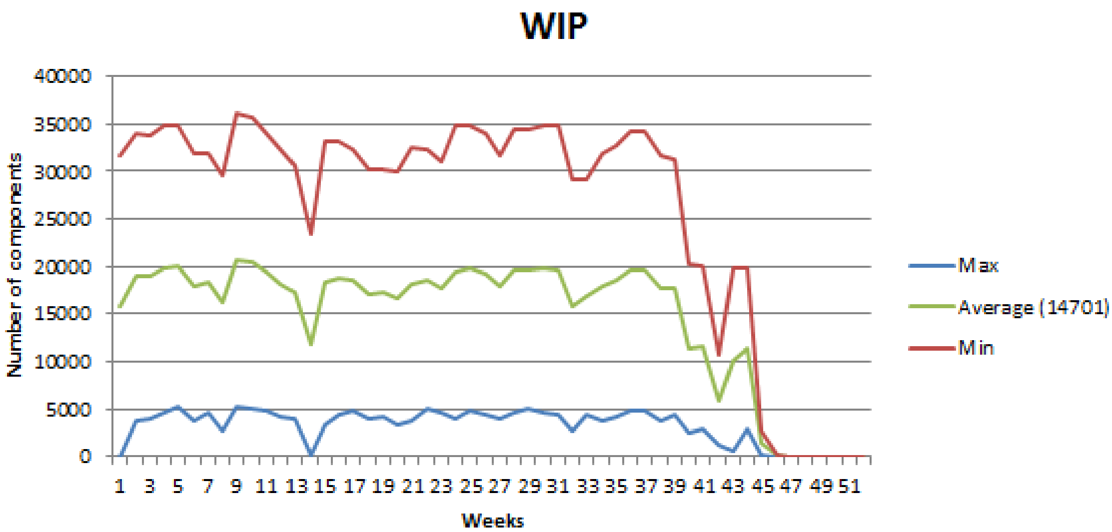

Figure 4.23: Supermarket WIP for Scenario 4

Scenario's pros:

- A product family is entirely managed by pull strategy.

Scenario's cons:

- The supermarket holds just 18% of the production volume;
- A very low percentage (16%) of this components are type A.

4.7 Results and Decision

In Table 4.1 a summary of the results obtained is displayed.

Table 4.1: Results Summary

Scenario	Size (m)	Size (pcs)	WIP (pcs)	Components produced by pull strategy (pcs)	Packaging delayed (pcs)
1. All Products	$\simeq$ 6.200	$\simeq$ 750.000	$\simeq$ 170.000	$\simeq$ 6.000.000	$\simeq$ 18.000
2.1. Higher Variability - Family 6	$\simeq$ 500	$\simeq$ 50.000	$\simeq$ 13.000	$\simeq$ 230.000	$\simeq$ 2.400
2.2. Higher Variability - Family 6&8	$\simeq$ 700	$\simeq$ 65.000	$\simeq$ 36.000	$\simeq$ 710.000	$\simeq$ 4.100
3. High Rotation	$\simeq$ 1.300	$\simeq$ 150.000	$\simeq$ 49.000	$\simeq$ 2.130.000	$\simeq$ 7.600
4. Single Family - Family 8	$\simeq$ 800	$\simeq$ 69.000	$\simeq$ 150.000	$\simeq$ 1.060.000	$\simeq$ 1.872

The analysis of Table 4.1 allowed to reach some conclusions:

- Scenario 1 would be the ideal one as it allows to produce all the components under a pull strategy. It would also allow keeping a high inventory of nearly finished products which would make responding the demand very easy. However, this scenario is utopian since it would be impossible to maintain a supermarket with over 6 km;
- Scenario 2.2 provides better results than Scenario 2.1 since it allows a better utilization of the supermarket real size ($\simeq$ 1200m) although it still leaves a lot of free room;
- Scenario 4 is the best alternative so far since it utilizes best the 1200m of the supermarket and still has room when the stock reaches its maximum value;
- Finally, Scenario 3, is the one that gets closer to the supermarket real size. Although the supermarket average size it's a little over 1200m, this value is only that high because there is no information on demand after week 43. This phenomenon makes the supermarket size increase in the last few weeks because nothing is withdrawn from it in those weeks. If there were still demand information, the average would drop to around 1200m. Still, if the supermarket couldn't take all the components when maximum stock values were reached, a solution could be taking out from this scenario some components that represent smaller production volumes or with low rates of variability or with low rates of variability or, if possible, increasing the supermarket size.

4.8 Analysis of Improvement Opportunities

In this section the impact of the variability parameters have in the system will be studied. To do this, Scenario 2.2: Higher variability will be used in order to reach some conclusions. The use of this scenario is due to, as the name unveils, its high variability parameters.

The approach taken was the following:

- Lead time reduction;
- Rework reduction.

4.8.1 Lead Time Reduction

As it is possible to see from (2.1) and (2.4) in 2, the lead time is proportional to the reorder point. This means that by reducing it, a reduction in the reorder point should be expected. In order to determine how relevant this parameter is, let's consider a reduction of 10% in all components' lead times and observe the impact it has on the supermarket.

"Scenario 2.2: High variability" was used because the families in this scenario show a standard deviation of lead time similar to the lead time average which creates high unpredictability and therefore, difficulties in the replenishment of the supermarket, which should provide more obvious results.

To achieve the following results reorder points were once again calculated and optimized to its new values.

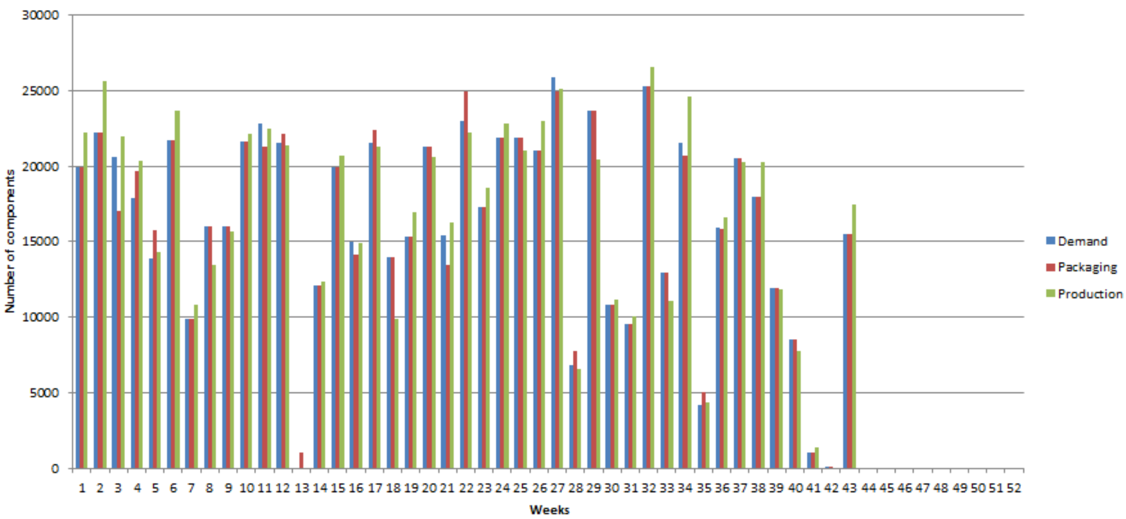

Figure 4.24: Demand, Packaging and Production Comparison for 10% Lead Time Reduction

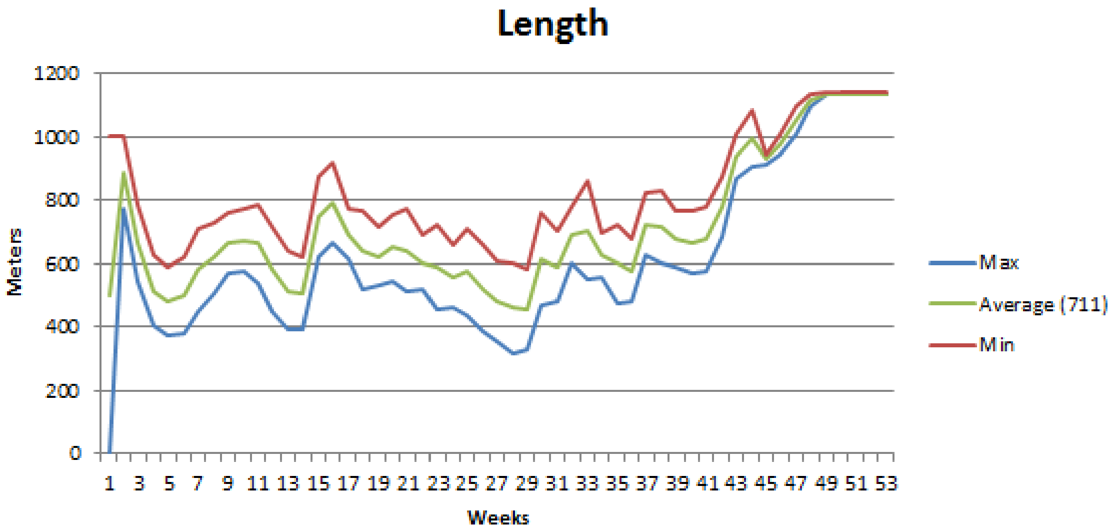

Figure 4.25: Supermarket Length for 10% Lead Time Reduction

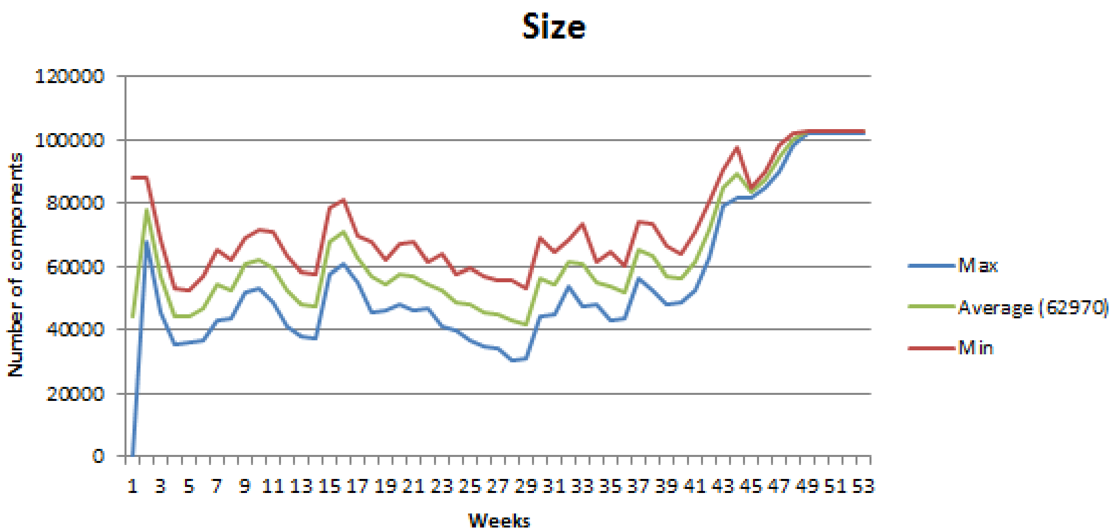

Figure 4.26: Supermarket Size for 10% Lead Time Reduction

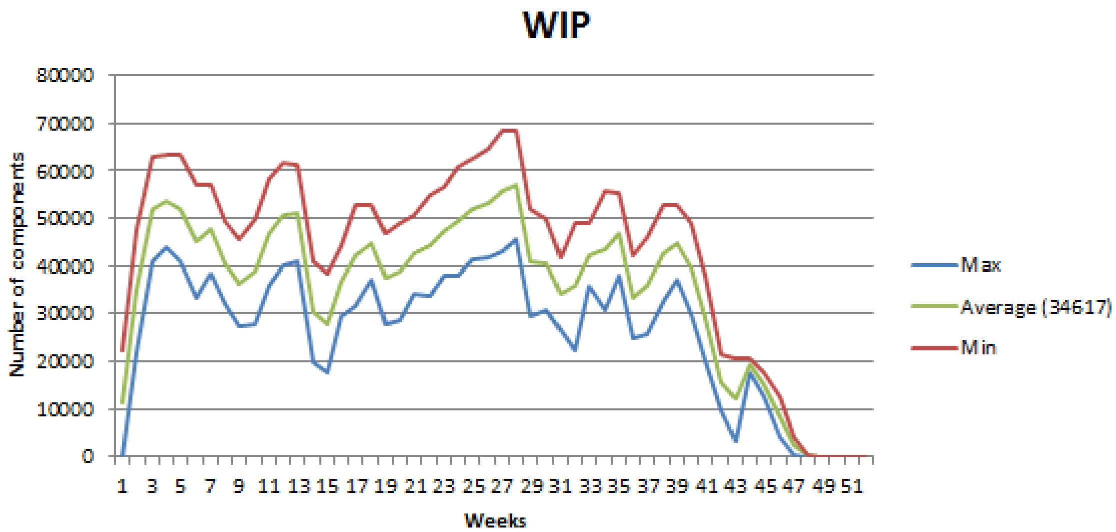

Figure 4.27: Supermarket WIP for 10% Lead Time Reduction

It is possible to observe that a reduction of 10% in lead time and its standard deviation enabled a reduction of 2.6% in the size of the supermarket. This was not only achievable due to the lower time components spend in production but also because of the more stable replenishment frequency granted by the smaller standard deviations.

Not only a reduction in supermarket length was verified. The reduction of the lead time also allowed a reduction of around 2.7% in WIP.

This lead time reduction results could be achieved with the implementation of lean techniques. In "A Review of Various Tools and Techniques for Lead Time Reduction" were studied ways to improve lead time [20]. This tools could either reduce setup times or processing, move and waiting times. To reduce setup times SMED or Method Study (a technique that consists in a 5 step methodology that analyses setup times and is concerned with the reduction of the work content) are proposed whilst to diminish processing, move and waiting times tools like the 5'S implementation, VSM, MTM and TPM are suggested.

4.8.2 Rework reduction

Rework is not included in the component's lead time which means that, besides having to go through all the production line, materials may still have to go through a rework process. Plus, rework is assumed to last, in average, 1 week for every component. This situation implies that a *kanban* may have to take large amounts of time since it is set intro production and actually returning to the supermarket. To illustrate the influence of this factor in the system let's consider a reduction of 10% in all components rework rates.

“Scenario 2.2: High variability” was used to gather results because the families in this scenario show high rework rates which makes data more clear.

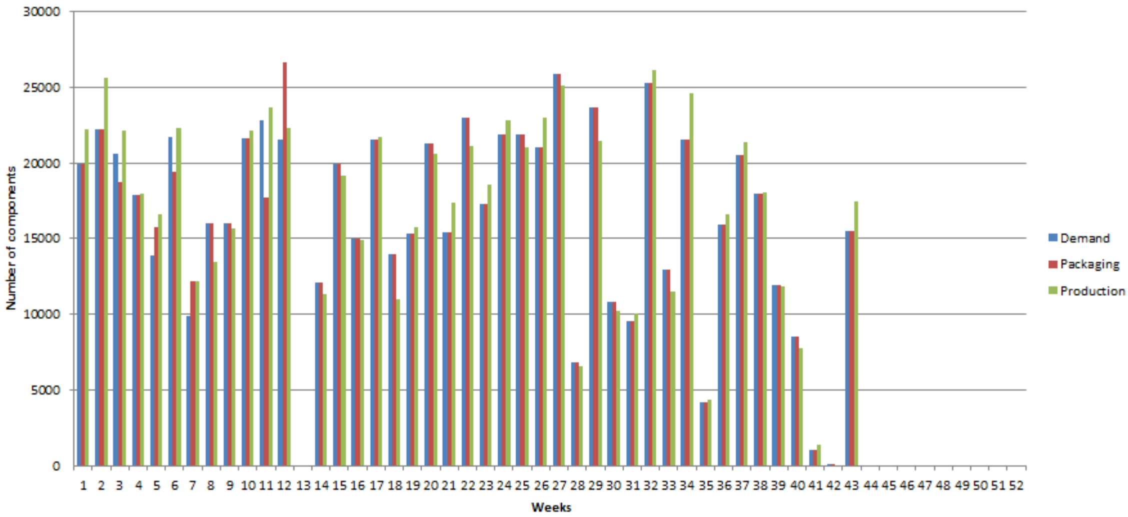

Figure 4.28: Demand, Packaging and Production Comparison for 10% Rework Reduction

The reduction of 10% in rework rates allowed a decreased of 1.4% in the size supermarket. This was possible because more components could go directly from the production line to the supermarket.

Unlike the considerable reduction of WIP registered when applied a 10% reduction in lead times, here is possible a decrease of only 1% in WIP. This reduction is directly related to the fewer number of components that need rework.

In order to reduce its rework rates, the company should try the implementation of techniques such as Standardize Work Instructions, error and mistake proofing (with the use of *Poka Yoke*) and Total Quality Management.

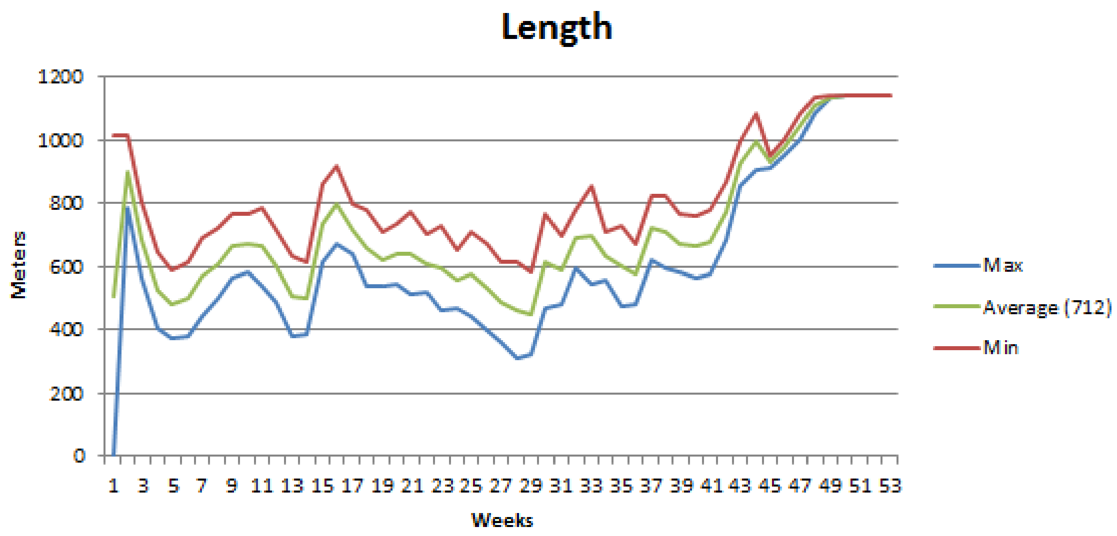

Figure 4.29: Supermarket Length for 10% Rework Reduction

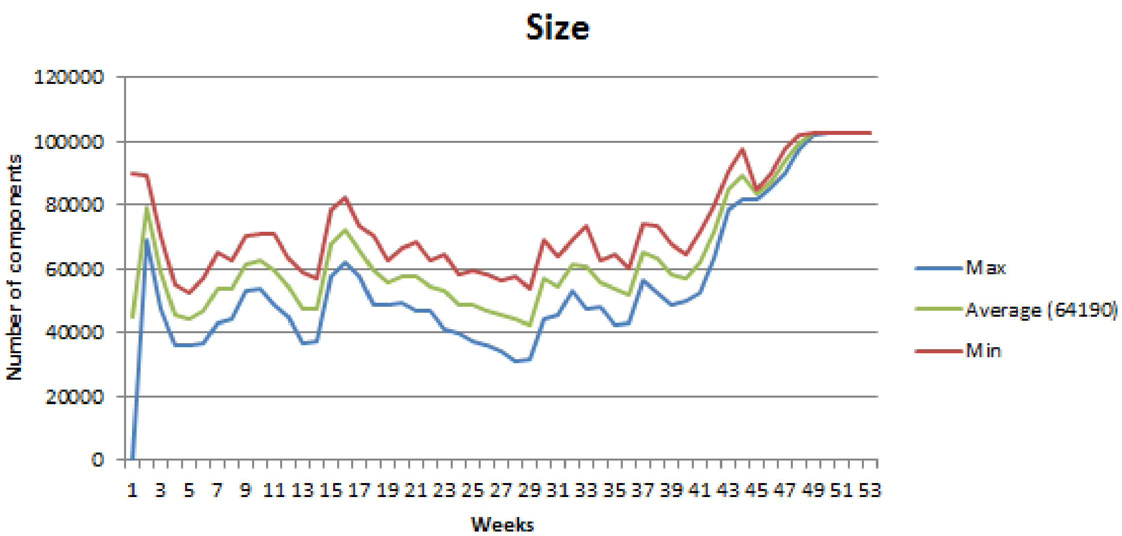

Figure 4.30: Supermarket Size for 10% Rework Reduction

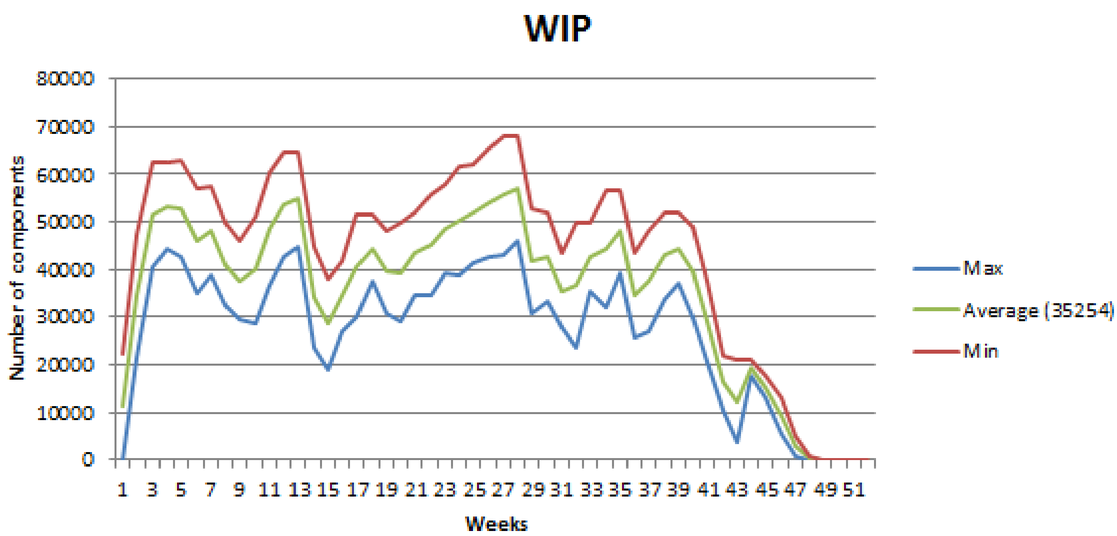

Figure 4.31: Supermarket WIP for 10% Rework Reduction

Chapter 5

Conclusions and Future Work

This chapter examines the outcome of the thesis with respect to the formulated objectives, identifying original contributions and proposing promising research directions.

5.1 Revision of Objectives

In this study, lean manufacturing tools and techniques were studied and applied in a case study in a furniture manufacturing industry. After a literature research on the applications of lean manufacturing, some of the most promising tools were applied.

The main objective of this thesis was to develop a tool that was capable of, through a set of inputs, generate an output which would allow to make decision on what components to store in the supermarket and calculate their reorder points in order to create a system capable of dealing with demand. This tool allows to predict, adjust and reach a nearly optimum solution for problems of production control such as this.

After calculating and optimizing a set of reorder points for over 300 components, 5 scenarios were created. This scenarios allowed to analyze the supermarket's length, number of components, work in progress and the way the demand was dealt with and were the basis to the decision making.

The influence of parameters such as lead time and rework rates were analyzed, discussed and their influence on the supermarket studied. Besides that, solutions on the reduction of these two parameters, which would obviously represent an improvement in the system, were proposed.

Another objective of this thesis was to study the modeling software Anylogic, and evaluate it in a prespective of simulation of production systems and determine its future use for INESC. Although this objective can not be totally fulfilled with the application of only one case study it was possible to realize that the integration of three simulation methodologies in one single software grants a great flexibility in the model construction. Also, the fact that it's a java based interface allows the adjustment of every single component and event to the user's needs which creates a very easy to adapt tool.

5.2 Future Work

Although the objectives were mainly fulfilled some aspects can be thoroughly studied in the future:

- The production block, that represents all processing activities to which a component is subjected could go through a more thorough study. The simulation of all the machines in the production line would allow a routing of the components and therefore, a more accurate representation of the production line;
- The data collection on the shop floor could be improved. Instead of gathering information for each family and applying that information to all the components in that family, an individual component study could be made. This would grant a better approximation of the simulation results to the reality;
- The formulas to the supermarket sizing were proven not to be as accurate as deserved. A further research could be pursued in this area with the objective of improving these formulas;
- This simulation tool is designed for a specific company. A generalization of the model could be investigated in order to make it an universal tool applicable to different systems;
- Finally, Anylogic's capabilities weren't fully studied. Special attention should be given to its teamwork functionalities that haven't been investigated at all since this was an individual project.

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