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Lean Games for Cork Industry Value Chain

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Abstract

The present document was produced in the context of the Integrated Master Degree in Electrical and Computer Engineering at *Faculdade de Engenharia da Universidade do Porto* with the aim of presenting the work developed in the Lean Games for Cork Industry Value Chain dissertation.

More and more, companies face more competitiveness and then, feel the need to produce more spending the less. Lean Manufacturing aims at creating value through the reduction of waste in the production processes. However, companies found that this is not enough. It was realized that the participants in a supply chain should work together in order to deliver the product to the client having the lowest costs. Thus, the Lean concept evolved from being applied independently in companies to being applied in the supply chain as a whole.

Yet the Lean philosophy is easy to understand, its concepts and tools as well as their benefits and how to implement them are not. Due to their practical component and because they allow participants to experiment and suffer the consequences of their choices, games are a popular way to teach those concepts.

Lean concepts have already been applied to the cork industry. Many companies have been implementing Lean tools in order to improve their processes and thus, the need for Lean games focused on the cork products' value chain emerges. Having this is mind, this project aims at developing tools that allow the people involved in the production of derived cork products to understand the benefits of implementing good practices of Lean in the referred industry.

The work developed consisted of developing two Lean games to be applied to the cork industry's value chain: the Cork Supply Game and the Cork Stoppers Production Game. In order to do it, the cork products' value chain was studied as well as the existing Lean games.

The Cork Supply Game is a supply chain management game. It aims at showing the problems that result from the lack of information sharing in the cork stoppers supply chain. The referred value chain is simulated in the game having in concern its specificities as the stages and the flows between them.

The Cork Stoppers Production Game is a production flow simulation. It is focused on one of the stages of the manufacturing process of stoppers: finishing. It simulates the operations performed in the finishing industry in order to make participants to identify some inefficiencies of the process and to discuss ways to improve it.

When finalized, the games were validated. They were experimented in workshops in order to see if they meet their requirements, to identify strengths and weaknesses and to collect opinions from the participants about the relevance of them.

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Abbreviations

ATO	Assembly-To-Order
IO	Incoming Order
Kg	Kilogram
OP	Order Placed
SD	Shipping Delay
WIP	Work In Progress

Chapter 1

Introduction

This chapter begins with the contextualization of the subject of this dissertation. Posteriorly, the problem is characterized and then the methodology used to solve it is presented. Finally, the dissertation outline is described.

1.1 Context

Companies face an everyday increasing competitiveness. Costumers have a wide variety of products to choose from which makes it very difficult for companies to satisfy their high demand. Costumers want the best product in the shortest period of time for the lowest price. So, in order to create value, companies have to adapt to the new circumstances and find ways and means to improve their work.

In order to satisfy the demand of costumers and to win to their competitors, most companies choose to implement Lean Manufacturing over other expensive improvements. A wide variety of Lean practices can be applied in order to reduce wastes and their inherent costs, and, in consequence, add value to the product.

The first implementations of Lean were focused in manufacturing processes. The goal was to improve their performance by eliminating their wastes, which was achieved by small continuous changes in operational terms [1] [2].

Meanwhile, the Lean philosophy have evolved from being applied only in manufacturing processes to being applied in all the supply chain length of all kinds of businesses. Supply chain management is a complex subject that consists of the management of the flow of goods, information and finances through the stages of a supply chain. The main goal of effective supply chain management is to reduce inventory, ensuring that products are available when needed [1] [2].

Supply chain management, as well as the Lean Manufacturing and its techniques are concepts of easy understand yet very difficult to implement. Games and simulations are immersive, which turns them an efficient and popular way of teaching that has already been successfully applied to the teaching of these domains.

1.2 Problem Characterization

This dissertation work was developed in the context of the European project FOCUS [1]. The FOCUS project aims at advancing the forestry control and automation through the development of technologies to support the management of the operations of the whole forest-based supply chain.

The FOCUS project covers the main forest-based value chains in Europe: pulpwood, timber, biomass and cork. As part of the FOCUS project, the present dissertation has as its only focus the cork value chain.

The aim of this project dissertation is to develop tools that are oriented to improve the awareness of Lean concepts in the cork industry. The developed tools have the advantage of explaining good Lean Manufacturing practices and of demonstrating their benefits as they are being applied. Tools were conceded that allow the people involved in the production of derived cork products to understand the benefits of implementing good practices of organization and management.

1.3 Methodology

The methodology used in order to accomplish the dissertation objectives divided in three big phases: the study of the problem, the development of the proposed solutions and the validation of them.

The first phase began by studying the application domain. The supply chain of cork stoppers was analysed as well as the processes in its industries. From the first came out the flows of the supply chain as well as its final products and other important aspects to have in attention in the development of a supply chain management game. From the study of the processes in the cork stoppers' manufacturing industries came out the operations performed in each of them as well as the problems attached to them. The existing Lean Games were also surveyed. The games found were separated according to their focus and the ones identified as being of relevant use were detailed. From this came out usual concerns had in the development of both kinds of games. During this phase, theoretical aspects were being researched in order to better understand them and to justify the choices made.

The development of the proposed solutions was based on the study performed in the first phase. From that study came out the basis of the proposed solutions. The development of the first game (Cork Supply Game) went through some phases where the following aspects were defined: the stages to represent, the products and the flows over the length of the supply chain, the rules, the steps by which each round goes through, the conditions in which the game is initialized, the three scenarios to experiment and the evaluation system. The development of the Cork Stoppers Production Game began by choosing which of the stages of the cork stoppers supply chain would be simulated and then, the activities to perform in order to simulate its operations. Then, the Lean concepts to implement and how and when to implement them were chosen. Finally, the steps of

[1] http://www.focusnet.eu/

the learning process were defined as well as the performance indicators and the way to calculate them.

The last phase consisted of the validation of the games. It was accomplished by the experimenting of them. The validation was performed in one single session where the people involved in the project in which the dissertation is encompassed and fellow students played the games. The data recorded during the game was finally analysed, the solutions validated and conclusions were drawn. In the figure below is displayed a schematic representation of the steps performed in the scope of the project.

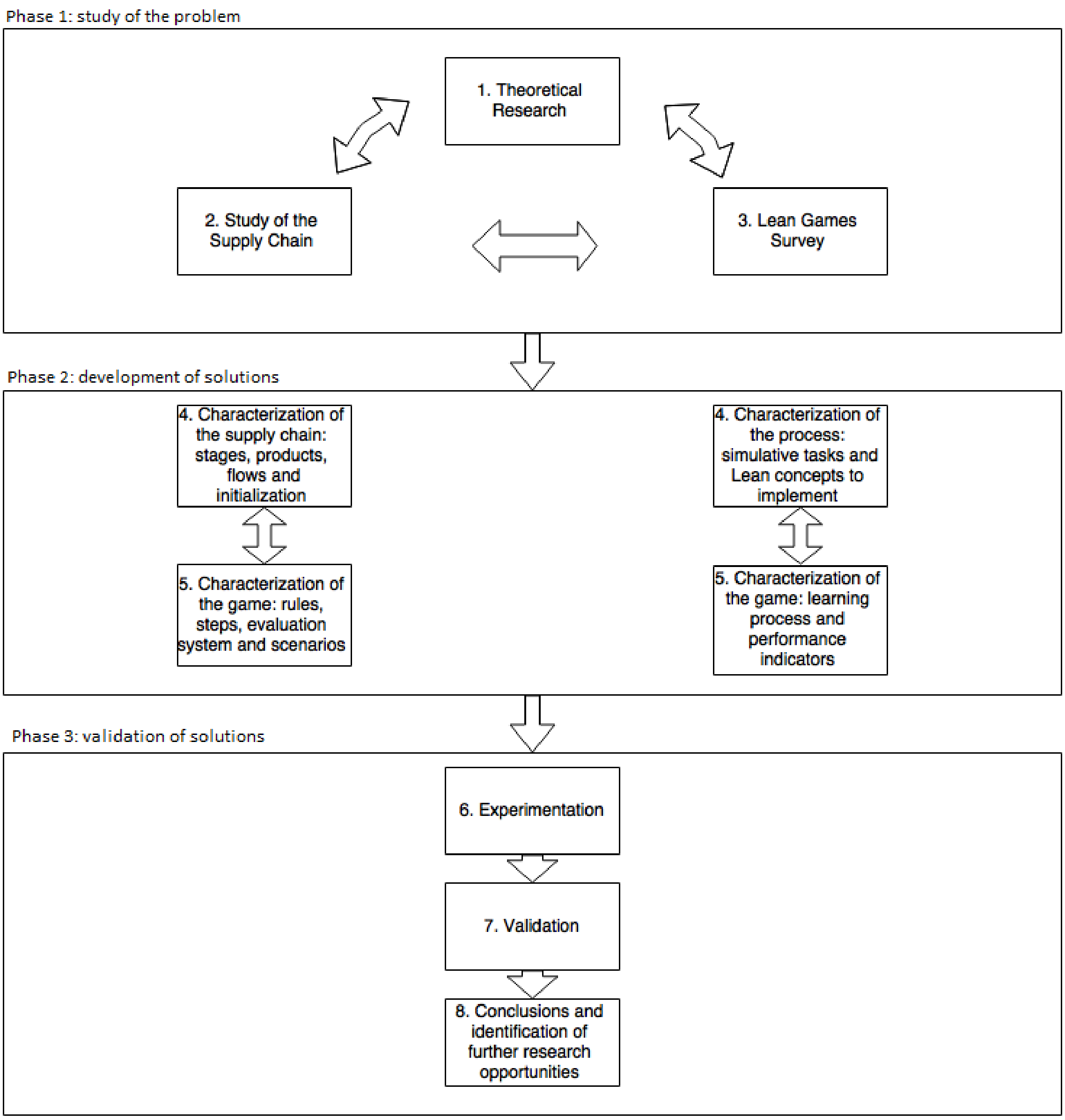


Figure 1.1: Schematic representation of the methodology used.

1.4 Dissertation Outline

As previously mentioned, in this introductory chapter the problem is contextualized and the way used to solve and to present it described. Chapter 2 presents a theoretical support to the subjects addressed in the dissertation and a survey of Lean Games in order to present the state of the art of subject. Chapter 3 focuses in the case study description, providing the reader with comprehension about the supply chain's stages and processes. Chapter 4 characterizes the developed solutions, while in chapter 5 is performed an analysis of the results obtained from the validation of the games. Finally, chapter 6 presents the conclusion taken from the work developed and discuss topics for further work development.

Chapter 2

Lean and Lean Games

In this chapter, a theoretical framework of the concepts in the body of this dissertation is presented. Firstly, it is introduced by a general presentation of the Lean Manufacturing philosophy and then, the concepts that supported the development of the project are specified. Those concepts are Production Flow and Supply Chain Management. Then, a survey of Lean Games is performed. It is introduced by the concept of teaching using games. Then, some games are presented and described. The games characterized are the examples of production flow simulations and supply chain management games in which the developed games were based.

2.1 Lean Fundamentals

Lean Manufacturing is a management principle that aims at eliminating the activities of a manufacturing process that generate no value for the customer [3], which are considered waste.

The elimination of waste is considered to be the fundamental point of Lean Manufacturing because it results in cost reduction and thus, increases the value delivered to the consumer. In [4], Ohno identified seven wastes that he suggests to be responsible for 95% of the costs found in a non-Lean environment:

- **Transporting** – While being transported, the materials in movement are not being improved and so there is no value added to them. Besides, there is the inventory held and the increased lead time that transport provokes.
- **Inventory** – The excess of inventory tends to hide problems that must be identified and solved in order to improve operating performance. Moreover, it increases lead time and consumes productive space. It also represent an investment that had no return.
- **Motion** – All the movements that workers have to do that do not add value to the products, being for replenishment of materials or by layout deficiency, fit in this waste.
- **Waiting** – People stopped, either because of lack of materials, information or equipments, means that they are not adding value to the product.

- **Overproduction** – This encompasses producing more, sooner or faster than the consumer ordered. The problem is that it uses manpower and equipments that could be filling other orders. Besides, it creates more inventory.

- **Over-processing** – The work done that do not add value to the product fits here. The inspection and correction of defected products are two examples of this waste.

- **Defects** – This encompasses the products that do not meet the specification. Besides the fact that the expenses on materials and manpower used to their confection are not returned, it also incurs in costs from the rework in them.

Due to its outstanding results, the Lean philosophy evolved from being exclusively applied in manufacturing processes to being applied to all the business' dimensions of an organisation and to all types of organizations.

Womack and Jones [5] narrow the concepts of Lean Thinking into five principles that aim at improving the way value is produced and delivered to the customer while minimizing the referred wastes:

- **Identify Value from the Perspective of the Customer** – Everything done on a lean project should focus on the customer and consider the costumer's viewpoint. It does not imply the verification of the acceptability of the current offerings, it takes an approach in identifying additional ways to provide value to the customer [6].

- **Identify the Value Streams** – Value stream is an end-to-end collection of activities that creates a result in satisfaction from the client [7]. In order to achieve the goal, the value stream should be analysed as a whole aiming at eliminating waste where it is possible.

- **Flow** – As referred, the excess of inventory is one of the seven wastes. Inventory usually accrues due to functional barriers in the transfer of goods between workstations. The elimination of such barriers creates continuous flow which leads to reduced delay-times and WIP and thus, better and faster fulfilment of the clients' needs.

- **Pull** – The aim of this principle is to produce what is required when it is required. This results in eliminating overproduction and reducing inventory levels which leads to increasing the value of the product.

- **Seek Perfection** – Perfection is never achieved. However, it should be pursued continuously. In order to be competitive, the seek and elimination of waste should always be the main concern.

2.2 Production Flow

As referred above in this chapter, "Flow" is one of the five principles of Lean Manufacturing.

Rummler and Branche [8] stated that functional interfaces are the ones that have greatest opportunities of improvement. Functional areas work as fast as they can having no concern about the other areas. This results in wastes like overproduction and high levels of inventory. Besides, functional layouts present high costs incurred from the transportation of materials between the workstations.

Creating flow implies that the materials go through the processes of an organization without stopping. This continuous flow is mainly acquired displacing the processes in logical sequence. This improvement results in shorter lead-times and reduced WIP inventory levels which increases the value delivered to the client.

Producing in continuous flow is not enough, though. Pull is the production strategy in which the goal is to produce what was required only when it was required. This technique reverses the flow: the consumer pulls the production instead of being the companies pushing it to him.

The push system is characterized by planning the production based on forecasts. The decisions of what and when to produce are made by management and thus, the information flows in the same direction as goods. The main problems that stand out from this strategy and that incur in higher costs for the company are: the inaccurate forecasts, the production in large batches, the long lead-times and the absence of flow.

On the other hand, the pull strategy transforms customers orders in production orders. The main advantages of producing following the pull system are: the low batch production, the reduced lead-times, the continuous flow and the synchronization of the different operations.

The most well-known way of coordinating and synchronizing the workstations in a production system that follows the pull strategy is the *kanban* system. It is a system composed by two cards in which one is associated to the need of materials replacement and the other gives the information about the quantity needed. When a workstation needs replenishment, the *kanban* system informs the upstream workstation and then it starts producing. In turn, this lastly mentioned workstation generates a *kanban* signal to their upstream station for replenishment and so on.

2.3 Supply Chain Management

Supply chain consists of suppliers, manufacturing centers, warehouses, distribution centers, and retail outlets, as well as raw materials, work-in-progress inventory, and finished products that flow between the facilities [1]. Muckstad, [2] defined a supply chain as a set of firms that design, engineer, market, manufacture, and distribute products and services to end-consumers.

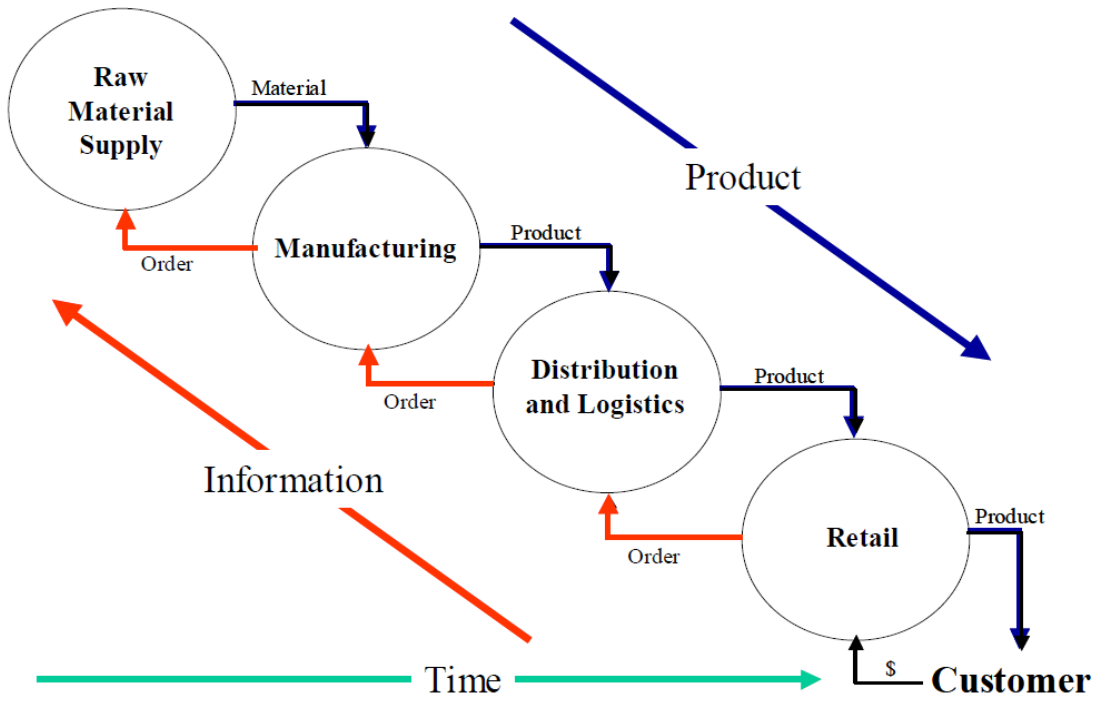


Figure 2.1: Traditional view of a supply chain [2]

Companies in general face a huge number of problems that have to be solved. Must of these problems are related to decision-making concerning: 1) production planning, 2) inventory management and 3) vehicle routing. Due to the complexity involved in the making of those decisions, they are managed separately. Moreover, it becomes even more complex because the decisions to make are interdependent. They should be taken together which makes the problem harder to solve. Furthermore, companies are not isolated, but impact on and are impacted by their supply chain partners. If a company makes decisions in order to maximize its own profits, having no concern about their supply chain partners, it may prejudice the other companies' decision-making and then result in higher supply chain costs than it would be desired. Thus, the best solution would be for the supply chain companies to make the decisions together in order to reduce the total supply chain costs. As this planning problem is hard for a single company, synchronizing all companies decisions together is of a very high complexity [9].

The bullwhip effect is a commonly found phenomenon in supply chains. It consists in an amplification of the demand variability which is a problem because it makes orders unpredictable [9]. As can be seen in figure 2.2, and as stated by Lee et al. in [10], a variation in the consumer sales, as small as it is, is largely amplified as moving up in the supply chain.

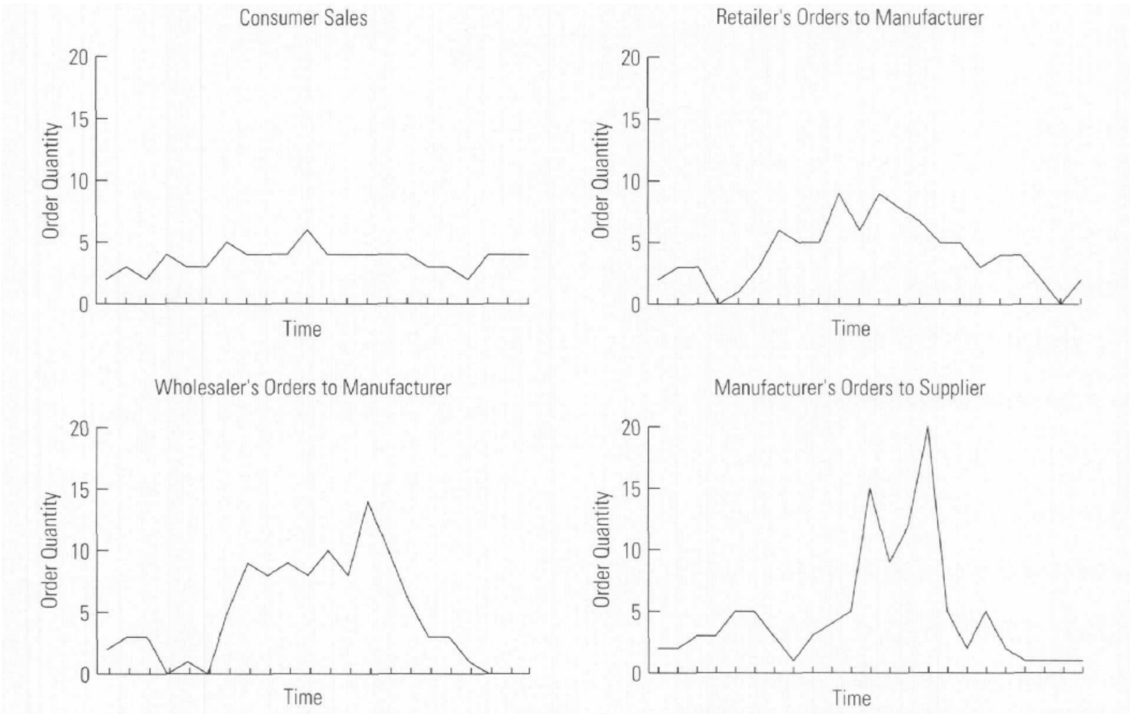


Figure 2.2: The bullwhip effect [10]

The bullwhip effect is indirectly responsible for several costs. It has consequences that entail costs for the supply chain. The first consequence of the bullwhip effect is the 1) higher inventory levels. This happens because participants have to be prepared for the high demand uncertainties and variabilities induced by the bullwhip effect [11]. This leads to 2) supply chain agility reduction as the supply chain should sell products in inventory before it sells the new products demanded by end-customers. This makes the end-customer demand more difficult to follow and understand [9]. Demand variabilities may also incur stock-outs, in which case, no products are available to be sold what 3) decrease the customer service levels [9]. Moreover, the demand uncertainties, result of the bullwhip effect, increase the difficulty of planning and thus lead to: 4) ineffective transportation and 5) missed production schedules [9].

In [10], Lee et al. identified four major forces that in concert with the chains' infrastructure and the order managers' rational decision-making cause the bullwhip effect. The first is demand forecast updating which is often based on the order history from the company's immediate customers which is not accurate. The second, order batching, happens when a company accumulates demands instead of immediately place it to its supplier. Thirdly, the price variations are referred which incite clients to over-order when price is low. Finally, the rationing and shortage gaming refers to when demand exceeds supply and the supplier rations its product to customers. From the analysis of the bullwhip effect's causes stands out that the main concern of a supply chain should be to reduce its variability and uncertainty.

As referred before, Lean Thinking aims at reducing wastes and costs. Short, predictable and repeatable lead-times, reduced WIP inventories, just-in-time delivery strategies and reduced setup times are attributes of Lean companies. The partners of an efficient supply chain must work in a way so that the supply chain has them too. However, even if the supply chain does have these attributes, it may not have a competitive advantage because variability and uncertainty will erode its efficiency and profitability. A Lean supply chain must be designed as a system that is capable of responding to the demand variations quickly and profitably. In resume, Lean Thinking must be extended beyond a company's operations to the operations of the supply chain as a whole [2].

This is also supported by the supply chain management concept that was defined as a set of approaches utilized to integrate the companies of a supply chain so that the merchandise is produced and delivered in the right quantities, to the right locations, and at the right time, in order to minimize costs, while satisfying service level requirements. [1]

A supply chain is a system and, as consequence, it is more important than the sum of their constituting companies. As such, the creation of synergies among the supply chain partners increase its competitiveness. Collaboration is a way to create those synergies [9]. It permits supply chain partners to share information such as demand or inventory status. Moreover, it requires more than the passing of data between successive supply chain members. It requires joint planning of inventory and production strategies to accomplish the goal: achieve competitive advantage for the supply chain [2].

2.4 Lean Games

Games are usually considered mental and/or physical activities of diversion. However, in addition to various forms of entertainment, games are used in more serious environments as teaching or training of students and professionals [12].

Lewis and Maylor [12] described a simulation game as a set of activities in which people can play within the setting of simplified and concise model with pre-defined rules.

Games are a powerful tool in teaching because they provide the student with the opportunity to experience real-life situations [13] while avoiding the inconveniences of the real environment [14]. Besides, games also provide the opportunity for experimental and active learning, high motivation, strategic thinking and ability to learn through repeated failure and timely feedback [15] which presents better results in the understanding and acquisition of concepts in long-term memory [13]. In addition, games make the student to develop certain qualities as creativity in problems resolution and teamwork.

Games are frequently used to demonstrate Lean Manufacturing tools and their benefits. Several games have been developed with academic purposes as well as in order to implement the Lean philosophy in working environments. Besides, Lean Games are very popular because they enable the players to develop the reward of discussion, participation and decision-making which are building blocks of Lean Manufacturing implementation and very difficult to obtain through the traditional methods.

Lean Games differ on the concepts they aim at teaching. The survey performed focused in supply chain management games and production flow simulations that are the two types of games in which the ones developed are encompassed.

2.5 Production Flow Simulations

Production flow simulations are hands-on activities where participants operate workstations along an assembly line. These physical activities are very effective in showing how to transform a company because they use scenarios according to the Lean concepts to demonstrate. Two examples of manufacturing games are described above.

The "Plane Exercise" is a very simple yet effective simulation used to explain and illustrate lean concepts as push, pull, kanban, bottleneck, throughput time and more. It utilizes four participants in a four workstations assembly line to build paper airplanes. The participants are set in line with a pile of raw material (paper sheets) at the beginning, space for WIP between each workstation and a space for finished goods inventory at the end. The setup can be observed in Figure 2.3. Seven students are asked to time task, cycle and throughput times and to collect the WIP quantities. The tasks, which consist of folding paper, are assigned in such a way as to place the bottleneck at the third workstation. [16]

Raw Material (Paper)	Student Work Center 1	WIP	Student Work Center 2	WIP	Student Work Center 3	WIP	Student Work Center 4	Finished goods (Airplanes)

Figure 2.3: Initial line setup of plane exercise [16]

At the first run the participants work in a standard push approach, being encouraged to work at their own comfortable pace as long as inventory is available. At an opportune time, a coloured sheet is inserted in the assembly line in order to measure the throughput time. At the end of the run participants discuss the best way to improve the system. [16]

At the second run, the pull concept is introduced. A space between workstations is designated as an imaginary kanban box where three units (a batch) of WIP are placed (Figure 2.4). The workers only produce when there is a batch in their kanban in box and when their out box is empty. When this two conditions met, it is considered as a kanban signal that more production is needed. The participants work following the new rules and the measurements are done as in the first run. At the end of the run, the times and WIP obtained are compared to the ones of the previous run and new improvements are discussed. [16]

The final run, keeps following the pull approach but of one unit at a time. Kanban boxes hold one unit, showing even more performance improvement. At the end, the significant reduction of the times measured and WIP counted justify the improvement achieved. [16]

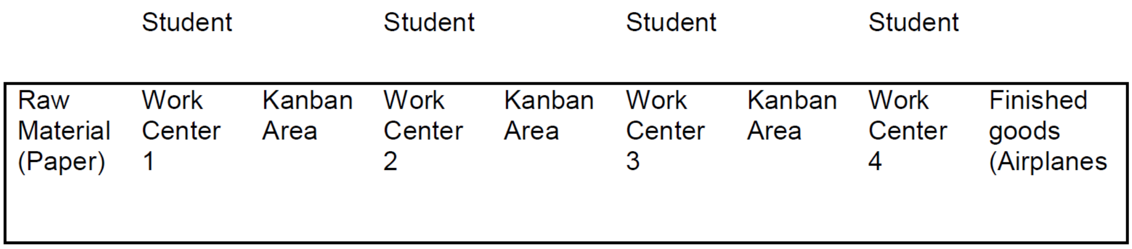


Figure 2.4: Final line setup of plane exercise [16]

Whitman et al. [6], describe the "Lego Airplane Factory" which is a manufacturing game that aim at teaching to the participants concepts considered to be an integral part of Lean Manufacturing as just-in-time, cellular manufacturing, pull systems of inventory control, teams, empowerment and standardization. It represents an aircraft manufacturer where participants assemble small airplanes from lego pieces. The goal of the game is to build as many airplanes as possible in a six-minute working day. The participants are distributed by the five workstations: four assembly workstations and one inspection workstation. The simulation consists of four different phases where new concepts are being introduced.

In phase one, participants are separated into five workstations that are spread across the room (functional layout) and airplanes are assembled in batches of five to simulate a traditional batch production flow. As participants deplete their raw material they should travel to the raw material warehouse. The quality control inspector analyses the airplanes when they are finished. [6]

At the end of phase one, the travel distance stands out as the major problem. So, in phase two the workstations are brought close together in a logical sequence and raw material brought to the workstations where it will be transformed. Inspector can now announce where problems occur to the participants. [6]

At phase three, the improvements implemented are batch reduction and the pull system. Batches are reduced from five to one and inventory is moved in a continuous flow. [6]

After the improvements implemented, the bottlenecks of the system stand out. In order to eliminate them, the teamwork concept is introduced and the line balanced. [6]

2.6 Supply Chain Management Games

Supply chain management games are the ones used to demonstrate the dynamics in a supply chain, in particular the bullwhip effect as well as its causes and consequences. Besides, they also allow participants to understand the whole supply chain and its processes and problems, as opposed to only understand the own company's ones and neglecting the consequences that the own company's behaviour has in the supply chain. They can be also used as an engineering tool to experiment changes to the real-world supply network. In this section is presented the most well-known example as well as its variants focused on forestry-based supply chains.

The most well known supply chain management game is the “Beer Game”. It is widely used to simulate common supply chain issues such as the bullwhip effect caused by misperceptions of feedback [17]. The "Beer Game" simulates a straight four stages (factory, distributor, wholesaler and retailer) supply chain that delivers beer to the customer. The customer demand is represented by a deck of cards that only retailer, the last stage, knows. In order to deliver to the customer the beer ordered, retailer orders from the wholesaler. Then, the wholesaler has to buy beer from the distributor who is supplied by the factory. The factory, by its way has to produce the beer to be available for selling. The aim of the game is to minimize costs and each stage has to order having in mind that backlog cost twice the inventory [18].

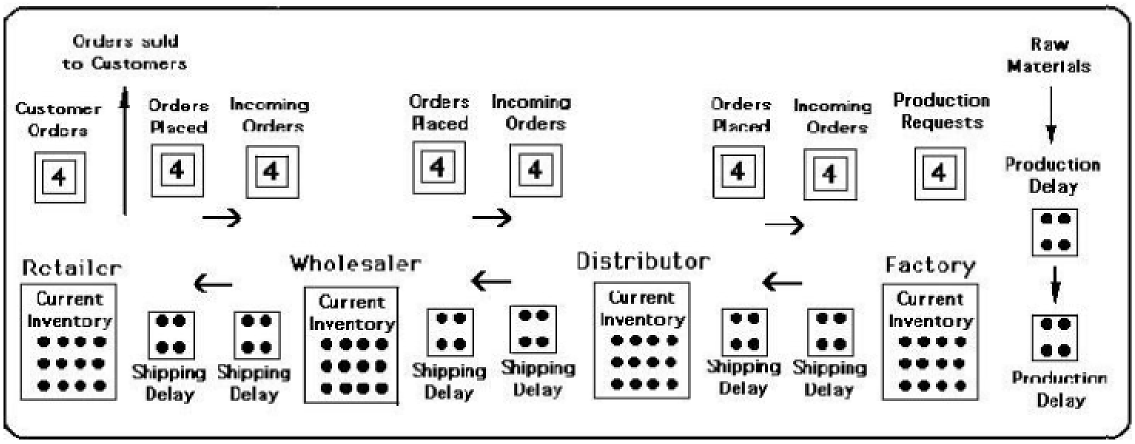


Figure 2.5: Initialization of the "Beer Game" board [18]

As already referred, the "Beer Game" is widely used to demonstrate supply chain dynamics. However, it does not have the desired impact in some supply chains. A realistic supply chain simulation has greater impact as its results and learning points are directly transferable into the practise, as the interaction of participants and their experience makes players more receptive to knowledge and as it allows participants to experience the system from a different position than they are used to [19].

The supply chain management concept in gaming was already applied to the wood industry in the "Wood Supply Games" [20]. As the target industry of the games developed in this dissertation has cork as raw material, these games were had in concern.

Forest industries have a large degree of diverging material flows where few raw materials create a greater variety of products [20]. In order to increase the relevance for the study of forestry dynamics, the "Wood Supply Games", which are based on the concept and structure of the "Beer Game", introduce divergent and convergent flows in the supply chain. The “Wood Supply Games” have two variants: the divergent and the integrated variant. Both variants have four stages and the forest as the source of raw materials. The first stage (wood supply group) is a divergence point where the flow diverges into two branches as pulpwood and sawlogs are distributed to a paper mill and a sawmill that are the second stages. Each mill supplies the respective wholesaler who supplies its retailer, creating two supply chains that distribute two different final products: paper and lumber. This variant of the game is called the divergent variant. Figure 2.6 presents the structure of the divergent variant of "Wood Supply Games" [20].

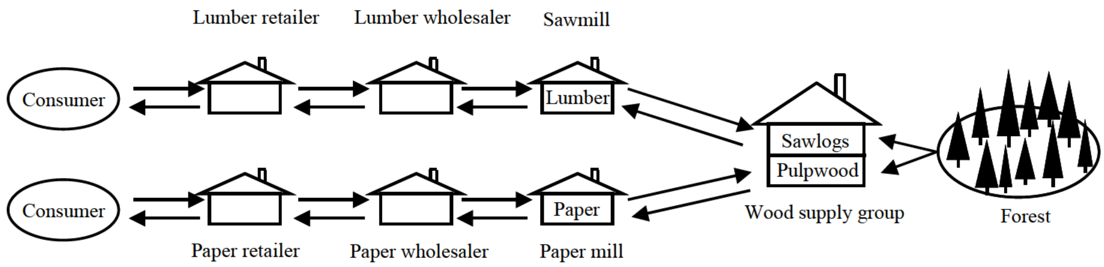


Figure 2.6: Structure of divergent variant of Wood Supply Games [20]

The second variant of the "Wood Supply Games" is referred to as the integrated variant (Figure 2.7). It has the same structure of the first variant, having a point of convergence at the second position where the chips that result of the lumber milling are delivered into the paper mill for paper production. This variant also introduces a second point of divergence with the production of by-products in the paper mill.

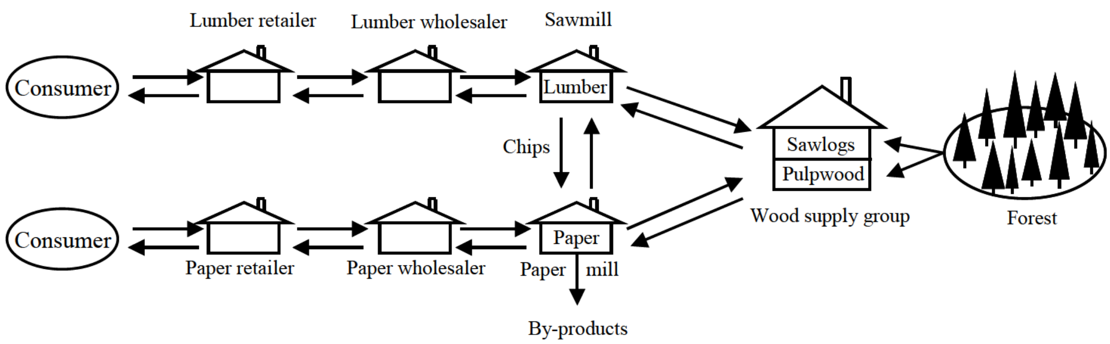


Figure 2.7: Structure of the integrated variant of Wood Supply Games [20]

The "Quebec Wood Supply Game" is an adaptation of the "Wood Supply Games" by the FOR@C Research Consortium. As the games previously characterized, the "Quebec Wood Supply Game" is used to teach supply chain dynamics in the forest sector and follows the same principles. The main difference between the two games adapted to the forestry supply chains is that in the "Quebec Wood Supply Game", the raw material for the pulp mill is supplied by the sawmill and not by the forest as in the "Wood Supply Games". Another great difference between these games is that, in the "Quebec Wood Supply Game" the forest has limited capacity and so, a maximum number of logs is available each turn. The structure of the "Quebec Wood Supply Game" is presented in Figure 2.8 [21].

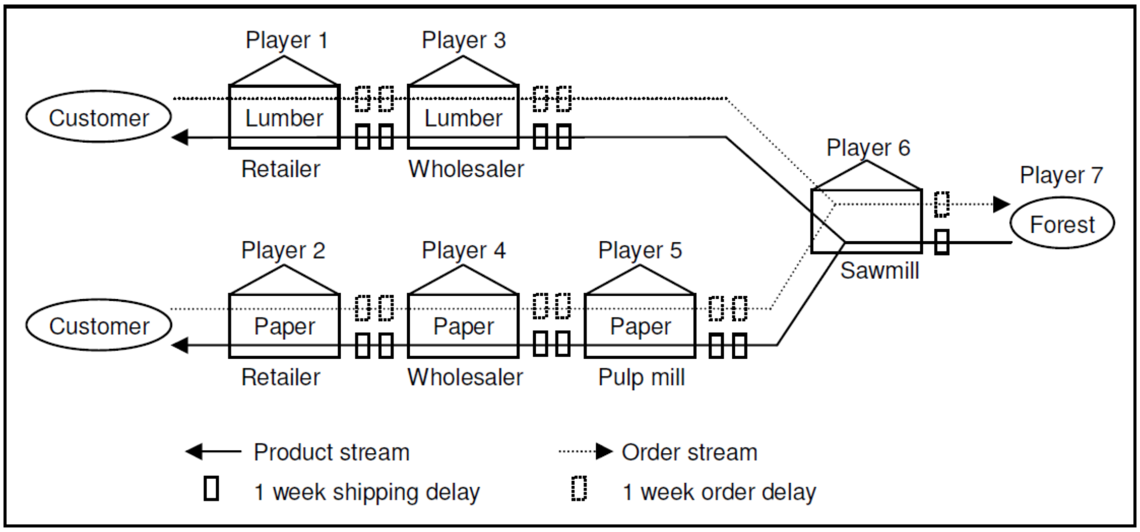


Figure 2.8: Structure of Quebec Wood Supply Games [21]

As told above, this games demonstrate the bullwhip effect. However, they only take into account one cause of the bullwhip effect: misperceptions of feedback [17]. Besides, the supply chains simulated are far from being realistic. Some unrealistic terms are the fact that they do not make any difference between distribution and production companies or that they assume that inventories have unlimited capacity. Moyaux et al., [22] made the "Quebec Wood Supply Game" more realistic using agents. They implemented the four causes of the bullwhip effect identified by Lee et al. [10] as well as added production and inventory capacity to the game. This led to a model too complex for teaching but effective to study supply chain dynamics.

Chapter 3

Case Study Description

The work developed in this dissertation had as target sector the industry of transformation of cork into stoppers. In this chapter the value chain of the target industry, their stages and the processes in each of them are characterized.

This chapter is divided in five sections. Firstly, the target supply chain is introduced by presenting its raw material, its final products and the stages in which it is divided. Then, each one of the four stages of the value chain are characterized in order to allow the understanding of the processes mentioned throughout this dissertation.

3.1 Introduction

Cork is the bark of the cork oak. It is an excellent thermal and acoustic insulator, it is fire retardant and highly resistant to abrasion. Besides, it has characteristics such as lightness, impermeability to liquids and gases, elasticity and compressibility which makes it to be used in a wide variety of areas such as alimentation, construction or even decoration [23].

Figure 3.1: Cork oak [23]

The main end of cork is the production of natural cork stoppers. However, several by-products result from the industrial process of this type of stoppers and are used in the industry of cork granulate. The industry of cork granulate produce other types of stoppers such as technical stoppers or champagne stoppers and products used in construction or decoration.

(a) Natural Stoppers (b) Technical Stoppers (c) Cork used in decoration

Figure 3.2: Some examples of cork derived products

The cork stoppers' value chain is divided in four main industries: the production, and then the preparation of cork, the manufacturing of stoppers and the distribution of them.

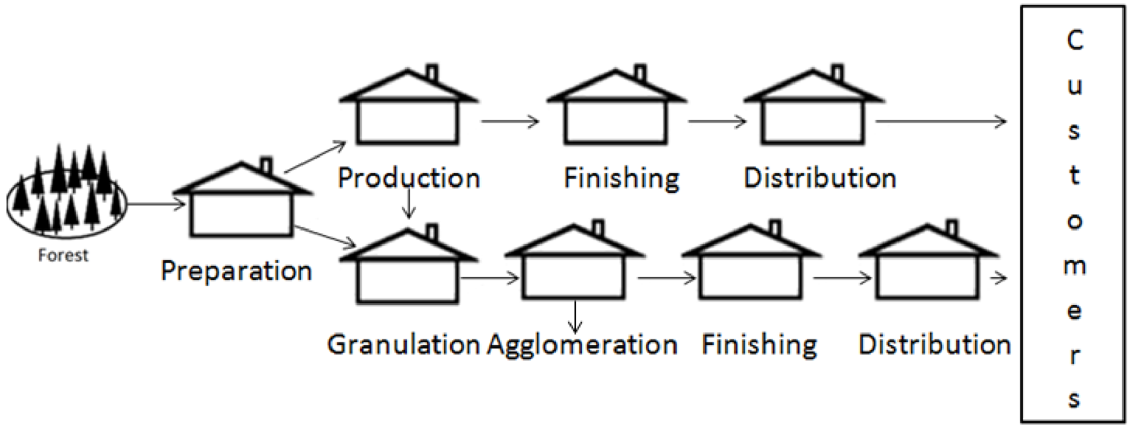


Figure 3.3: Overview of cork supply chain

3.2 Production of Cork

As told before, cork is the bark of cork oak. Cork oaks usually grow in Mediterranean regions, most particularly in the south of Portugal. The process of extracting the cork from the tree is as complex as can be noted from the description below.

3.2.1 Cork Harvesting

It takes 25 years for cork oak trunk to start to produce cork and be profitable. At this time, the first stripping, which is known as *desbóia*, takes place. The cork from this first stripping is called virgin cork and has not the required quality to manufacture stoppers. Thus, virgin cork is granulated and used for applications other than cork stoppers as, for example, construction [24].

The second harvest takes place nine years later. The cork produced is called secondary cork. It has a regular structure and is less hard than virgin cork. However, it is still not suitable for cork stoppers' manufacturing [24].

It is from the third harvest, about 45 years after the cork oak planting, that cork has the proper properties for the manufacturing of natural stoppers. This high quality cork is called *amadia* or reproduction cork and is supplied for about the next 15 bark strippings [24].

The stripping of the cork oak is a five steps manual process performed by skilled specialists in order not to harm the tree [24]:

1. **Opening**: a vertical cut is made with an axe in the deepest crack. At the same time, the axe is twisted in order to separate the outer from the inner bark.

2. **Separating**: the edge of the axe is inserted between the strip and the inner bark and then is twisted.

3. **Dividing**: a horizontal cut is made in order to define the cork plank size.

4. **Extracting**: the plank is removed from the tree with care so that it does not split.

5. **Removing**: the debarker gives a few taps with the axe to the fragments of cork that remain attached to the tree in order to remove any parasites.

(a) Opening (b) Separating (c) Extracting (d) Removing

Figure 3.4: Some steps of cork harvesting [24]

Finally, the tree is marked with the year in which the extraction took place so that to know when the next extraction will take place.

Concluded the cork harvesting, cork planks are stacked in piles on materials that do not contaminate them, and remain there for about six months in order to stabilise [24].

3.3 Preparation of Cork

After six months of stabilisation, cork is ready to the manufacturing process. At the first stage cork is prepared to be ready for the transformation into stoppers.

Boiling the planks

In order to clean the cork, to extract water-soluble substances, to increase thickness and thus reduce density and to improve flexibility and elasticity, cork planks are immersed in clean boiling water for at least one hour. This process is called boiling.

As a result of this process, the structure of cork becomes more regular and its volume increases by around 20 per cent. Besides the improving of the internal structure of cork, boiling also ensures that the microflora is significantly reduced [25].

Stabilisation

After the boiling, the process of stabilisation of cork planks takes place. This process lasts for about three weeks and serves to flatten the planks and allows them to rest. Cork reaches the necessary consistency and moisture content for the transformation of cork into stoppers [25]. Stabilised, the cork planks are selected and separated based on their thickness, porosity and appearance [26].

Figure 3.5: Stabilisation of cork planks

3.4 Cork Stoppers Manufacturing

The different types of stoppers vary on the characteristics of the cork used as well as on their manufacturing process which can be separated in natural and agglomerated cork stoppers manufacturing as described below.

3.4.1 Natural Cork Stoppers Manufacturing

The manufacturing process of natural stoppers uses the stabilised cork planks which were previously selected for the referred manufacturing process.

Slicing

After the stabilisation period, the cork planks are cut into strips a bit larger that the length of the cork stoppers to be produced [25].

Punching

This activity encompasses the process of perforating the strips of cork with a drill, obtaining cylindrical stoppers within the dimensional limits prescribed [25].

The debris and wastes from punching are used in the agglomerated products manufacturing, as it will be described below.

Figure 3.6: Slicing [25]

Figure 3.7: Punching [25]

Rectification

The punched stoppers are not within the final dimensions. In rectification, stoppers dimensions are corrected according to specified and the surface regularised [25].

Selection

In this operation the stoppers are separated into different grades according to their surface. During this stage, defective stoppers are also eliminated [25].

3.4.2 Agglomerated Cork Stoppers Manufacturing

Agglomerated cork stoppers are entirely made of granulated cork.

3.4.2.1 Granulation

The cork used in the production of the agglomerated cork stoppers comes from the by-product of high quality cork products and punching of natural cork stoppers [26]. These by-products are ground and transformed into granules measuring 3-7 mm [26]. After grinding, granules are cleaned and dried, giving them the required moisture content [27].

3.4.2.2 Agglomeration

The granules resulting from granulation are then agglomerated using food-grade polyurethane glue, and the bodies are either individually moulded or extruded, resulting in rods which are cut in the desired length [26].

Figure 3.8: Rolls of agglomerated cork

The stoppers are dried in order to ensure that the glue is dry. Agglomerated stoppers are also polished and corrected as the natural cork ones [26].

3.4.3 Finishing of Stoppers

Washing and Drying

After the manufacturing process, stoppers are washed using hydrogen peroxide or paracetic acid which cleans and disinfects them. Then, the moisture level is stabilised, thus maximising stopper performance as a seal and simultaneously reducing microbiological contamination [25].

Colmation

Stoppers may also be colmated (process of sealing the surface pores with a mixture of cork powder) to improve their presentation and helps to obtain a better seal [25].

Printing or Branding

This operation is carried out according to customers' specifications. It may be ink printed or heat branded [25].

Surface Treatment

Finally, stoppers are given a paraffin or silicon surface treatment to make them easier to insert and extract from the bottles [25].

3.5 Distribution of Cork Stoppers

Finished the production process, the stoppers are packaged in plastic bags filled with SO2 (sulphur dioxide) which is a gas that blocks microbiological proliferation. Then, the stoppers are transported to the distributors, which are usually located near the bottler, all over the world, or to the bottler himself.

As shown, due to the wide variety of products, processes and locations of the industries, the cork stoppers' supply chain is a complex one which means that its management is no easy task.

Chapter 4

Games Developed

In this chapter the solutions developed in the aim of this dissertation are presented. Firstly is presented the "Cork Supply Game". Its characterization begins by the presentation of the structure of the game. Then, the rules, the steps that each round goes through, the initialization of the board and the different scenarios that the game encompasses are presented. Finally is presented the End of the Game section. The other game developed is the Cork Stoppers Production Game. The topics addressed in the characterization of the game are The Learning Process, Process Description, Performance Indicators and the Rounds.

4.1 Cork Supply Game

The "Cork Supply Game" is a supply chain management game and so, was developed to demonstrate supply chain dynamics. It is also a tool that can be used to study the way the chain behaves in order to satisfy different demand patterns.

The Cork Supply Game is an adaptation of the games presented in chapter 2 to the cork stoppers supply chain. It follows the same designing model and thus demonstrates the bullwhip effect as a cause of misperceptions of feedback. The goal of the game is also kept the same: to minimize the total costs of the supply chain. The costs are related to inventory and backlog levels and participants seek to keep their inventory as low as possible, avoiding out-of-stock condition and satisfying their customer uncertain demand. The lag between the stages in the supply chain (due to shipments and orders delays) was kept the same too, as it has a crucial role in the dynamics and makes the goal more difficult to achieve.

In order to increase the relevance to the sector, the characteristics of the studied supply chain were taken into account in the designing of the game. The main aspect had in consideration was that, as in most of the forestry-based supply chains, raw material generates a wide variety of products: the raw material (cork) is sorted into two categories to further processing into four types of stoppers (final products). The divergency of flows was already introduced in gaming by Haartveit and Fjeld [20] in their "Wood Supply Games" where the material flow of the "Beer Game" was adapted to a divergent pattern. The Cork Supply Game uses diverging flows of materials as well.

The differences introduced in the game that make it more relevant to the study of the cork stoppers supply chain are the stages, which are representative of the ones by which the manufacturing process of cork stoppers goes through and the way and the volume in which materials flow between them. The orders placed by the customer were also had in consideration once that the quantities ordered are in the range of the ones found in real life.

4.1.1 General Structure of the Game

The Cork Supply Game is played on a board which portrays the stages that cork goes through since it is harvested in the forest until it is sold as stoppers to the customer.

The cork stoppers supply chain delivers a wide variety of products (stoppers) to the final customer. The final products (stoppers) vary in their transformation process, in the raw material used in it and in their dimensions.

As told above, the game simulates the cork stoppers supply chain using diverging flows resulting from branching. The simulated supply chain is composed by two branches that produce three types of natural cork stoppers (S1, S2 and S3) and agglomerated cork stoppers (S4). The first stage and the only one common to both branches is preparation. At this stage the flow diverges into two branches. The natural cork stoppers' branch is composed by three more stages: production, finishing and distribution; and the agglomerated cork stoppers' one has four more: granulation, agglomeration, finishing and distribution.

The three types of natural cork stoppers differ in their quality: premium (S1), super (S2) and normal (S3). Over the length of the game, in order to produce the final products referred, raw cork (RC) is first separated in *amadia* (C1) used in the production of natural stoppers and in lower quality cork (C2) which is the one used to produce S4.

Customer demand is predetermined and represented by a deck of cards. Each round, which simulates a week, stoppers are demanded from distributions (the final stages of the supply chain) which triggers the flows of the game. The orders flow in the upstream direction while deliveries flow in the downstream direction of the supply chain. However, due to the variety of products over the length of the supply chain, the material's flow is not straight. The flows of materials was defined according to some practical rules obtained from some of the major industries in Portugal. Next, the flows of the Cork Supply Game are detailed:

- **Preparation** – preparation is the first point of divergence. It receives orders from both branches: production orders C1 and granulation orders C2. In order to fulfil the orders, preparation orders raw cork from the forest. The raw cork is sorted: 40% is C1 and the rest is C2.

- **Production** – production is also a point of divergence. It orders and receives C1 from preparation and 75% of it result in debris and waste that is sold to granulation as C2. From the remaining 25%, 10% is transformed into S1 and S2 in equal proportions and 15% is transformed into S3.

- **Finishing of natural stoppers** – finishing orders and receives S1, S2 and S3 from production.
- **Distribution of natural stoppers** – distribution receives stoppers from finishing and ships it to the customer according to its demand.
- **Granulation** – granulation is a point of convergence. It orders and receives 2/3 of C2 from preparation and 1/3 from production.
- **Agglomeration** – agglomeration is the third point of divergence. It orders and receives C2 from granulation but only 1/3 of it is used to produce S4. The remaining C2, that in reality is used to produce other agglomerated products, is excluded from the supply chain.
- **Finishing of agglomerated stoppers** – finishing orders S4 from agglomeration.
- **Distribution of agglomerated stoppers** – distribution receives S4 from finishing and delivers them to the customer according to its demand.

Between the stages there are shipping delays (SD) and order delays (incoming orders - IO and orders placed - OP) that represent production and logistics time. Each delivery takes two week since it is shipped until it is delivered to the next stage. The same happens with the orders slips, since they take two weeks from the time they are placed until they are received at the previous stage. This lag time takes an important role in the dynamics of the game.

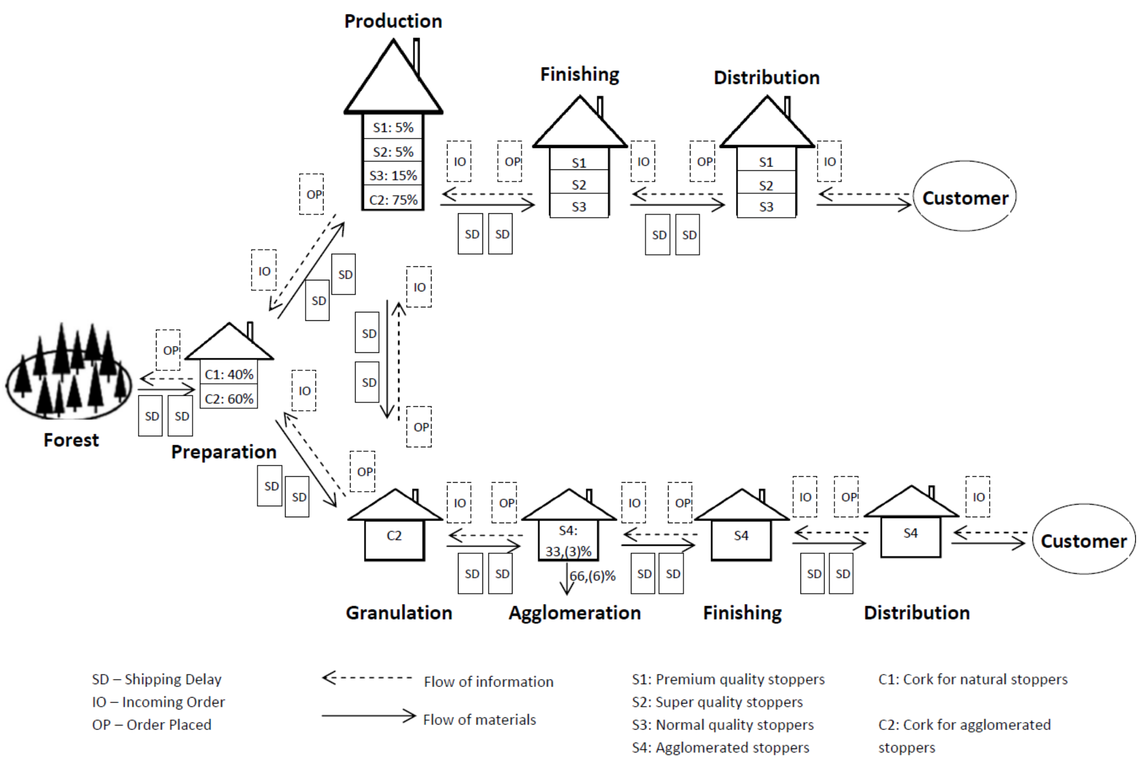


Figure 4.1: Structure of the Cork Supply Game

Batches of cork or stoppers are represented by chips which are physically manipulated by the participants as the game proceeds.

4.1.2 Rules of the Game

As told in chapter 2, a game must have rules. The Cork Supply Game was developed taking this into account and the following set of rules was defined:

- The first rule is that stages must not communicate between them. The only information they are allowed to exchange is the passing of orders and the receiving of goods. Therefore, the distributions are the only ones who know the customers' demand and should not reveal this information to anyone else.
- Secondly, all IO must be filled. If the inventory is not sufficient to fill IO plus backlog, participants should fill as many orders as they can and add the remaining orders to backlog.
- Thirdly, the object of the game is to minimize the total cost of the supply chain. Each Kg of stoppers hold in inventory cost €1 per week and the cost for having a backlog of unfilled orders is €2 per Kg per week. The total cost is calculated by the sum of the weekly costs of every stages.

4.1.3 Dynamics/Steps of the Game

The Cork Supply Game was conceded to be played by eight people, distributed by the eight stages of the simulated supply chain, responsible for managing their inventory. Every week, the mechanics of the game repeats as the participants carry out the following steps:

1. **Receive inventory**: participants move goods from SD 2 into current inventory; and **advance the shipping**: from SD 1 to SD 2. The incoming shipment shall be recorded.
2. **Look at the incoming orders and fulfil them from the inventory**: players look at the IO and record them. Then they calculate the goods to ship by adding the IO to the last week backlog and record it. Finally, they move the goods to ship out of their inventory into SD 1 of the player downstream.
3. **Record current inventory and backlog**: backlog is calculated by deducting the goods shipped to the goods to ship.
4. **Advance the orders**: participants move the orders slips in the OP to the IO of the player upstream. The Forest introduces the OP into the SD 1.
5. **Place orders**: participants take the decision on the orders they wish to place, they write them on the orders slips and place them in OP. Finally, participants record the orders they have placed.

4.1.4 Initialization of the Game

As previously told, the Cork Supply Game was conceded to show supply chain management problems. This is easier demonstrated if the system begins in equilibrium. In order to begin in equilibrium, the system is initialized with proportional levels of inventory, orders and shipments as shown in figure 4.2.

The initial inventory levels are of 30 000 stoppers for S1 and S2, of 90 000 for S3 and of 450 000 of S4. In preparation, the inventory level of C1 at the beginning is of 2 400 Kg. The initial levels of inventory of C2 are of 3 600 Kg in preparation, of 1 800 Kg in production and of 5 400 Kg in granulation.

The orders slips of S1 and S2, S3 and S4 are initialized with 10 000, 30 000 and 150 000 stoppers written on them, respectively. The C2 orders slips between preparation and granulation have written on them 1 200 Kg , the ones between production and granulation have 600 Kg and the ones with 1 800 Kg are placed between granulation and agglomeration. The order slip that represent the order placed by the preparation is of 2 t.The quantities initially placed in the shipping delays follow the same way of thinking as the orders slips.

4.1.5 Scenarios

Yan and Woo [28] outlined three demand patterns that can be modelled in order to study supply chain's behaviour. This demand patterns were experimented in gaming by Liu et al. [29] who used it in the "Beer Game".

In the development of the Cork Supply Game was asked to experiment different patterns of customer demand. In order to accomplish this requirement, three scenarios were developed that differ in the demand pattern:

Scenario A

This scenario follows a one step demand which is the most commonly used in the "Beer Game". This demand changes only once over the length of the simulation. The customer demand begins constant and equivalent for each one of the final products and then steps for the double. In figure 4.3 is presented the demand of S1 stoppers. The demand of each one of the final products are in Appendix C.1.

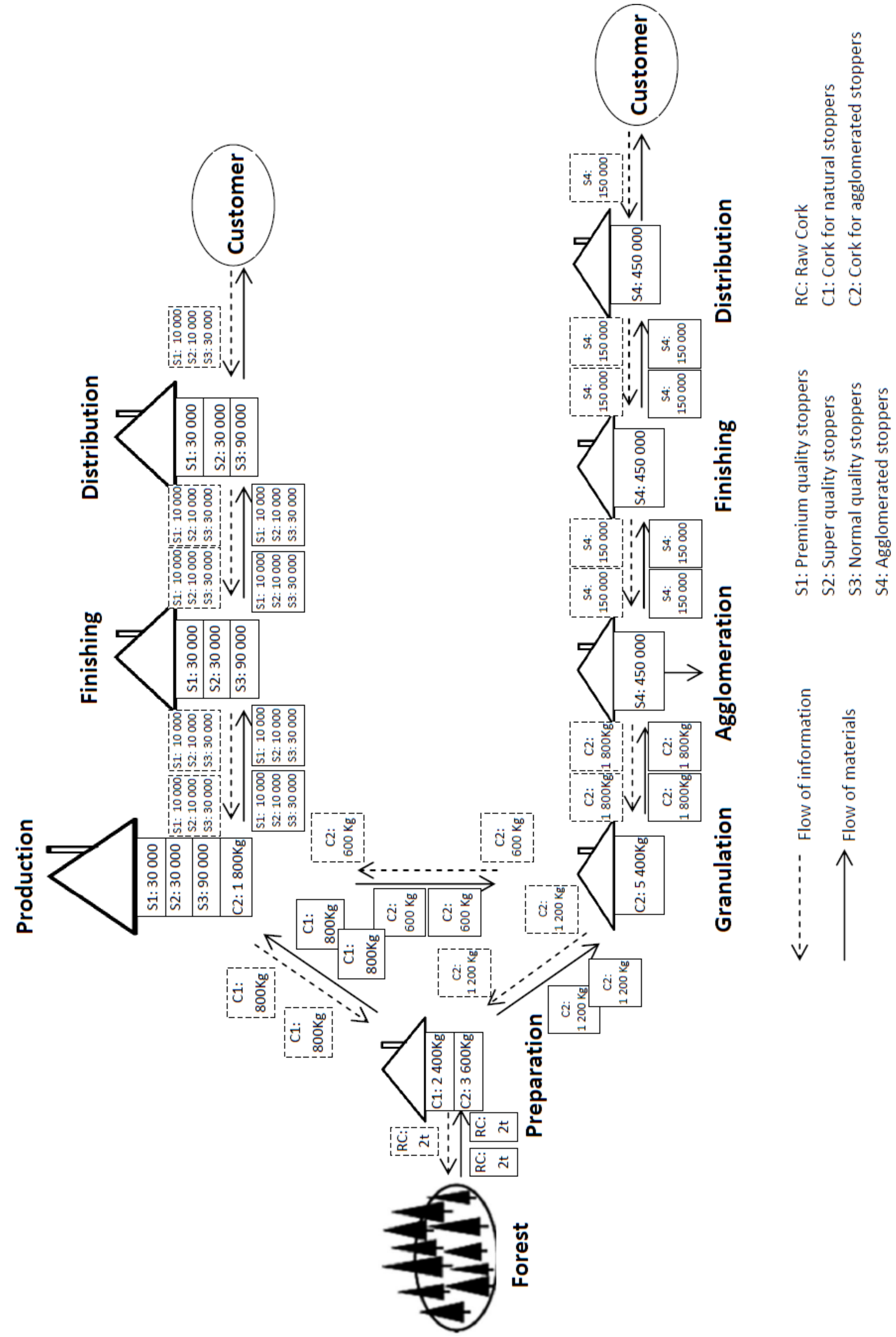


Figure 4.2: Initial state of the Cork Supply Game

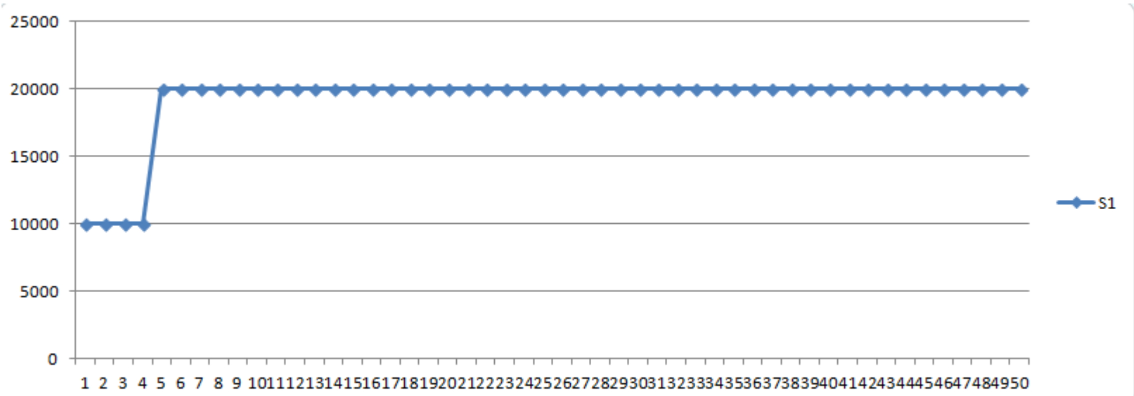


Figure 4.3: Orders for S1 in Scenario A

Scenario B

The scenario B follows a stationary demand which is a closer representation of cork stoppers market dynamics. This demand pattern keeps the mean demand constant over time. The distribution of the demand conforms to a normal distribution.

Yet the demand pattern is the same for every types of stoppers, the demands vary independently of each other. The mean and standard deviation used for the distribution of the demand of each type of stoppers was respectively: 20 000 and 5 000 for S1 and S2, 60 000 and 15 000 for S3 and 300 000 and 75 000 for S4. The demands used in each one of the types of stoppers can be observed in Appendix C.2. In the figure below is presented the demand for S1.

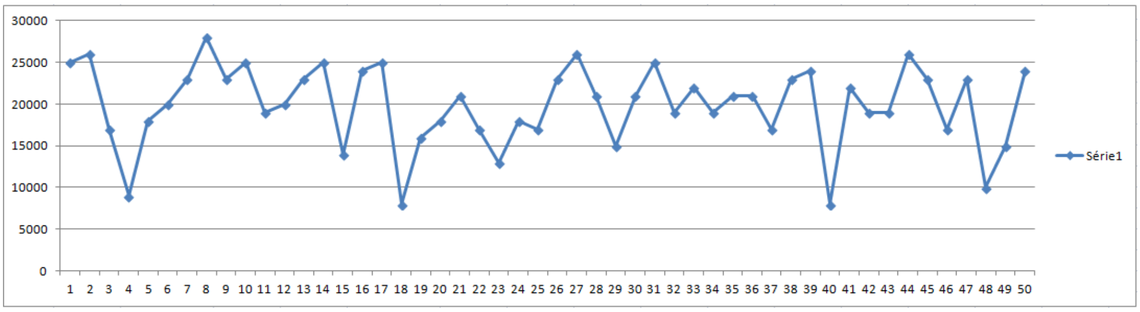


Figure 4.4: Orders for S1 in Scenario B

Scenario C

The scenario C follows the same demand pattern of the scenario B. However, this scenario gets even closer to the demand of cork stoppers because of the introduction of orders for stoppers of different dimensions. Besides the stationary demand of regular size stoppers, unexpectedly, stoppers of special size are ordered as represented by red dots in the figure 4.5. The demands for the four types of stoppers are in Appendix C.3.

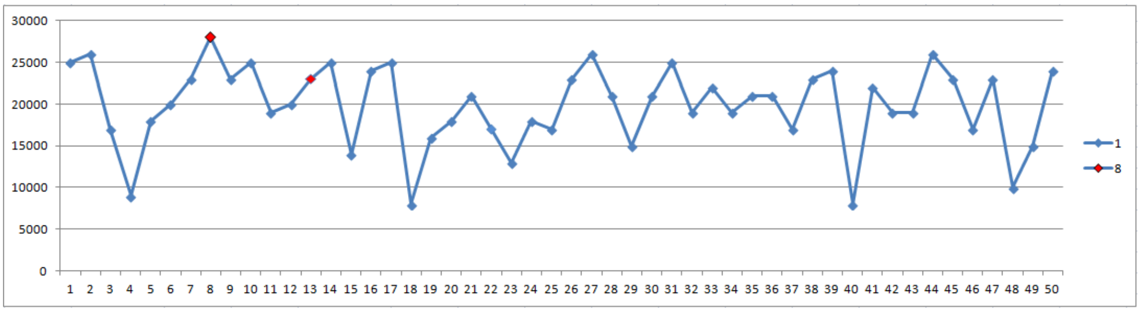


Figure 4.5: Orders for S1 in Scenario C

4.1.6 End of the Game

The game should be played for around 20 weeks, depending on the facilitator and the time available. At the end of the game, the total cost of the supply chain is calculated. The first step is to convert the inventory and backlog levels in stoppers to Kg. Once that 1 000 of stoppers weigh around 4 Kg, this was the relation used. Then, the weekly inventory and backlog levels of each one of the eight stages are summed and multiplied by €1 and €2 respectively. The sum of those costs equals to the total cost by stage. Finally, the total cost of the supply chain is calculated by summing the eight stages' total cost.

4.2 Cork Stoppers Production Game

The Cork Stoppers Production Game is a production flow simulation of the finishing industry of cork stoppers' manufacturing. The objective of the game is to demonstrate the improvements that the change of layout, the change of the production system (push vs. pull) and the reduction of batches have in the manufacturing process.

In the development of the game, the three industries involved in the manufacturing of cork stoppers were considered. They all were a possibility for simulation. The factor that made the difference in the choosing was the order fulfilment system used in them. The choice fell on the finishing stage because it is the only one that follows the Assembly-To-Order (ATO) philosophy.

4.2.1 The Learning Process

As told above, the game was developed in order to demonstrate the improvements that the implementation of Lean Manufacturing have in the performance of the finishing of cork stoppers production line. It is also very effective in the understanding of Lean concepts as *kanban*, bottleneck or throughput time because participants experience them.

The game is played in four rounds in which the improvements are being introduced. Each round follow the same learning cycle which is composed by the following steps:

1. **Implementation of improvement** rounds begin by rearranging the process and by the explanation of the rules.

2. **Simulation**: at this point the process is run.

3. **Results analysis**: when the order is fulfilled the simulation is halted. The performance indicators are measured and compared to the ones of the previous rounds.

4. **Discussion**: after the analysis of the results, the performance improvement is obvious. At first, a discussion is raised about the reasons why the changes made had such an impact in the performance of the process. Then, the players are asked about new improvements to implement.

This approach encourage participants to observe and experience the limitations of the process. It is easier then to identify and analyse its problems and to suggest solutions to correct them. It also allows participants to understand the impact that each Lean tool implemented have in the performance of the production line.

4.2.2 Process Description

As referred before, the cork stoppers' finishing industry follows an ATO policy of order fulfilment. When stoppers are ordered, the specifications as the branding mark and the quantity are detailed. At this time, the information necessary is available to start the finishing stage. The stoppers go through four steps: 1) washing and drying, 2) colmation (when needed), 3) printing or branding and 4) surface treatment.

The major concern had in the development of the simulation was that the Lean tools were explicit and easily understandable. So, the workstations used are just representative of the steps by which the stoppers go through and the activities performed in them do not correspond to the operations performed in the industry.

The game consists of four workstations plus transportation, each occupied by a player. The simulation begins with the announcement of the specificities of the stoppers (number and branding mark) to be finished. Hereupon the participants in the workstations do their tasks as described below:

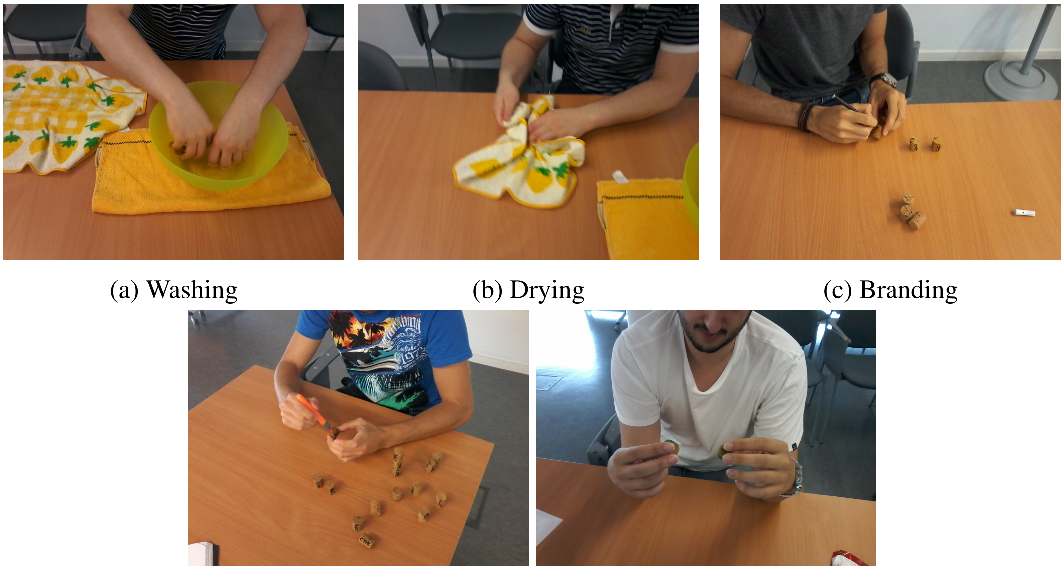
- **Washing and drying** – the stoppers are washed in a recipient full of water and dried with a towel.

- **Branding** – at this station, the participant writes the name of the company on the stoppers.

- **Surface treatment** – in order to simulate the surface treatment of stoppers, the participant paints the external area of the stoppers with a marker.

- **Counting, packaging and inspection** – the participant responsible for this station has three jobs. First he inspects the stoppers. If they are as required, he counts them and puts them in the bag. When the number of stoppers ordered is reached he informs that the order is fulfilled and the simulation stops.

- **Transportation** – the participant to whom this station is assigned is responsible for the transport of materials (from the warehouse to the line and between workstations).



(a) Washing (b) Drying (c) Branding

(d) Surface Treatment (e) Inspection

Figure 4.6: Tasks performed during simulation

The activities performed in the workstations were assigned in a way that the bottleneck of the system was placed at the third station (surface treatment).

4.2.3 Performance Indicators

The goal of the game is to demonstrate the benefits of the improvement implemented. This is much more effective if it presents numerical results that can be used as comparison between rounds. Thus, in order to evaluate and compare the performance of the rounds, the following performance indicators were selected:

- **Throughput time** – The throughput time is the time required to produce a single batch of stoppers. It is measured by marking a batch and measuring the time from when it is taken out of the raw material, to the time it is bagged. During the length of the production line, the First-In-First-Out principle must be assured.

- **Total time** – It is the time required to produce the number of stoppers ordered. It is measured with a stopwatch started at the beginning of the simulation and stopped at the end.

- **Cycle time** – This is the average time needed to produce a single batch of stoppers. It is calculated by measuring the difference between the times of the completion of the first and the twenty-first unit and dividing it by the number of batches produced (twenty). In figure 4.7 is presented the form used in the calculation of the cycle time.

- **WIP units** – It is the number of stoppers that, at the end of the round, started being manufactured but are not finished yet.
- **Number of defective products** – It is the number of finished stoppers that the participant on the final station considered as defective.

	Time (s):			
	Round 1	Round 2	Round 3	Round 4
Time at completion of 21st unit				
Time at completion of 1st unit	-	-	-	-
Difference	=	=	=	=
Cycle Time	/20=	/20=	/20=	/20=

Figure 4.7: Form for cycle time calculation

The performance indicators described above are recorded in the table presented in figure 4.8.

Round	Throughput time	Total time	Cycle Time	WIP units	Defective products
Round 1					
Round 2					
Round 3					
Round 4					

Figure 4.8: Table for the recording of the performance indicators

4.2.4 Rounds

The game has four rounds as it was already mentioned. The first one is the representation of the current state of the industry of cork stoppers' finishing where the low performance is clear. As the rounds progress, the Lean tools are introduced and performance evaluated.

Round 1

Round 1 is the round in which the performance is the lowest. It was designed in order to represent in a clear way the operational problems in the current state of the industry studied.

One of the problems detected in the cork industry in general and in the finishing industry in particular is the layout used: the functional layout. In order to simulate the travel distances associated to it, the workstations are spread across the room. The raw material warehouse is also separated from the workstations. The participant responsible for the transport of materials is called by the other participants when they have a batch that need to be transported to the next station. A possible layout to use can be observed in the figure 4.9.

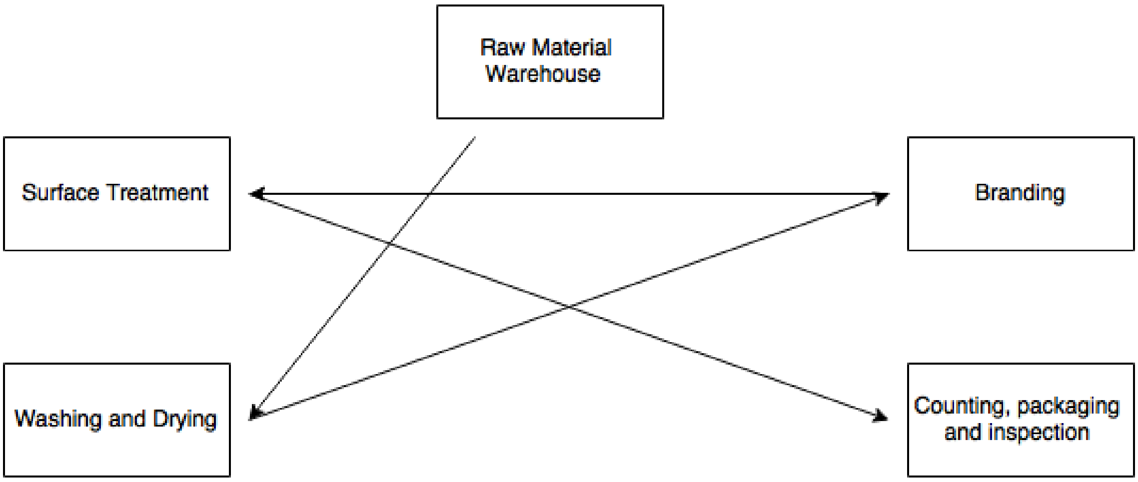
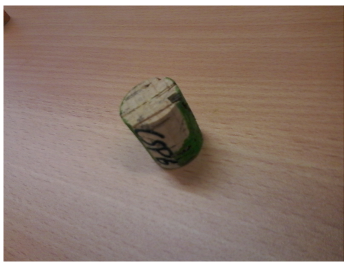


Figure 4.9: Example of layout to use in round 1.

Other problem found was the production flow. The cork stoppers industry works in a traditional batch production flow. Thus, in this first round the participants work in a push approach. The players are instructed to produce stoppers in batches of three at their own pace as long as inventory is available. They make inventory as fast as they want and push it to the next workstation.

The quality inspector is represented by the participant assigned to the last station. He examines the stoppers when they reach his station and separate the good ones from the defective ones. In this round the inspector is not allowed to tell to the other stations where the defects occurred. In the figure 4.10 are presented examples of an acceptable and a defective stoppers.

(a) Example of a stopper without defect.



(b) Example of a defective stopper

Figure 4.10: Examples of a good and a defective stopper

Round 2

The most obvious waste is the distance travelled by the participant responsible for transportation. Thus, in this round the functional cells are brought close together in one single cell where all the operations of the process are performed. The workstations in the new cell are arranged in a logical sequence that facilitates the flow of WIP which is now passed through the operators in the stations. The raw material is brought to the beginning of the production line. Transportation is not necessary now.

The quality inspector has new instructions too. He can now announce the defect to the workstation responsible for it and, if possible, let it be corrected.

Round 3

Even with the workstations arranged as described in round 2, the WIP levels between them is still far from the desired. In order to reduce it, the main improvement of this round is the production using the pull system approach. *Kanban* areas are settled between workstations, where inventory is held. A batch is placed in each *kanban* area. An empty out box simulates a *kanban* signal that more production is needed. When the worker detects a *kanban* signal, he checks if the in box has a batch ready to be processed. Being these two conditions met, the worker produces a batch and puts it in the out box.

In this round the workers are told to also work as quality control inspector. They are instructed to announce when they find a defect in a stopper instead of continue the processing of that stopper.

Round 4

In the final round, the improvement is already evident. However it is yet possible to enhance the performance of the process. In this round the batches are reduced from three to one.

Chapter 5

Validation of the Games

In this chapter is presented the way both games were validated. It is divided in two sections where each one refers to a game developed. The first section begins by describing the workshops in which the Cork Supply Game was validated and then the experimental results are presented and analysed. The Cork Stoppers Production Game's section characterizes the workshop as well as the results obtained.

5.1 Cork Supply Game

The validation of the Cork Supply Game was accomplished by experimenting the game. It was played in three workshops in which one of the three scenarios was run. In this section the workshops are described and then the results taken from them are presented and analysed.

5.1.1 Workshop

As told, the validation of the game was carried out in three workshops. Each one of the workshops used eight participants that were distributed by the eight positions of the game.

In order to ensure that everything went as planned and that the facilitator kept the experimentations in track, a facilitator's guide was produced where the tasks to perform before, during and after the game were described (appendix A). Moreover, a general instructions' sheet for participants, containing indispensable information as the goal, the overview, the rules and the steps of the game, was also produced. Besides, specific instructions sheets explaining the flow of materials in stations where transformation of them occur (preparation, production and agglomeration) and in granulation, where goods are ordered from two stations, were done too, in order to make the game easier to play and consequently avoid time losses and mistakes doing the maths of conversions of materials (appendix B).

Before the game, the board was initialized as described in chapter 4. In figure 5.1 can be seen the initialized board. In figure 5.2 is shown an example of an order slip used. Facilitator also placed the respective instructions sheets at each position.

Figure 5.1: Initialized board in the experimentation of the game

ORDERS:

S1: 10 000 stoppers

S2: 10 000 stoppers

S3: 30 000 stoppers

Figure 5.2: Example of an order slip used in the experimentation of the game.

The workshops were begun providing an overview of the game to the participants. It was explained that the board of the game portrays the cork stoppers supply chain and that each stage has to order goods from the upstream stage and deliver them to the downstream one. The stages that receive orders or goods from more than one stage were had in special concern and their flows were explained individually. Then, the products that each position manage were told as well as the chips by which they are represented. Once more, the positions that manage more than one product were had in special attention, specially the ones that receive and order different products, where the conversions from one type of cork to other types of cork or to stoppers is made (preparation, production and agglomeration). At this time the goal of the game was stated and the way that costs are computed explained. This was the time that the other two rules were also stated. Finally the links to the excel files containing the tables (figure 5.3) where the data would be recorded were distributed and the steps of the game were explained and exemplified. The tables were produced in such way that the participants just had to record the 'Incoming Shipments', the 'Incoming Orders', the 'Goods Shipped' and the 'Orders Placed'. The backlog and the inventory were calculated automatically what made the third step to be skipped.

Round	Incoming shipment	Incoming order	Last round backlog	Goods to ship	Goods shipped	Backlog	Inventory	Order placed
1							30000	
2								
3								
4								
5								

Figure 5.3: Example of one table used to record data during the Cork Supply Chain workshop. In this case the first five rows of the table used by Finishing of Natural Stoppers to record the data related to S1.

Hereupon, everything was ready to start the game. It started slowly in order to make sure that participants have the mechanics of the steps down. As long as the weeks advanced, the rhythm was increasing. Due to the time spent in the first weeks and in the resolution of some mistakes in conversions and as the objectives of the game were already met, the game were halted at the end of the week 20 in the three workshops what took for about three hours for each one of them.

Figure 5.4: Workshop of scenario A.

At the end of the game, the costs by stage were already calculated as well as the total cost for the supply chain. The inventory levels and the orders placed by each stage were plotted as well as their costs. The data collected is presented and analysed in the next sections.

5.1.2 Results Analysis

As already told, data was recorded while playing the games in the workshops, and thus, the decisions were taken by the participants in a free will. Each scenario was played just once and the data recorded is now presented and discussed.

The results are available at appendix D, separated according to the scenario in which they were obtained. For each scenario are presented the inventory levels, the orders placed and the costs. The costs presented are the total costs obtained by stage. Inventory levels of each stage were plotted showing backlog as negative inventory. The orders placed by each stage were also plotted.

However, the results available are not comparable once that the stages in the game have different volumes in flow. The stages where the volume in flow is the lowest are the last two of the natural stoppers branch (finishing and distribution). Then, the same stages of the other branch plus agglomeration have in flow three times the volume in flow there, followed by production which has quadruple volume in flow. The stages where the volumes in flow are highest are granulation (nine times higher) and preparation (ten times higher). In order to make the results obtained comparable, they were made equivalent by adjusting them for the lowest volume in flow (finishing and distribution of natural stoppers). The adjustment made for the volumes in flow in agglomeration's orders was slightly different from the one made in costs and inventory since in this station two thirds of the quantity ordered is not transformed and thus, it place orders nine times larger than finishing and distribution of natural stoppers. Hereupon, inventory levels and orders placed were converted to the same unity of measurement (Kg). Adjusted costs, inventory levels and orders placed were plotted by scenario and are presented during this chapter.

In figures presented in appendixes D.1.2, D.2.2 and D.3.3 and in figures 5.5, 5.6 and 5.7 can be seen, in a general way, that at the beginning the orders placed were of low quantities. Then, the last stages of the chain (distributions) felt the need to place higher orders. This event triggered the bullwhip effect as the quantity ordered increased with every stage in the supply chain. The orders placed by the stations closer to the customer tended to be quite constant while, as going upstream in the supply chain, the orders became more variable and unpredictable.

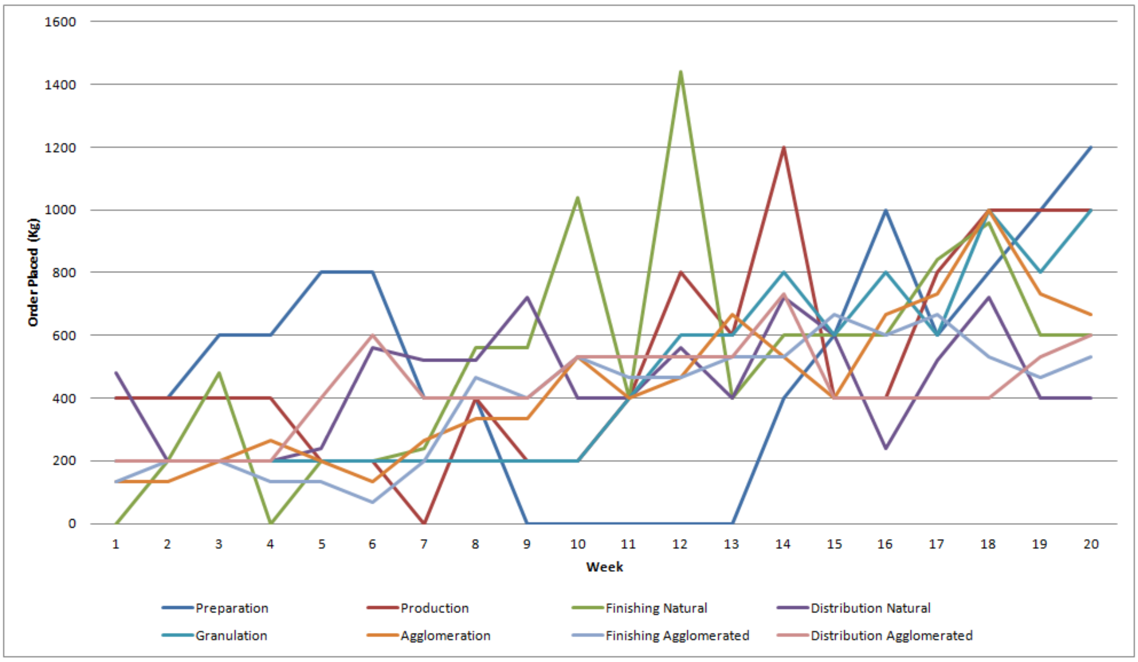


Figure 5.5: Total orders placed in scenario A

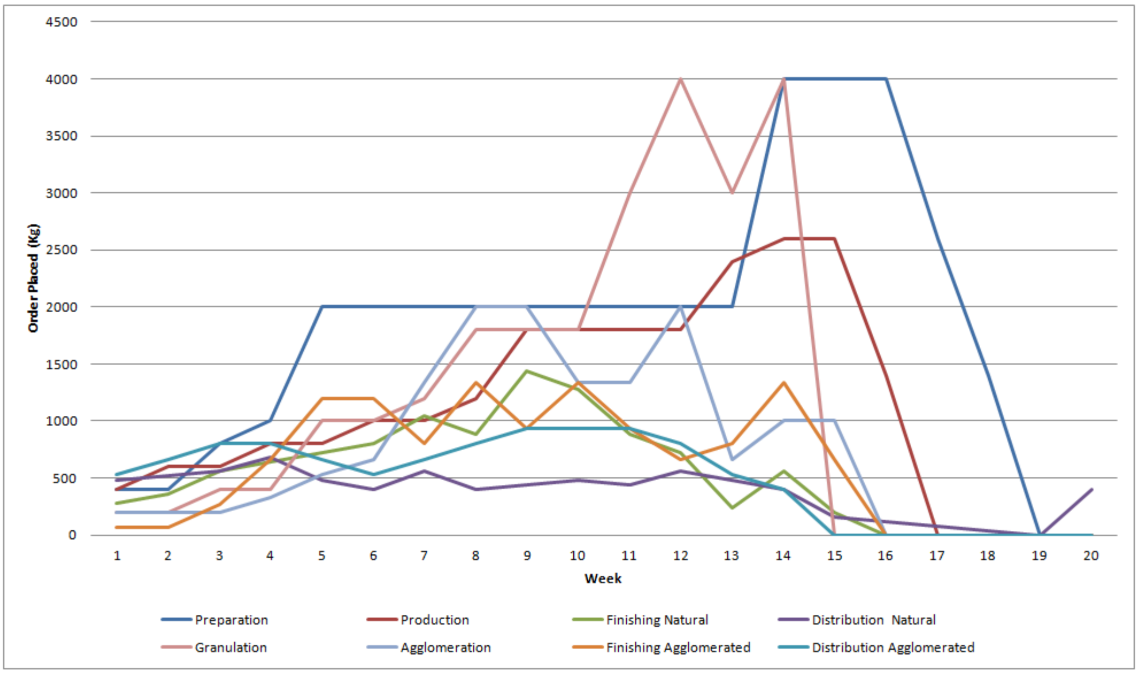


Figure 5.6: Total orders placed in scenario B

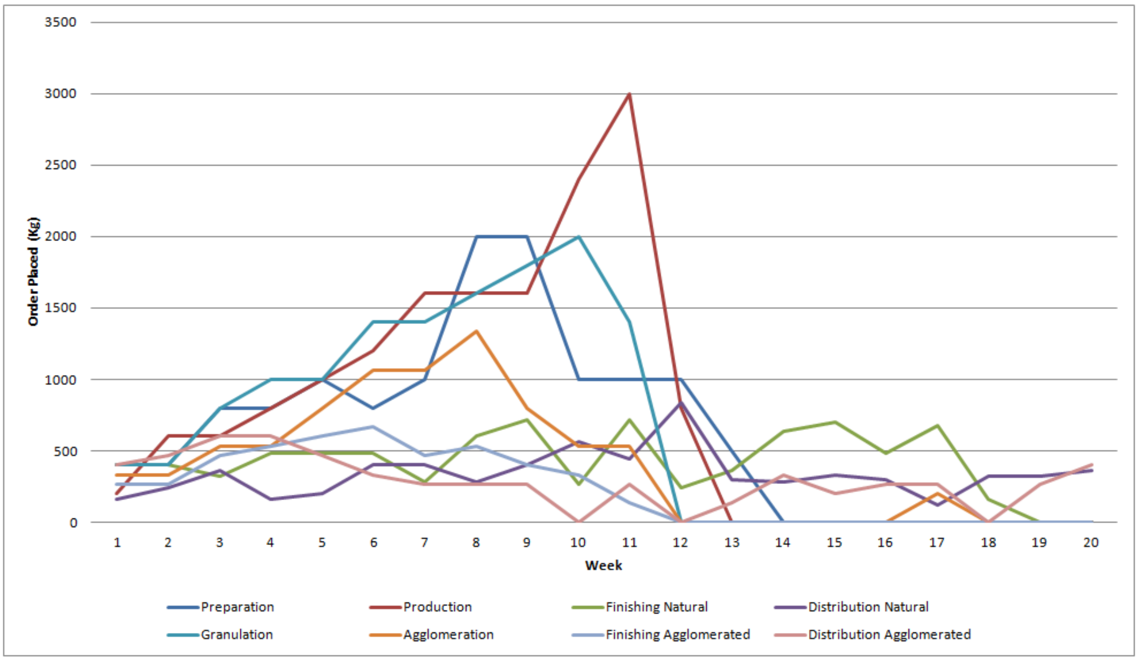


Figure 5.7: Total orders placed in scenario C

This effect is also noted in figures 5.8, 5.9 and 5.10 where can be seen the variance of the orders placed by each stage during the experimentations of the three scenarios A, B and C, respectively.

Observing them can be noted that the variance of the orders tend to increase from the last positions (distributions) to the most upstream one (preparation).

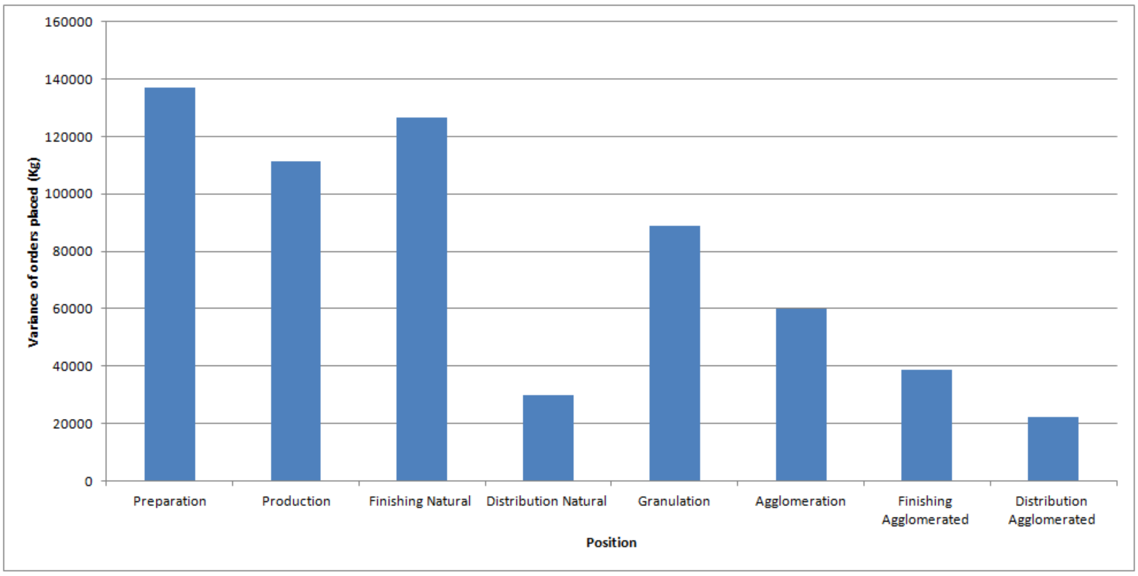


Figure 5.8: Variance of orders placed in scenario A

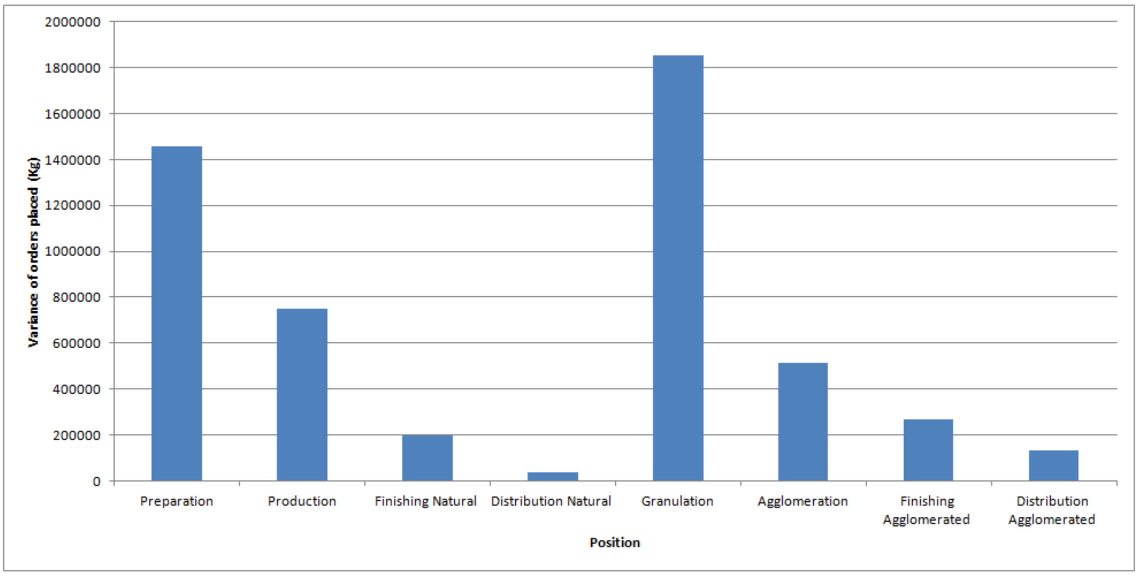


Figure 5.9: Variance of orders placed in scenario B

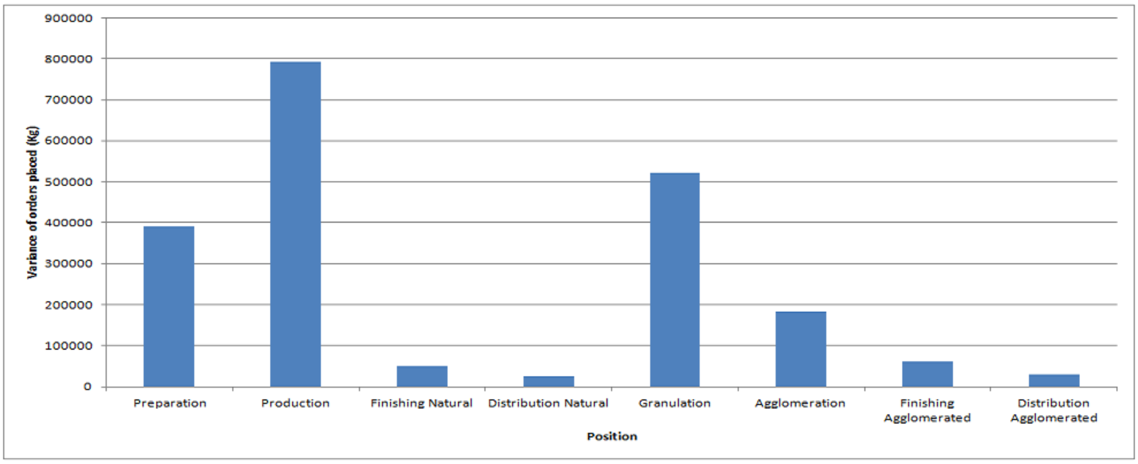


Figure 5.10: Variance of orders placed in scenario C

In chapter 2, higher inventory levels and lower customer service levels, which are measured in the game by inventories shortages, were presented as consequences of demand fluctuations.

The increase of orders placed plus the delivery delays, which makes that goods take quite some time to move through the supply chain to the customer, forced stages to deplete their inventories and then their backlogs grew. Having backlog, companies could not fulfil the incoming orders which is considered as low customer service level. As backlog was growing, participants were ordering even larger quantities in order to counteract it. As forest was not limited, when goods arrived, they did it in large scale what flooded the supply chain with goods. Scenario B was the one in which this phenomenon was more evident (figure 5.12). In scenario C (figure 5.13) this happened too, although on a smaller scale. In turn, in scenario A (figure 5.11), when the game was halted, most of the stages were having backlog. However, orders were still being a lot higher than in the beginning. It is assumed that the game was halted too soon and it is expected that, if the game had proceeded, the inventories would increase in following weeks.

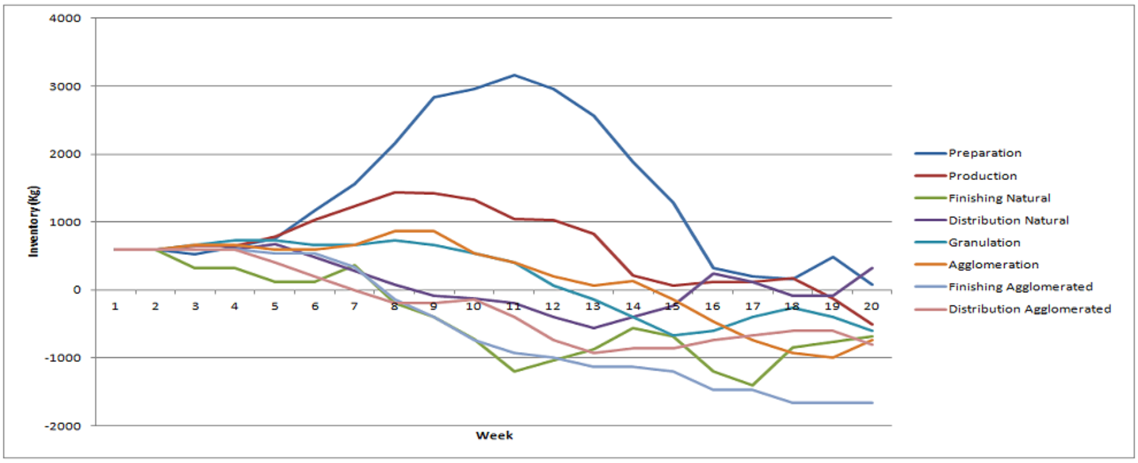


Figure 5.11: Inventory levels in scenario A

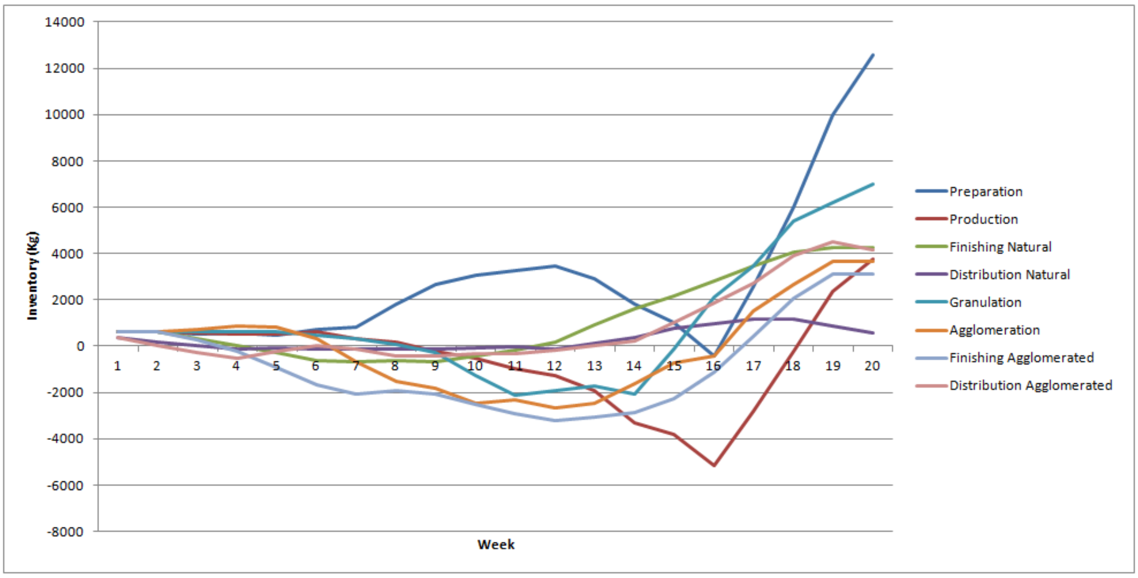


Figure 5.12: Inventory levels in scenario B

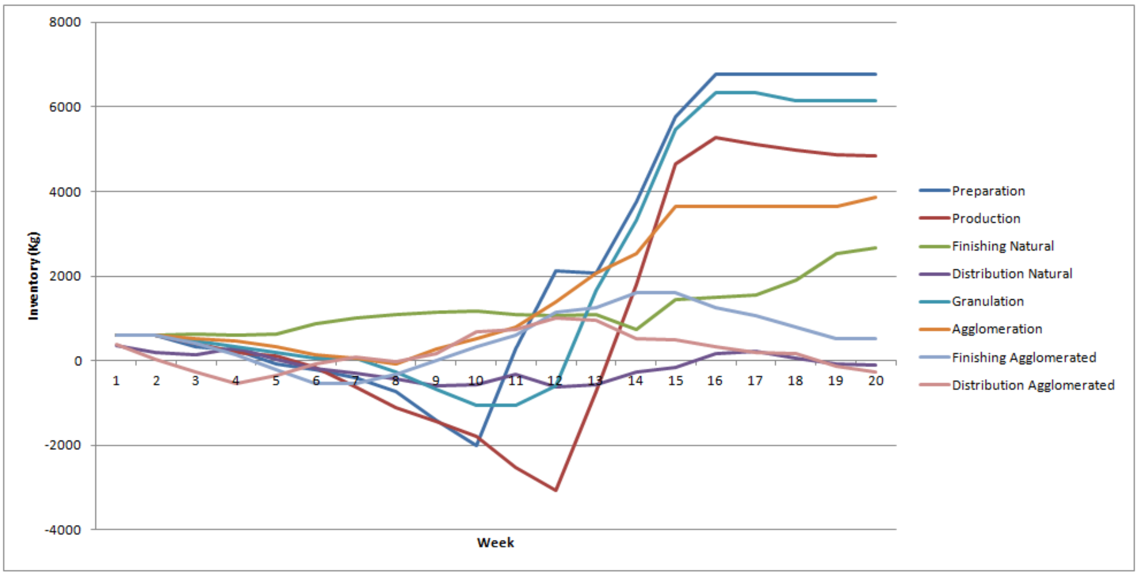


Figure 5.13: Inventory levels in scenario C

On the other hand, it was observed in scenario A and B that preparation decided to order large quantities during the game (figures D.10 and D.28), keeping high inventory levels. This strategy allowed preparation to have small orders in backlog and to counteract in few weeks when that happened (figures D.1 and D.19). Thus, in these scenarios, preparation was able to fulfil most of its incoming orders when they arrived at the expense of having high inventory levels.

The performance of the supply chain is measured by its costs. The costs of the supply chain, in the game, are composed by two parameters: inventory and backlog levels. Thus, it can be said that the performance of the supply chain depends on those levels. As high inventory and backlog levels are consequences of demand variation, it also can be said that demand variation creates higher costs and thus, lower performance.

The three scenarios of this game vary in their demand pattern. Scenario A has the most constant one, scenario B lesser and scenario C the least constant. Hereupon, it was expectable a relation between demand variation and performance ans thus, scenario A would be the one having lower costs and scenario C the one with the highest. However, the performance of the chain was also dependent of the managing skills of the participants. As expected, the results showed that scenario A was the one that had the lowest costs (€673120). Yet, scenario B had higher costs (€1773244) than scenario C (€1552312). Even having this unexpected results, it is noted that scenario B and C had much higher costs when comparing to scenario A. Besides the managing skills of participants, other possible reason for the lower costs in scenario C than in scenario B is the fact that, when customers ordered special stoppers of one type, regular stoppers of that same type were not ordered. Those weeks had, then, a pause in regular stoppers orders which allowed stations to balance their inventory levels. This phenomenon can be well observed in figure D.41, at the eleventh week, when distribution of natural stoppers received an order for special S3 and its backlog orders of regular S3 was reduced by half. Even having this discrepancy between the expected and the obtained results, can be said that the more variable the demand is, the lower the performance of the supply chain.

The performance of the different stations in a supply chain was also identified as an important point of study. It was already demonstrated that the variability of demand increase as going upstream in the supply chain. Moreover, it was also demonstrated that the performance of the chain and the demand variation are related. Thus, it is expectable that as going upstream in the supply chain, the performance decrease (costs increase). The experimental results (figures 5.14, 5.15 and 5.16) were not so linear as the theory, however it is noted a tendency of the stages placed more upstream in the chain to have higher costs than the ones placed closer to the customer.

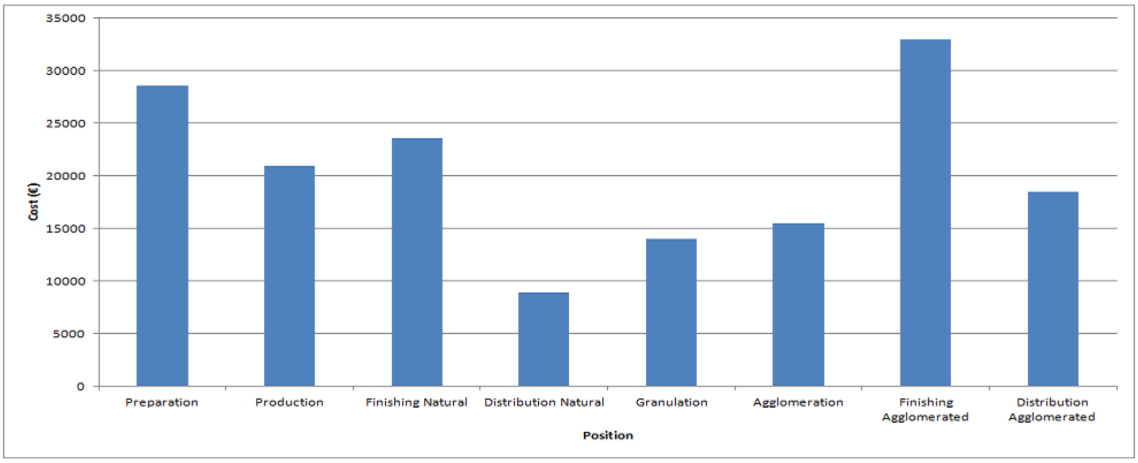


Figure 5.14: Total costs in scenario A

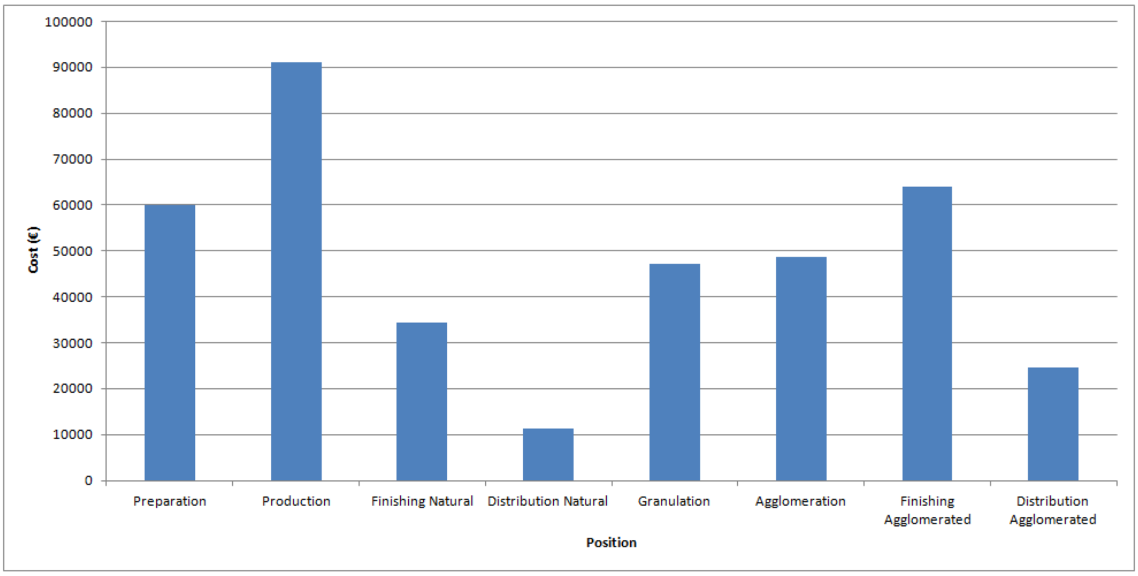


Figure 5.15: Total costs in scenario B

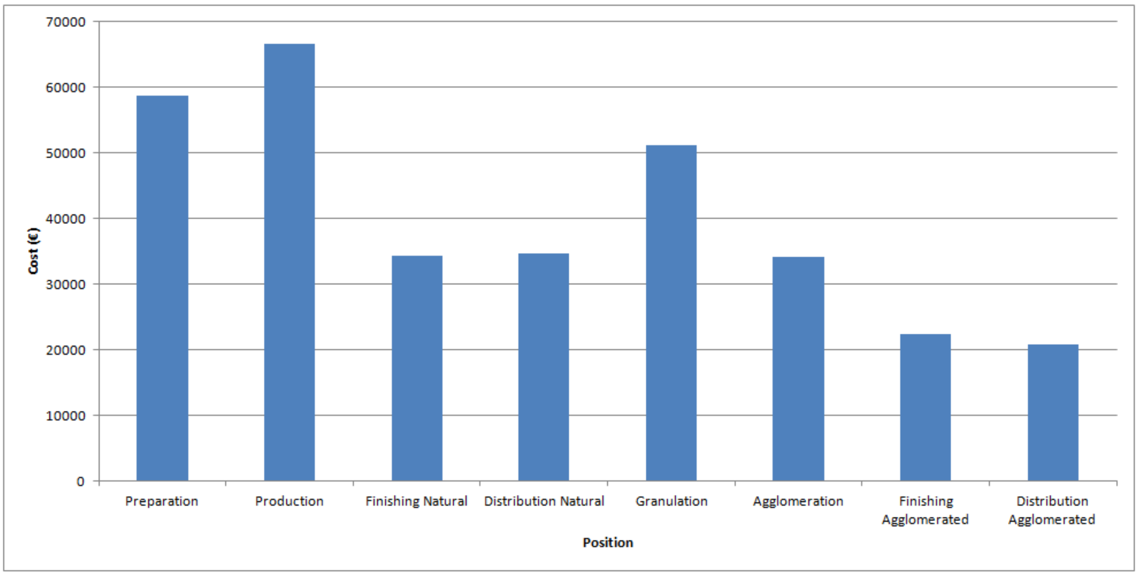


Figure 5.16: Total costs in scenario C

Moreover, Haartveit and Fjeld, in [20], stated that increasing the constrains in the divergence point of the "Wood Supply Games"' supply chain, costs will magnify for the first position as it is forced to order goods for both branches even when inventories are sufficient to satisfy the demand from one of the branches. This explains the high costs of preparation and production in Cork Supply Game as these are the points of divergence, where the restrictions are applied. It also justify the difference in production's costs from scenario A to scenario B and C, once that while in the first the customer orders are in equilibrium for both branches, in scenarios B and C that does not happen an thus, discrepancies in orders from both branches are even more likely. This makes that those stations have to choose from meeting orders from one branch and accept inventory's costs for the other branch's goods, or accept backlog's costs from the goods of one branch and decrease the inventory of the other branch's goods. Whatever the choice, the performance of the stage will decrease and consequently the entire supply chain will have lower performance as well.

It was referred in chapter 4 that scenario C simulates that customer orders stoppers of special dimensions, referred in the game as special orders. The special orders have to be made to order (Make-To-Order) and thus, the orders go from distributions to production and agglomeration, where the stoppers are made, and then the stoppers go downstream in the supply chain.

The time that the supply chain need to fulfil the order is an important aspect as it is the way to measure the satisfaction of the client. The faster the client get what he ordered, the more satisfied he is. This time is dependent of the time delays between the stages and thus, does not reflect reality. It is also dependent of the orders that the stages where cork is transformed into stoppers have in backlog and of the incoming shipment in those stations in the week in that they receive the special order.

The inventory levels of special S1, S2, S3 and S4 stoppers are presented in D.3.2. In figures D.48 and D.49, where the inventory levels of special S3 and S4 stoppers are presented can be seen that, if production and agglomeration have conditions to produce the stoppers when asked, the supply chain takes eight weeks to fulfil a special order. This is the time that, due to the delays between stations, the orders take to go through the three stages and goods take to do the reverse path. However, if the conditions to produce the special stoppers are not met, the time needed to fulfil the order increases according to the time took by production or agglomeration to have conditions to produce the stoppers. In figures D.46 and D.47 are presented the inventory levels of special S1 and S2. In those figures is noted that production took one week to fulfil the orders in backlog and to produce and ship the special ones. Due to this delay, these orders took one more week (nine) to be fulfilled. In the case of S2, the week took by production made the second special order, which had been placed with one week delay, to be fulfilled at the same time. Moreover, in figures D.46 and D.49 can be noted that second orders would took more time to be fulfilled. The reason was the fact that in the week when the orders arrived to production and agglomeration, the referred stations had no cork incoming and thus had to order it. They had to wait for the incoming shipment to produce the stoppers. The game was halted in week 20, and the time needed to fulfil the customer order was not measured. However, it is expectable that the total time to fulfil the special order would be of four more weeks (twelve in total) once that preparation and granulation had sufficient inventory to immediately fulfil them.

5.2 Cork Stoppers Production Game

The experimentation of the Cork Stoppers Production Game was performed in a single workshop. It used five people, divided by the workstations as described in the previous chapter. The workshop took for about three hours to complete the four rounds.

In this section is described the workshop and the results taken from it are presented. It is expectable that results vary according to the dimensions of stoppers used, to the performance of the participants and to the distance between workstations. In this workshop were used 200 stoppers whose diameter was equal to 2 cm and the length equal to 2,6 cm. The participants had limited knowledge of Lean Manufacturing practices and thus, the discussion was, in times, a bit limited.

Previously to the workshop, facilitator informed participants that they would simulate the production line of the finishing stoppers industry and that the aim of the game was to improve the process. He also told them the steps of the learning process and then explained the tasks individually to participants. The orders placed were of 20 stoppers per round and the branding information was "CSPG", the initials of the game. After this explanation, participants were encouraged to practice their tasks.

Hereupon, simulation was in condition to start.

Round 1

As described, in first round the layout used tried to simulate a functional one. Workstations, as well as the warehouse were spread across the room as shown in figure 5.17.

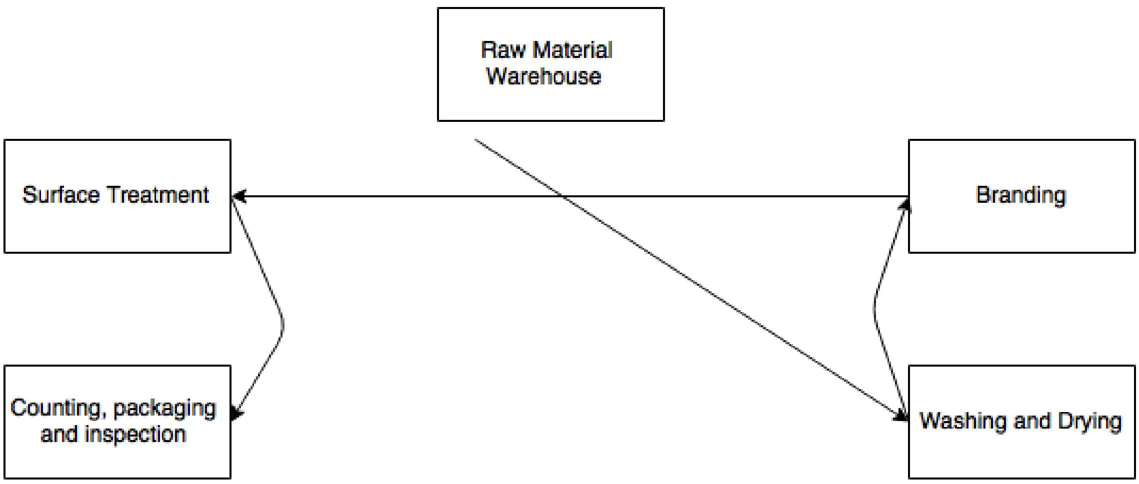


Figure 5.17: Representation of the layout used in round 1

As can be seen in figure, although separated, workstations were displayed in a logical sequence. The space between two consecutive workstations was about four meters and the warehouse was placed about five meters away from the first station: washing and drying. The figure bellow shows the disposition of workstations during the first round of the workshop.

Figure 5.18: Layout used in round 1

Before the simulation, facilitator also informed participants that stoppers should be produced in batches of three and that they should produce at their own pace as long as they have raw material.

Hereupon, the simulation was begun. As expected, the third workstation (surface treatment) was the one where the accumulation of WIP was more evident as shown in figure 5.19. When the WIP was considerable, three marked stoppers were introduced in the production line in order to measure the throughput time. This happened at the eleventh batch and it took 24 minutes and 56 seconds to go throughout the production line.

Figure 5.19: WIP at the entrance of surface treatment in round 1

The first round finished 34 minutes and 12 seconds after the beginning, when the order was met. At this point the WIP units were counted as well as the units that the participant in the last station considered as defective. The majority (69 units) of WIP was at the entrance of the third station and the rest was divided by the other stations, where it was being transformed: 3 stoppers in each of the first two stations and 2 in the last one to be inspected. The defective stoppers were 11 in total. The most common defect found by inspection was related to the surface treatment station but defects of branding were also found. The cycle time was also calculated and as shown in table 5.1, was of 87,55 seconds. The results from the first round are presented in table 5.2.

Table 5.1: Cycle time calculation for round 1

	Round 1
Time at completion of 21st unit (s)	2052
Time at completion of 1st unit (s)	-301
Difference (s)	=1751
Cycle time (s)	/20= 87,55

Table 5.2: Results from round 1

Round	Throughput time	Total time	Cycle Time	WIP units	Defective products
Round 1	24min 56s	34min 12s	87,55s	77	11

Participants were asked about the problems they found in the process. All participants promptly identified the surface treatment station as the one decreasing the performance of the production line and the distance travelled by transportation as a waste that was possible to eliminate. Besides, they also complained about not being allowed to correct the defects and suggested that, if some defective stoppers return to the station where the error occurred, it might be possible to fix it.

Round 2

In order to start the second round, workstations were brought together and displayed in a logical sequence as shown in figure 5.20. Moreover, it was also explained to the participant responsible for inspection that he can now announce where the error occurred and that he should pass it down to the participant in cause. Transportation was dismissed.

Figure 5.20: Representation of the layout used in round 2

The simulation was begun. Once again, WIP accumulated between branding and surface treatment. The marked batch was also the eleventh and took 17 minutes and 34 seconds to go through the production line. At the beginning several stoppers were sent back to surface treatment to re-work but, as time progressed, this was happening fewer and fewer.

The order was met past 29 minutes and 24 seconds and then, the game was halted at that point. The WIP and defective units were counted and the cycle time calculated. The results are displayed at tables 5.3 and 5.4. The improvement in performance was evident in the times measured since they all were reduced. The defective units also reduced as most of the errors found were lack of painted areas and could be corrected by surface treatment. The defects that prevailed were the ones caused by branding. The number of WIP units was the only performance indicator that increased. It increased at surface treatment entrance (76) and kept the same in the others.

Table 5.3: Cycle time calculation for round 2

	Round 2
Time at completion of 21st unit (s)	1764
Time at completion of 1st unit (s)	-272
Difference (s)	=1492
Cycle time (s)	/20= 74,6

Table 5.4: Results from round 2

Round	Throughput time	Total time	Cycle Time	WIP units	Defective products
Round 1	24min 56s	34min 12s	87,55s	77	11
Round 2	17min 34 s	29min 24s	74,6s	84	4

When asked about what could be done to improve the performance of the process, participants, even though they were complaining during the game about the other stations' work, were not capable of identifying anything. Facilitator reminded that high number of WIP and defective units were also considered as bad performance and asked to the participant in branding what was the cause of his errors. He blamed washing and drying because stoppers were wet and the ink did not stick to the stoppers. Then, facilitator suggested that if wet stoppers went back to washing and drying it might be better. Participants agreed. It was also referred that if other stations work at the same pace as surface treatment it would result in lower WIP levels.

Round 3

At this point, facilitator explained the pull system and stated that this would be the production strategy to use hereafter. He also instructed participants to pass a defective stopper over to the responsible for the defect when they found it.

The third round was begun. Branding sent back some stoppers to be dried again and the final inspector found some stoppers having surface treatment's defects. However, much fewer comparing to the previous rounds. The eleventh batch was also marked and the throughput time measured 8 minutes and 23 seconds.

The round ended past 21 minutes and 56 seconds. The reduction in WIP units was the most evident once they were diminished to 10: 3 in each of the first stations and 1 in the last one. Cycle time was calculated (table 5.5) and reduction was accomplished, as well as in the other times measured. The reduction in defective products was almost null once that participants were already being made responsible in the previous round. The results of the third round are presented in table 5.6.

Table 5.5: Cycle time calculation for round 3

	Round 3
Time at completion of 21st unit (s)	1316
Time at completion of 1st unit (s)	-440
Difference (s)	=876
Cycle time (s)	/20= 43,8

Table 5.6: Results from round 3

Round	Throughput time	Total time	Cycle Time	WIP units	Defective products
Round 1	24min 56s	34min 12s	87,55s	77	11
Round 2	17min 34 s	29min 24s	74,6s	84	4
Round 3	8min 23s	21min 56s	43,8s	10	3

At this point, the improvement to implement for next round was not so obvious and then participants were not able to identify it. Facilitator asked what they think that would happen if batches would be reduced to one unit. They answered that in their opinion only throughput time and WIP units would be reduced.

Round 4

Before the game, facilitator informed that everything would be done in the same way and that the only difference would be the batch reduction from three to one unit. This round was very similar to the previous one. The defects found were the same and the throughput time (1 minute and 47 seconds) measured in the same way.

As can be seen in table 5.8, the order was met after 12 minutes and 49 seconds. There were just three WIP units, one at each of the first three stations, and two defective products. The cycle time was once again calculated as shown in table 5.7.

Table 5.7: Cycle time calculation for round 4

	Round 4
Time at completion of 21st unit (s)	786
Time at completion of 1st unit (s)	-106
Difference (s)	=680
Cycle time (s)	/20= 34

Table 5.8: Results from round 4

Round	Throughput time	Total time	Cycle Time	WIP units	Defective products
Round 1	24min 56s	34min 12s	87,55s	77	11
Round 2	17min 34 s	29min 24s	74,6s	84	4
Round 3	8min 23s	21min 56s	43,8s	10	3
Round 4	1min 47s	12min 29s	34s	2	2

At the end of the simulation, participants were amazed with the reduction in times, WIP units and defected products over the four phases. They told that they were expecting the benefits of the change of layout or the reduction in defective units when they were allowed to correct them, however, they also admitted that they were not expecting, for example, the reduction of the total time between the last two rounds.

Chapter 6

Conclusions

This chapter is divided in two sections. The first presents a general overview by summarily characterizing the developed solutions and the conclusions drawn. Then, in section 6.2, directions for further research are discussed.

6.1 General Overview

In this project two games were developed: the Cork Supply Game and the Cork Stoppers Production Game. The first is a supply chain management game aimed at studying the behaviour of the cork stoppers supply chain facing three different demand patterns and at providing opportunities to the people involved in the sector to experience supply chain dynamics within a relevant framework. The second, a production flow simulation, was developed with the intent of instill and demonstrate the benefits of some Lean Manufacturing tools to the people in the cork stoppers industry. Both games were tested by real people and the results analysed.

The Cork Supply Game portrays the cork stoppers supply chain and thus, tries to consider specificities of the referred supply chain such as the flow of goods through positions, with three divergence points and several transformation constrains, which allows to also simulate the diversity of existent stoppers in the market. It allows participants to experience several weeks of stoppers procurement, in three different patterns, where they have to move goods down through the supply chain to the client. In experimentations, the game has shown himself a powerful tool where participants experience the bullwhip effect. They feel the lack of inventory as consequence of the increase of variability in ordering as going upstream in the supply chain, and the repercussion that it has in the performance of the supply chain. The game also allows participants to see how the cork supply chain reacts to special orders and the effect that those orders have in performance.

The Cork Stoppers Production Game is a physical simulation of the process of finishing stoppers. It simulates five workstations in which participants perform representative tasks of the real process. First round has evident lack of efficiency and thus, during three more rounds, Lean Manufacturing tools and concepts, such as the differences between process and product layouts, push vs pull strategies or the benefits of batch reduction, are being introduced, experienced and the improvements in performance observed, reaching a much more efficient process. This game proved to be very efficient in demonstrating those Lean tools as it allows participants to experience them and to see the benefits of it in real time.

6.2 Recommendations for Further Research

The main objective of both games was to work as a teaching tool of Lean concepts and thus, the exact representation of the processes simulated was sometimes left apart.

One special characteristic of cork value chain is that cork takes six months of stabilization since it is harvested until it is ready for being transformed. Moreover, cork is usually harvested in two specific times of the year. Then, preparation industry buys cork for half year at a single time with a six month delay. Still in preparation and in production, the manufacturing process is not immediate. As the delay times used in the Cork Supply Game are the same as used in the "Beer Game", the game does not correspond to reality. It would be a relevant further research point, the introduction of more realistic delays, between stages and in the stages' processes themselves. Batch production would also be an interesting point of research once it is widely used in the sector. In order to do it, the inventories of the stations where materials suffer transformation (preparation, production, granulation and agglomeration) are divided in the three phases: before, during and after; of transformation, in which the batch dimensions and the time that batches would stay in each of the phases would be according to the ones practised in reality. Other possible recommendation for further research that would increase the relevance to the sector is the approaching to the real number of existing varieties of stoppers in the market. It was also referred that the game demonstrates the bullwhip effect as a consequence of misperceptions of feedback. Research aiming at demonstrate the bullwhip as consequence of the four causes identified by Lee et al. [10] would be interesting too.

The recommendations made increase the relevance to the sector once that they become it more realistic. However, with the increase of realism, the simplicity would be compromised. In the case of realism being a requirement in future research, a computerised model is advised once that the game developed has proved a bit complicated itself when tested.

During the experimentation of the Cork Stoppers Production Game stood out that the main defect found in stoppers was the one caused in the task performed in surface treatment. Tasks could be reformulated in order to increase the variety of defects. In this game, the relevance to the sector would be interesting too. The analysis of the real process and the development of a more realistic representation of it, with more realistic tasks, encompassing the times needed in real world to complete each task or the introduction of machines in the process would be of higher interest for the sector.

Appendix A

Cork Supply Game Facilitator’s Guide

Facilitator’s Guide for Cork Supply Game v2.1

By José Graça

Facilitator's guide:

Goal of the game:

The goal of the game is to **minimize the total cost of the chain**. The cost of the chain is represented by the **inventory and backlog levels** in each stage at each round. The **backlog costs twice** the inventory.

Number of players:

Each team must be composed by, at least, eight people.

Materials:

- Game board (1 per team).
- Green, pink, blue, red, yellow and purple chips (around 200 of each per team).
- Customer decks (2 per team).
- Order slips (400 per team).
- Pencils (eight per team).
- Computers with internet access (8 per team).

Before the game:

1) Initialize the board (figure 2):
   a) Inventories:
      - There should be 30 000 stoppers (3 chips) in inventories of S1 and S2.
      - There should be 90 000 stoppers (9 chips) in inventories of S3.
      - There should be 450 000 stoppers (9 chips) in inventories of S4.
      - There should be 2 400 Kg (3 chips) in inventories of C1.
      - There should be 3 600 Kg (6 chips) in Preparation's inventory of C2.
      - There should be 1 800 Kg (3 chips) in Production's inventory of C2.
      - There should be 5 400 Kg (9 chips) in Granulation's inventory of C2.
   b) Orders slips:
      - There should be 10 000 stoppers written in the order slips of S1 and S2
      - There should be 30 000 stoppers written in the order slips of S3
      - There should be 150 000 stoppers written in the order slips of S4
      - There should be 800 Kg written in the order slips of C1
      - There should be 1 200 Kg written in the order slips of C2, between Granulation and Preparation
      - There should be 600 Kg written in the order slips of C2, between Granulation and Production.
      - There should be 2 000 Kg written in the order slip of Raw Cork

c) Shipping Delays:
   - There should be 10 000 stoppers (1 chip) in the SDs of S1 and S2
   - There should be 30 000 stoppers (3 chips) in the SDs of S3
   - There should be 150 000 stoppers (3 chips) in the SDs of S4
   - There should be 800 Kg (1 chip) in the SDs of C1
   - There should be 1 200 Kg (2 chips) in the SDs of C2, between Granulation and Preparation
   - There should be 600 Kg (1 chip) in the SDs of C2, between Granulation and Production.
   - There should be 2 000 Kg in the SDs of Raw Cork

d) The deck of cards with customer demand should be faced down and should not be revealed in advance.

e) The order deck should have fifty rounds' worth of cards, and the players should be told that the game will be fifty rounds long. The game should be played for about 20 rounds, however participants are told that there will be 50 rounds in order to avoid end-of-game moves.

2) Give to participants the instructions sheet:
   a) Provide an overview of the game. Explain carefully the products that each stage manages and the flows in the points of divergence and convergence.
   b) State the rules of the game.
   c) Explain the steps of the game.
   d) Issue the tables to the participants. Make sure that everybody knows how to record data on them.

<u>During the game:</u>

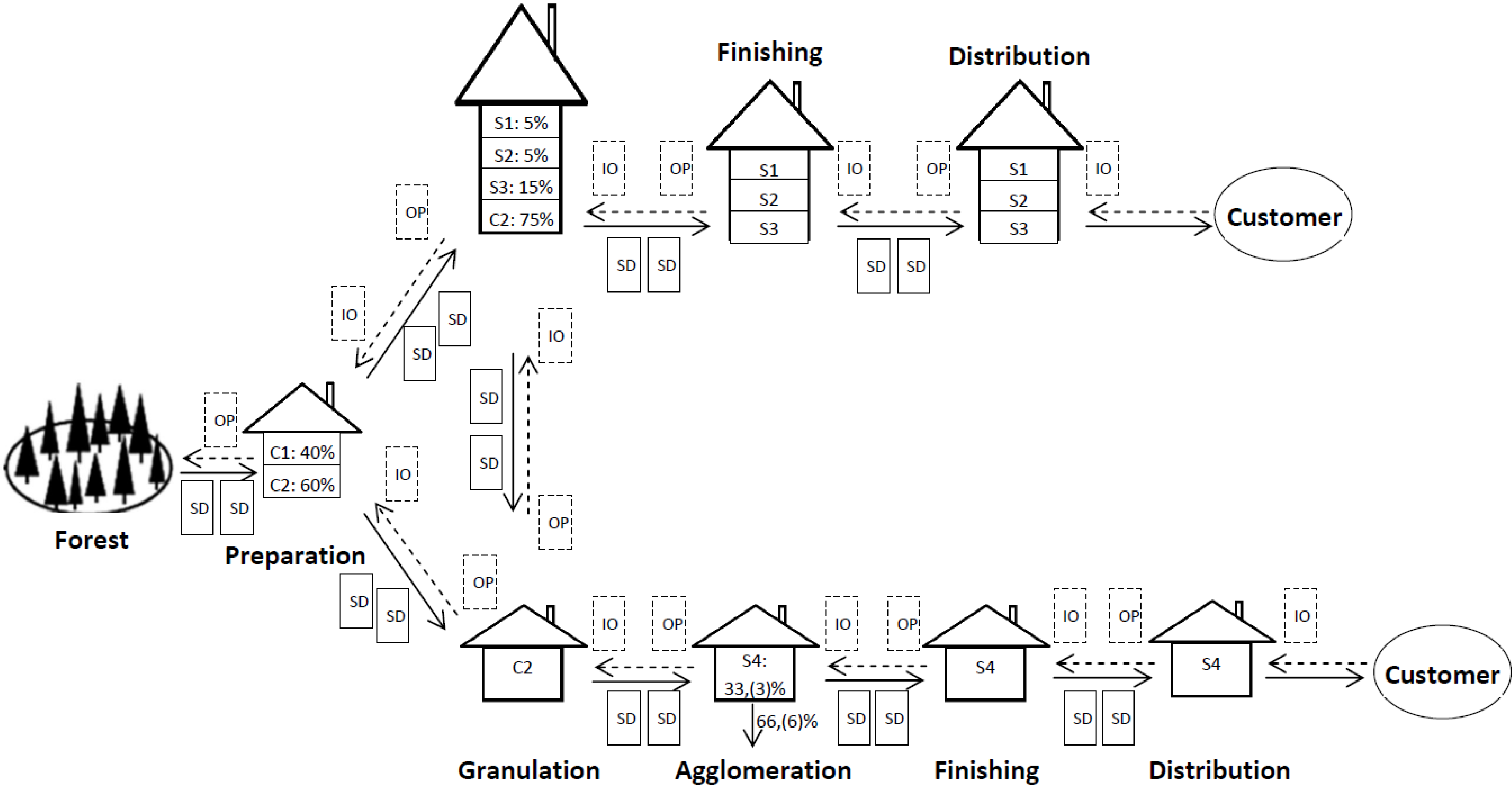
1) Say the steps out loud. Remind the participants to stay in step, in order to keep pace of the game.
2) Write the current week where everybody can see it.
3) The first few times when the system is still in equilibrium go through the steps very slowly to make sure people understand it. Make sure no one has doubts about how to record the data on the tables.
4) In about the eight week, distributions will run out inventory and have a backlog for the first time. It is important, at this point, to explain to everybody how backlog accounting works (use the table). Emphasize that backlog costs twice as much as inventory.
5) Each round, change the chips in the SDs before the stages where products are transformed:
   a) In the SDs between Preparation and Production, each chip of C1 should be replaced by one chip of S1, one chip of S2, three chips of S3 and one chip of C2.

b) In the SDs between Granulation and Agglomeration, each chip of C2 should be replaced by one chip of S4.

<u>End of game:</u>

1) Stop the game after about 20 weeks.
2) The costs are automatically calculated.
3) Ask participants to graph their orders (OP)
4) Ask participants to graph their stage's inventory levels, showing any backlog as negative inventory.

Fig. 1 - Game Board



SD – Shipping Delay
IO – Incoming Order
OP – Order Placed

Flow of information

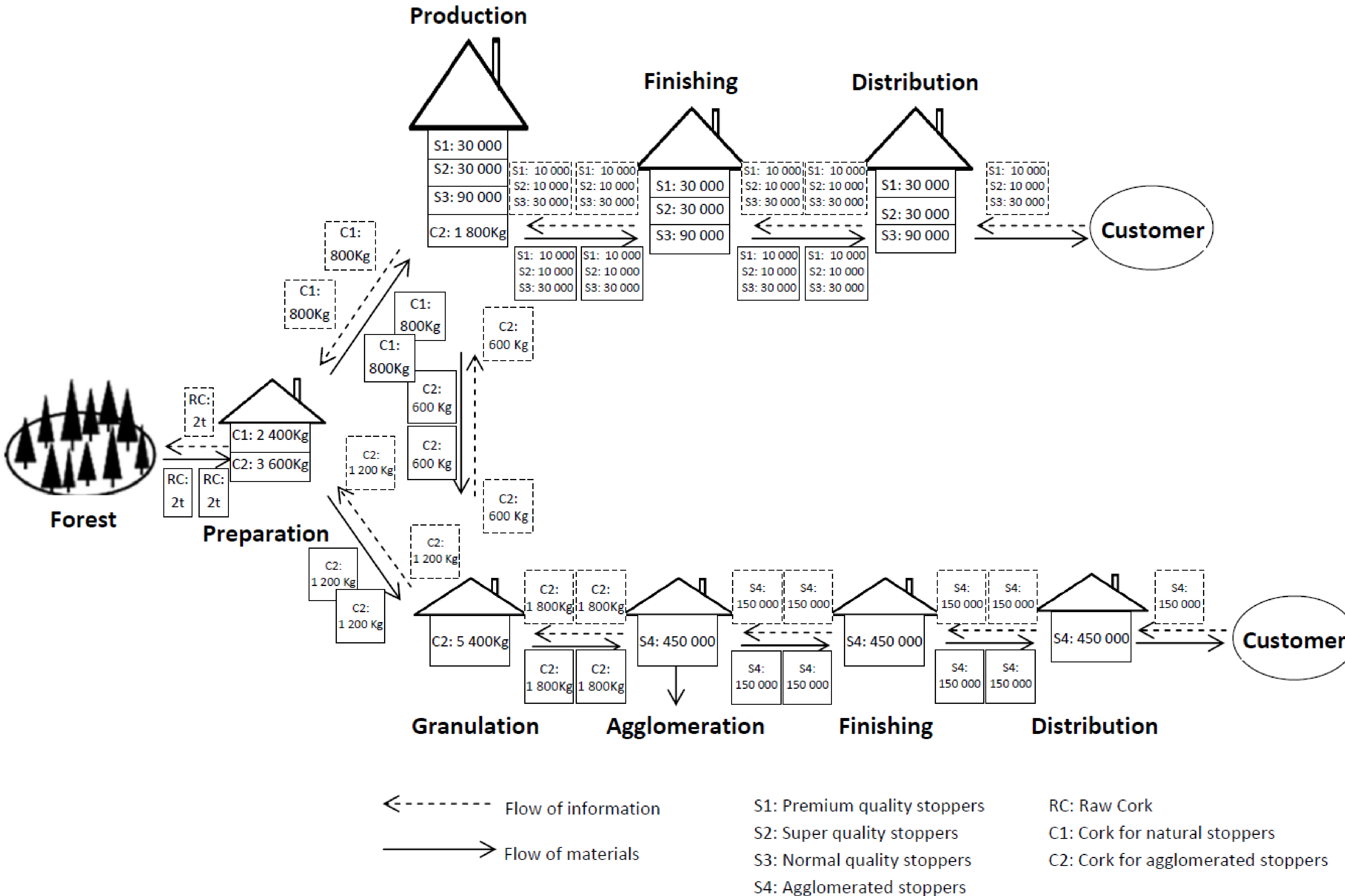
Flow of materials

S1: Premium quality stoppers
S2: Super quality stoppers
S3: Normal quality stoppers
S4: Agglomerated stoppers

C1: Cork for natural stoppers

C2: Cork for agglomerated stoppers

Fig. 2 – Initialization of the Game Board



Appendix B

Cork Supply Game Instructions’

Instructions for Cork Supply Game v5.0

By José Graça

Goal of the game:

The goal of the game is to **minimize the total cost of the chain**. The cost of the chain is represented by the **inventory and backlog levels** in each stage at each round. The **backlog costs twice** the inventory.

Overview of the game:

- The game is played on a board that simulates the cork industrial process, from the forest to the customer.
- The process simulated produces three types of natural stoppers, according to their quality: premium (S1), super (S2) and normal (S3); and agglomerated stoppers (S4).
- Stoppers also vary in their dimensions which can be regular or special.
- High quality cork (C1) is used to produce natural stoppers. Low quality cork (C2) is the one used to produce S4.
- The game consists of eight stages divided by two branches. Preparation is the first stage and the only common to both branches. The other stages of the natural cork stoppers branch are: production, finishing and distribution. The agglomerated cork stoppers branch consists of four more stages: granulating, agglomerating, finishing and distribution. (Figure 1) One or more people manage each stage.
- Customers' demand is represented by a deck of cards. At each round, participants have to order goods to the upstream stage and ship materials to the downstream one.
- The flow of information goes from the Customer to the Forest (upstream) and the flow of materials goes downstream, from the Forest to the Customer.
- Each round goes through six steps which are described below.
- The game is played in three different scenarios that vary in the demand pattern.
- Stoppers and cork are represented by chips which simulate different quantities as can be seen in table 1.
- Each folded chip represents 1/10 of the quantity of one chip.
- The data is recorded on the tables provided. The data of one material is recorded on one table. The stages that manage more than one material use the same number of tables.
- The game is played for 50 rounds.

Chip	Material	Quantity
Green folded	C1	80 Kg
Green	C1	800 Kg
Pink folded	C2	60 Kg
Pink	C2	600 Kg
Blue folded	S1	1 000 stoppers
Blue	S1	10 000 stoppers
Red folded	S2	1 000 stoppers
Red	S2	10 000 stoppers
Yellow folded	S3	1 000 stoppers
Yellow	S3	10 000 stoppers
Purple folded	S4	5 000 stoppers
Purple	S4	50 000 stoppers

Table 1 – Representation used

Rules:

1. No communication between sectors. The only information allowed to exchange is the passing of orders and the receiving of goods. Distributions are the only ones who know what costumers order.
2. All Incoming orders (IO) must be filled. If inventory is not sufficient to fill IO plus backlog, fill as many orders as possible and add the remaining orders to backlog.
3. The object of the game is to minimize total costs of the chain. Total costs are the sum of the carrying costs of inventory (€1 per Kg per round) and the backlog costs (€2 per Kg per round)

Steps of the Game:

1. **Receive inventory**: move goods from SD2 into current inventory; and **advance the shipping**: from SD1 to SD2. **Record incoming shipment**.
2. **Look at the incoming orders and fulfil them from the inventory**: look at the IO and **record the Incoming Order**. Then look at the goods to ship in the table. According to rule 4, ship the goods that you must by moving them out of the inventory into SD1 of the player downstream. Finally, **record the goods shipped.**
3. **Look at inventory and backlog**: backlog is calculated by deducting the goods shipped to the goods to ship. See if the values for inventory and backlog in the table and your inventory match.
4. **Advance the orders**: move the orders slips in the OP to the IO of the player upstream. The Forest introduces the OP into the SD 1.
5. **Place orders**: take the decision on the orders you wish to place, write them on the orders slips and place them in OP of the upstream stage. Finally, **record the orders** you have **placed**.

Instructions for Preparation:

- Preparation orders Raw Cork from forest and sells C1 to Production and C2 to Granulation.
- Preparation has to manage two inventories: C1 and C2.
- From the received Raw Cork, preparation transforms 40% of it into C1 and 60% of it into C2. The proportion in which the cork is transformed in preparation is presented in the tables below.

Raw Cork		C1		C2	
Chips	Kg	Chips	Kg	Chips	Kg
1	200	1	80	2	120
2	400	2	160	4	240
3	600	3	240	6	360
4	800	4	320	8	480
5	1000	5	400	10	600
6	1200	6	480	12	720
7	1400	7	560	14	840
8	1600	8	640	16	960
9	1800	9	720	18	1080

Table 2 – Proportion in which cork is transformed in Preparation: folded chips

Raw Cork		C1		C2	
Chips	Kg	Chips	Kg	Chips	Kg
1	2000	1	800	2	1200
2	4000	2	1600	4	2400
3	6000	3	2400	6	3600
4	8000	4	3200	8	4800
5	10000	5	4000	10	6000
6	12000	6	4800	12	7200
7	14000	7	5600	14	8400
8	16000	8	6400	16	9600
9	18000	9	7200	18	10800

Table 3 - Proportion in which cork is transformed in Preparation: chips

Instructions for Production:

- Production orders C1 from Preparation and sells S1, S2 and S3 to Finishing and C2 to Granulation.
- Production has to manage four inventories: S1, S2, S3 and C2.
- From the received C1, Production transforms 10% of it into S1 and S2 at equal proportions (5% + 5%), 15% of it into S3 and the rest (75%) of it is transformed into C2. The proportion in which the cork is transformed in Production is presented in the tables below.

C1		S1		S2		S3		C2	
Chips	Kg	Chips	Stoppers	Chips	Stoppers	Chips	Stoppers	Chips	Kg
1	80	1	1000	1	1000	3	3000	1	60
2	160	2	2000	2	2000	6	6000	2	120
3	240	3	3000	3	3000	9	9000	3	180
4	320	4	4000	4	4000	12	12000	4	240
5	400	5	5000	5	5000	15	15000	5	300
6	480	6	6000	6	6000	18	18000	6	360
7	560	7	7000	7	7000	21	21000	7	420
8	640	8	8000	8	8000	24	24000	8	480
9	720	9	9000	9	9000	27	27000	9	540

Table 4 – Proportion in which cork is transformed in Production: folded chips

C1		S1		S2		S3		C2	
Chips	Kg	Chips	Stoppers	Chips	Stoppers	Chips	Stoppers	Chips	Kg
1	800	1	10000	1	10000	3	30000	1	600
2	1600	2	20000	2	20000	6	60000	2	1200
3	2400	3	30000	3	30000	9	90000	3	1800
4	3200	4	40000	4	40000	12	120000	4	2400
5	4000	5	50000	5	50000	15	150000	5	3000
6	4800	6	60000	6	60000	18	180000	6	3600
7	5600	7	70000	7	70000	21	210000	7	4200
8	6400	8	80000	8	80000	24	240000	8	4800
9	7200	9	90000	9	90000	27	270000	9	5400

Table 5 – Proportion in which cork is transformed in Production: chips

Instructions for Granulation:

- Granulation orders C2 from Preparation and Production and sells it to Agglomeration.
- Granulation must order 1/3 of the desired C2 from Production and 2/3 from Preparation. The proportion in which the cork must be ordered is presented in the tables below.

C2		**C2 from Preparation**		**C2 from Production**	
Chips	**Kg**	**Chips**	**Kg**	**Chips**	**Kg**
3	180	2	120	1	60
6	360	4	240	2	120
9	540	6	360	3	180
12	720	8	480	4	240
15	900	10	600	5	300
18	1080	12	720	6	360
21	1260	14	840	7	420
24	1440	16	960	8	480
27	1620	18	1080	9	540

Table 6 - Proportion in which C2 is ordered in Granulation: folded chips

C2		**C2 from Preparation**		**C2 from Production**	
Chips	**Kg**	**Chips**	**Kg**	**Chips**	**Kg**
3	1800	2	1200	1	600
6	3600	4	2400	2	1200
9	5400	6	3600	3	1800
12	7200	8	4800	4	2400
15	9000	10	6000	5	3000
18	10800	12	7200	6	3600
21	12600	14	8400	7	4200
24	14400	16	9600	8	4800
27	16200	18	10800	9	5400

Table 7 - Proportion in which C2 is ordered in Granulation: chips

Instructions for Agglomeration:

- Agglomeration orders C2 from Granulation and sells S4 to Finishing.
- Agglomeration has to manage one inventory: S4.
- From the received C2, Agglomeration transforms 1/3 of it into S4. The rest (2/3) of it is used to manufacture products other than stoppers that are not represented in the game. The proportion in which the cork is transformed in Agglomeration is presented in the tables below.

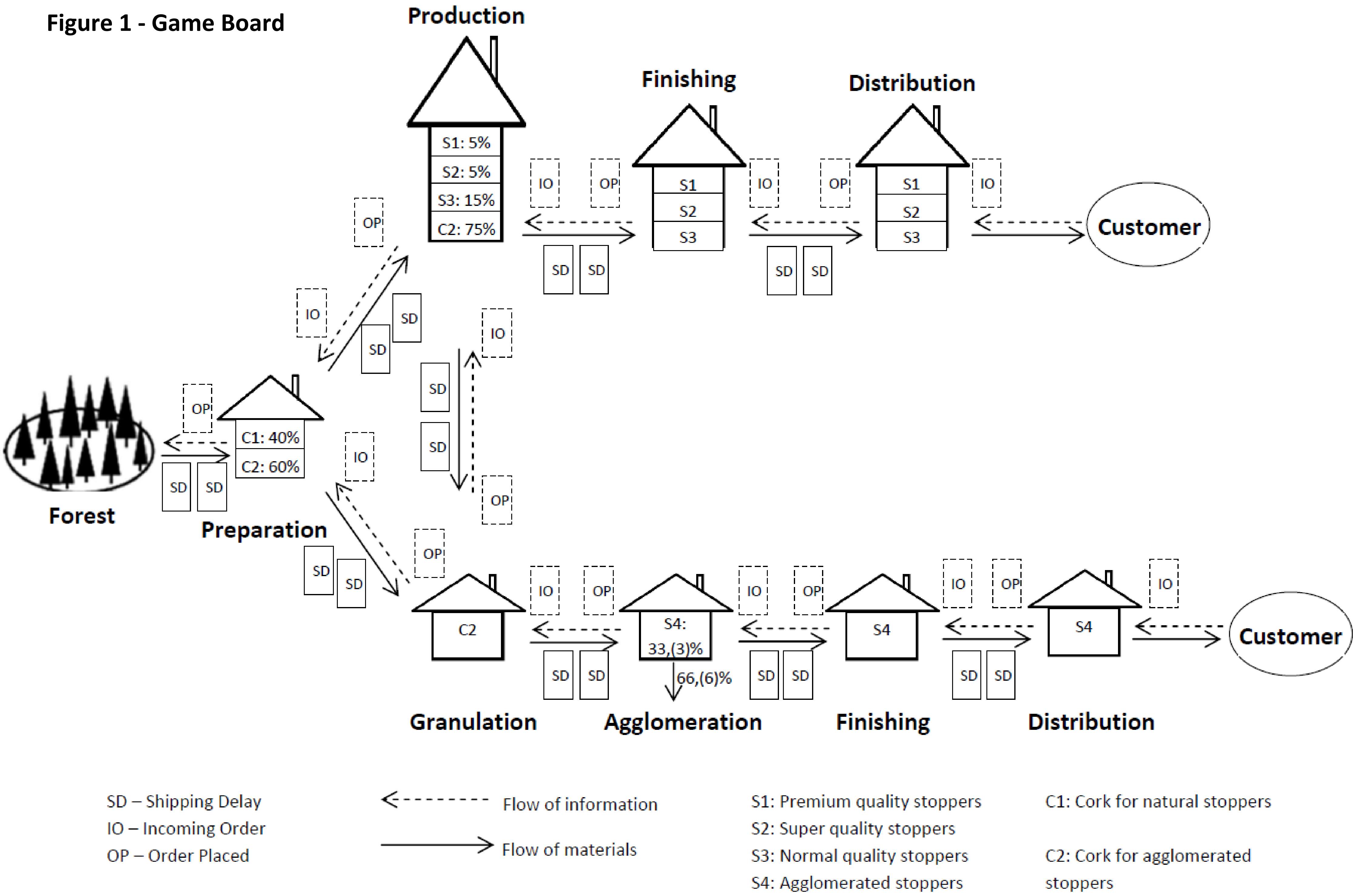
C2		S4	
Chips	Kg	Chips	Stoppers
1	60	1	5000
2	120	2	10000
3	180	3	15000
4	240	4	20000
5	300	5	25000
6	360	6	30000
7	420	7	35000
8	480	8	40000
9	540	9	45000

Table 8 - Proportion in which cork is transformed in Agglomeration: folded chips

C2		S4	
Chips	Kg	Chips	Stoppers
1	600	1	50000
2	1200	2	100000
3	1800	3	150000
4	2400	4	200000
5	3000	5	250000
6	3600	6	300000
7	4200	7	350000
8	4800	8	400000
9	5400	9	450000

Table 9 - Proportion in which cork is transformed in Agglomeration: chips

Figure 1 - Game Board



Appendix C

Customers' Orders of Cork Supply Game

C.1 Orders in Scenario A

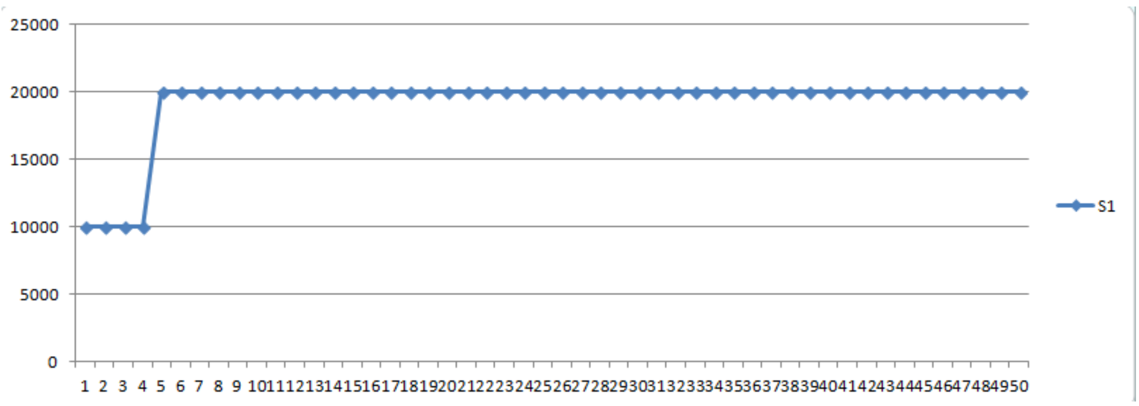


Figure C.1: Orders for S1 and S2 in Scenario A

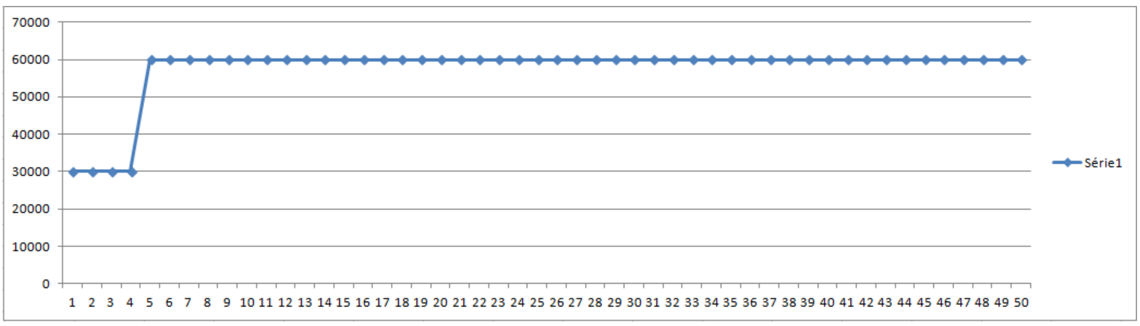


Figure C.2: Orders for S3 in Scenario A

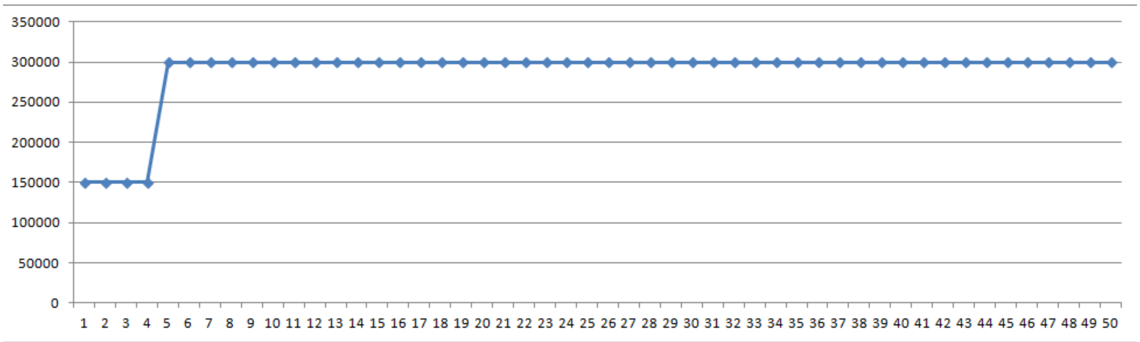


Figure C.3: Orders for S4 in Scenario A

C.2 Orders in Scenario B

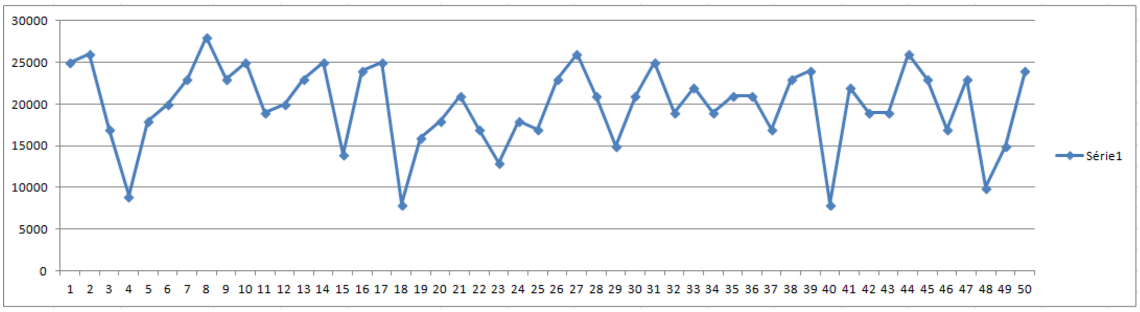


Figure C.4: Orders for S1 in Scenario B

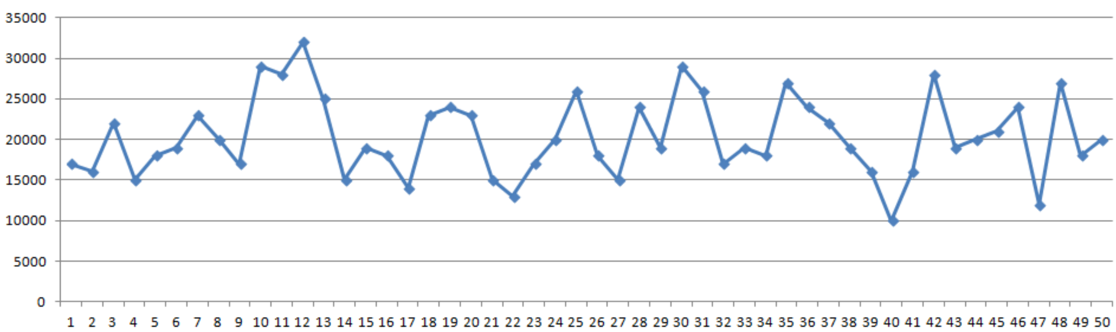


Figure C.5: Orders for S2 in Scenario B

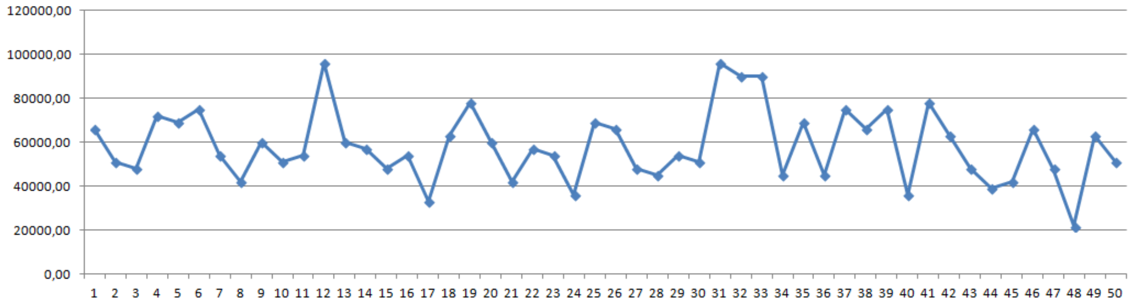


Figure C.6: Orders for S3 in Scenario B

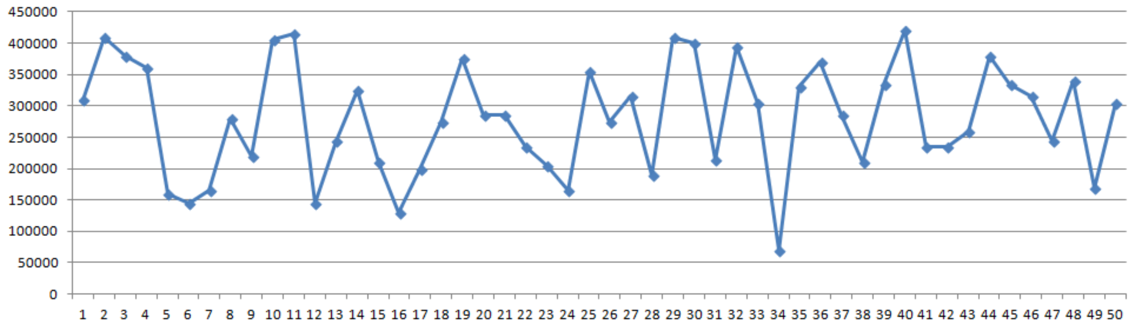


Figure C.7: Orders for S4 in Scenario B

C.3 Orders in Scenario C

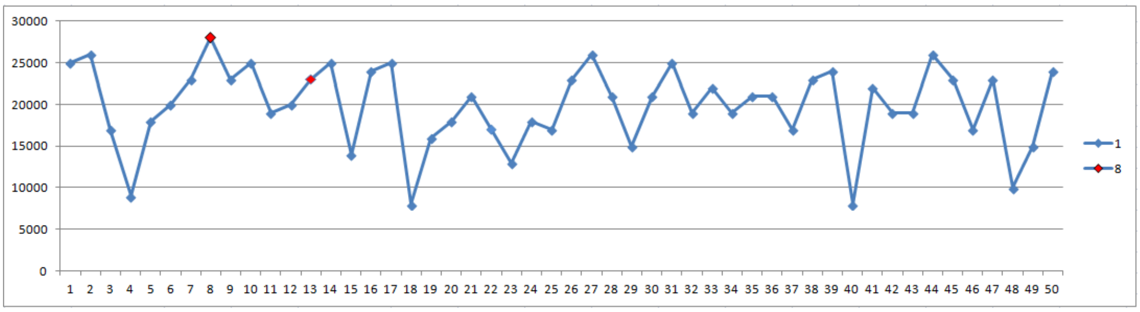


Figure C.8: Orders for S1 in Scenario C

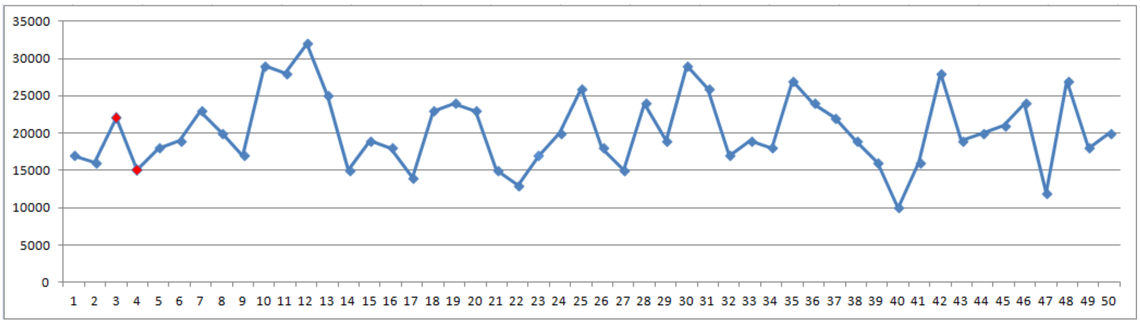


Figure C.9: Orders for S2 in Scenario C

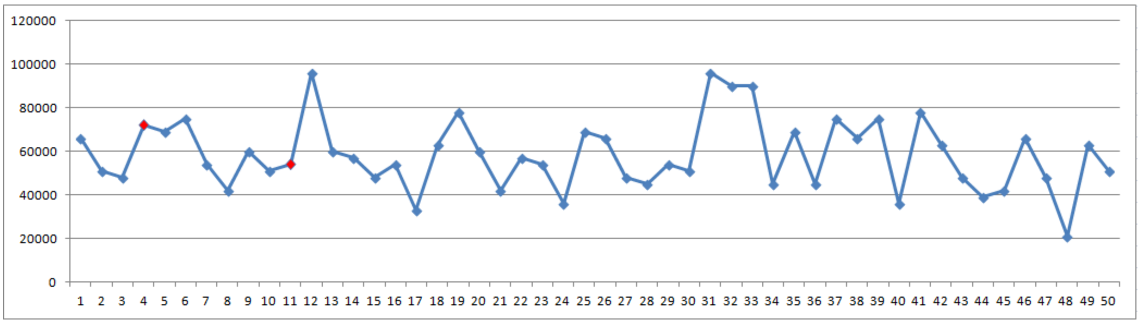


Figure C.10: Orders for S3 in Scenario C

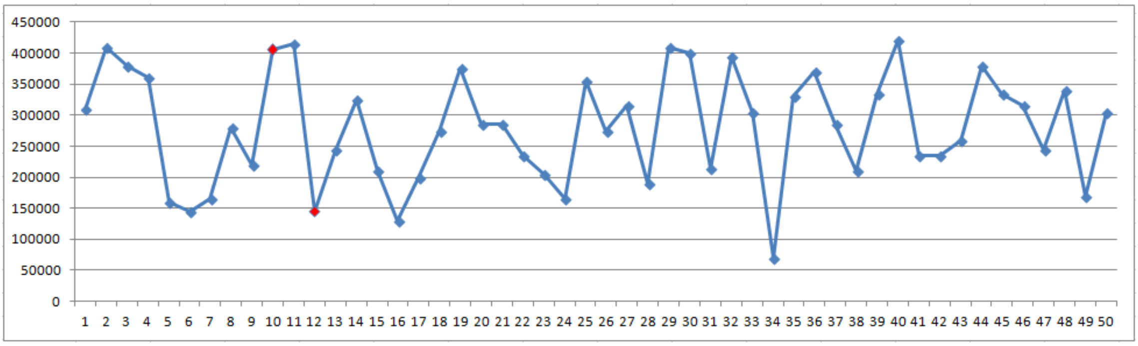


Figure C.11: Orders for S4 in Scenario C

Appendix D

Results of Cork Supply Game

D.1 Results of Scenario A

D.1.1 Graphs of Inventories

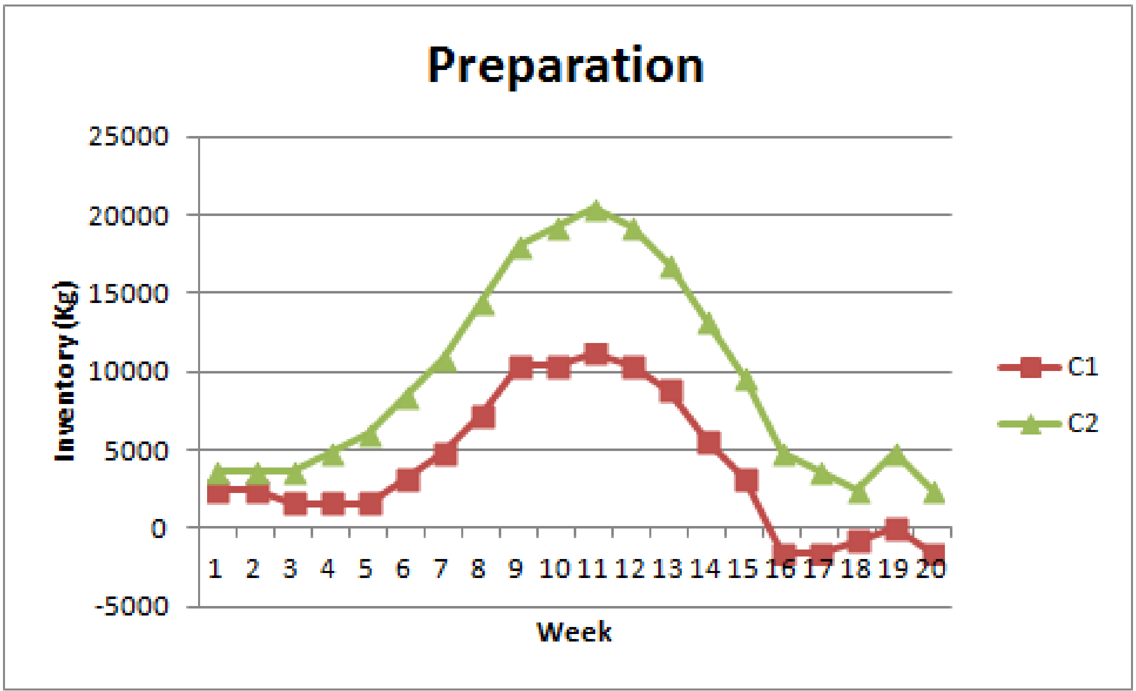


Figure D.1: Effective Inventory of C1 and C2 in Preparation in Scenario A

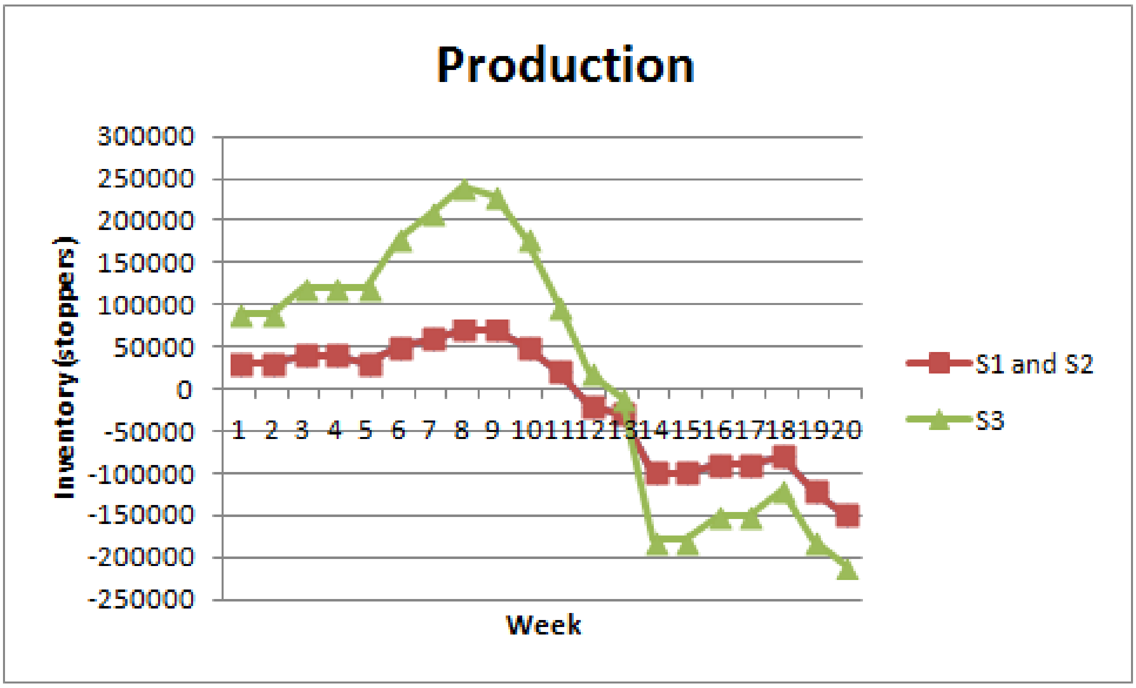


Figure D.2: Effective Inventory of S1, S2 and S3 in Production in Scenario A

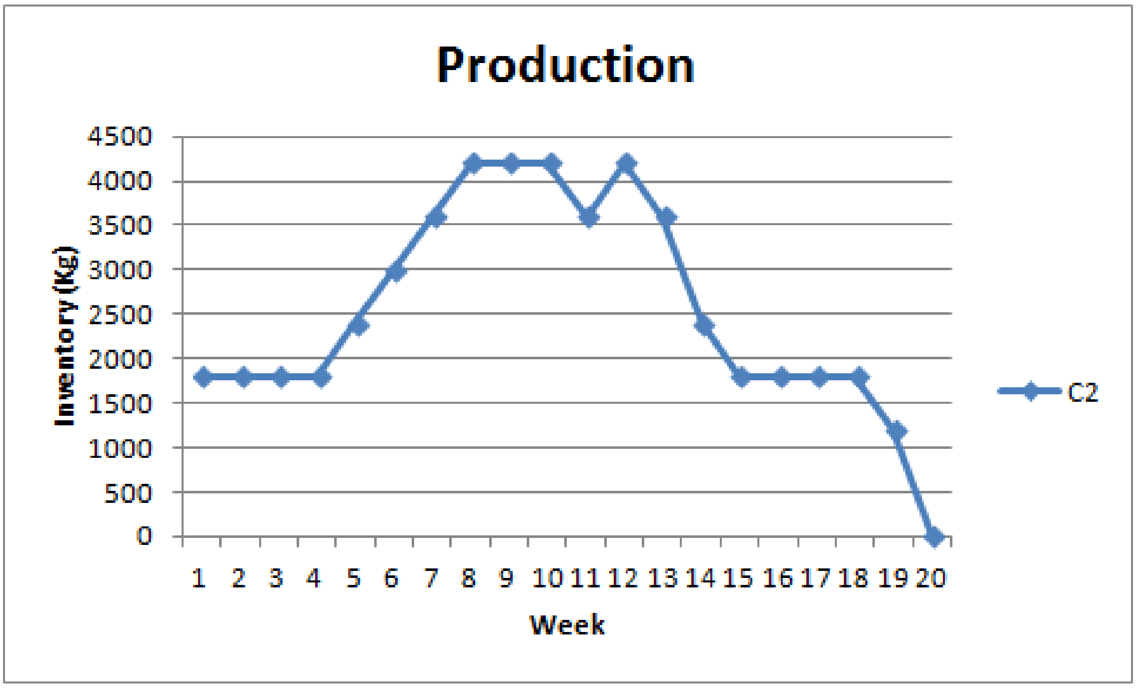


Figure D.3: Effective Inventory of C2 in Production in Scenario A

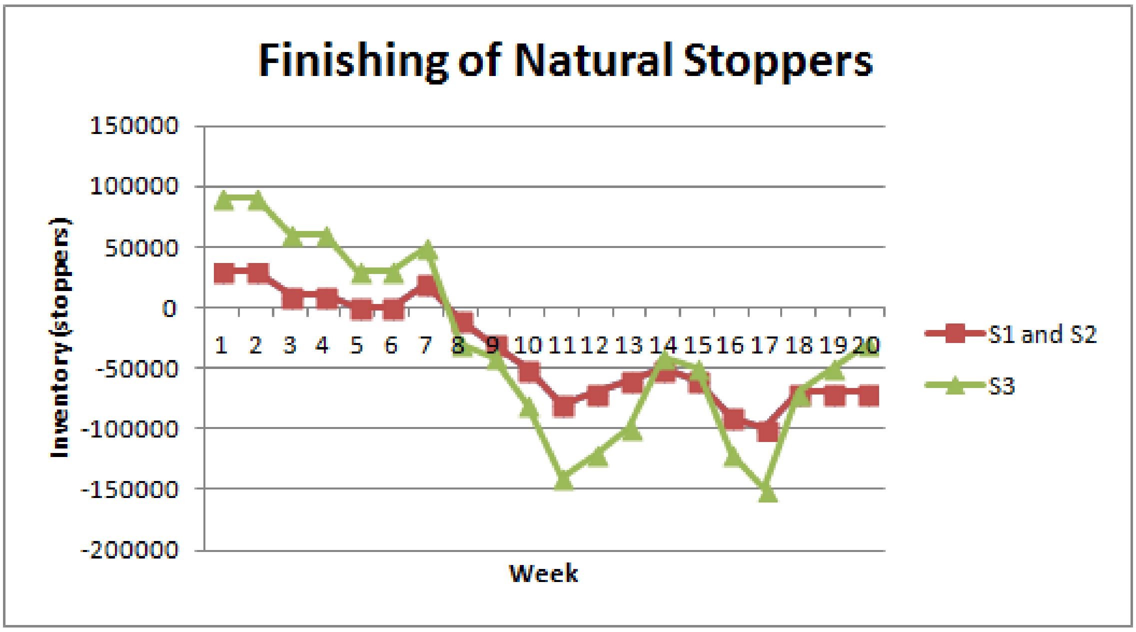


Figure D.4: Effective Inventory of S1, S2 and S3 in Finishing of Natural Stoppers in Scenario A

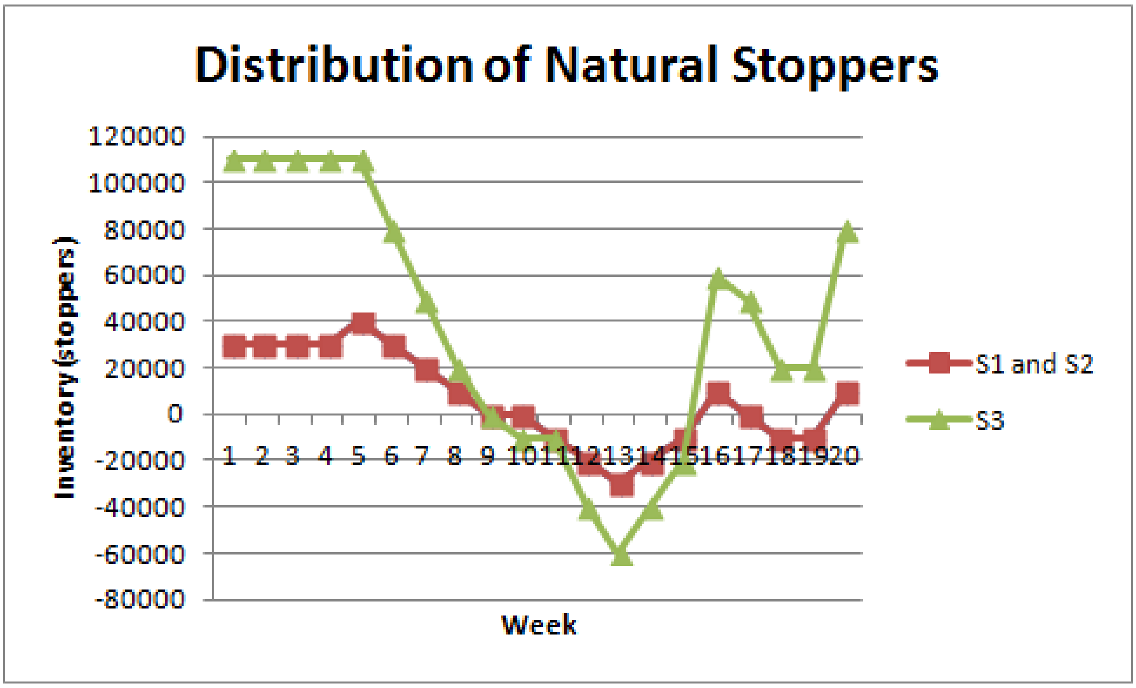


Figure D.5: Effective Inventory of S1, S2 and S3 in Distribution of Natural Stoppers in Scenario A

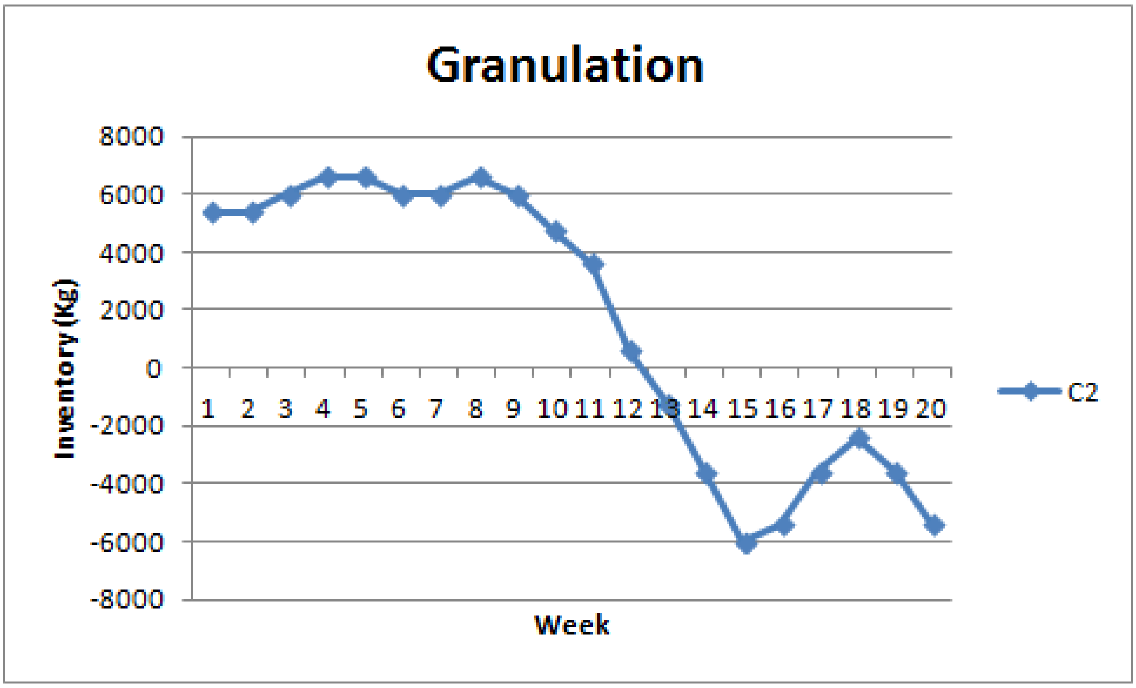


Figure D.6: Effective Inventory of C2 in Granulation in Scenario A

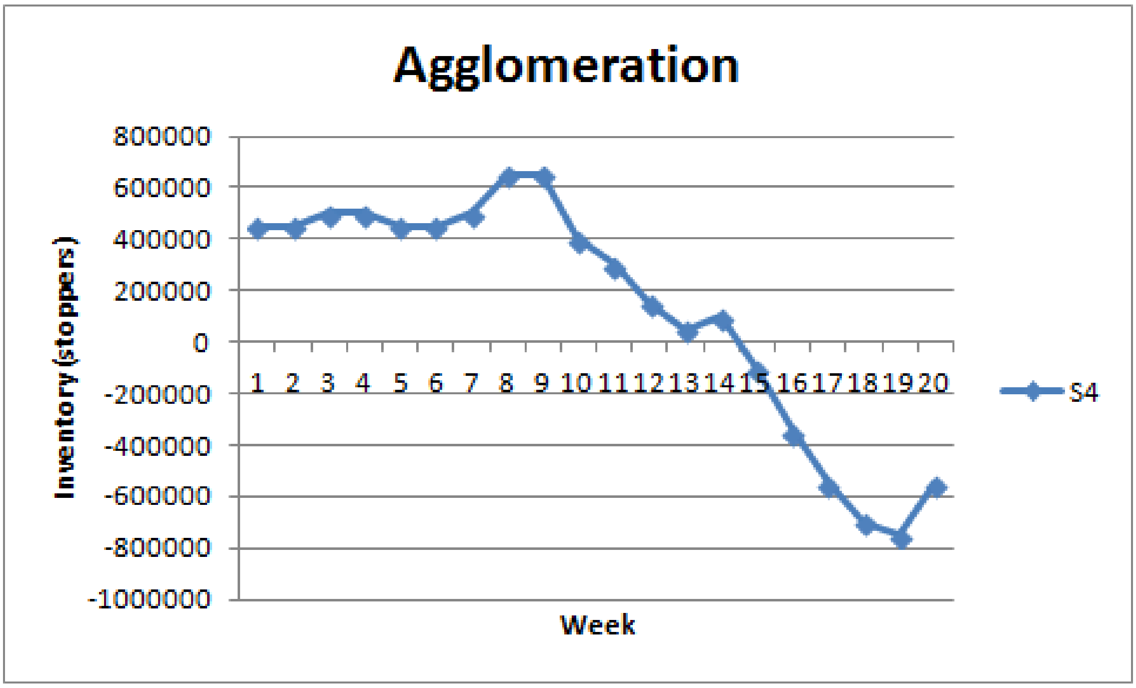


Figure D.7: Effective Inventory of S4 in Agglomeration in Scenario A

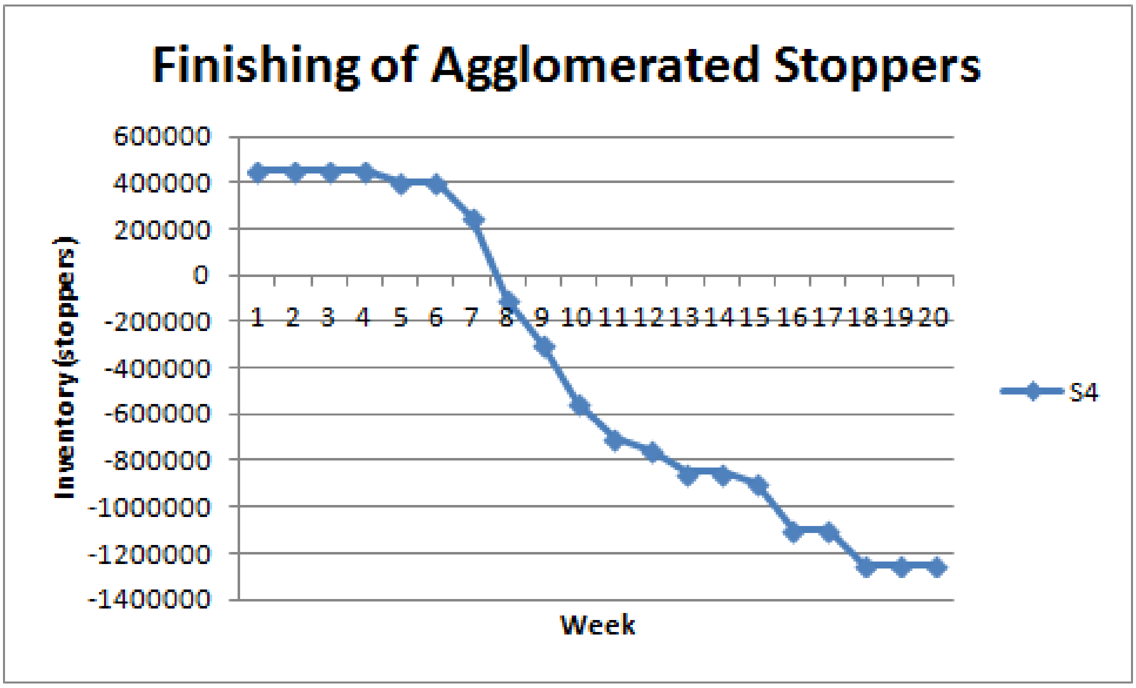


Figure D.8: Effective Inventory of S4 in Finishing of Agglomerated Stoppers in Scenario A

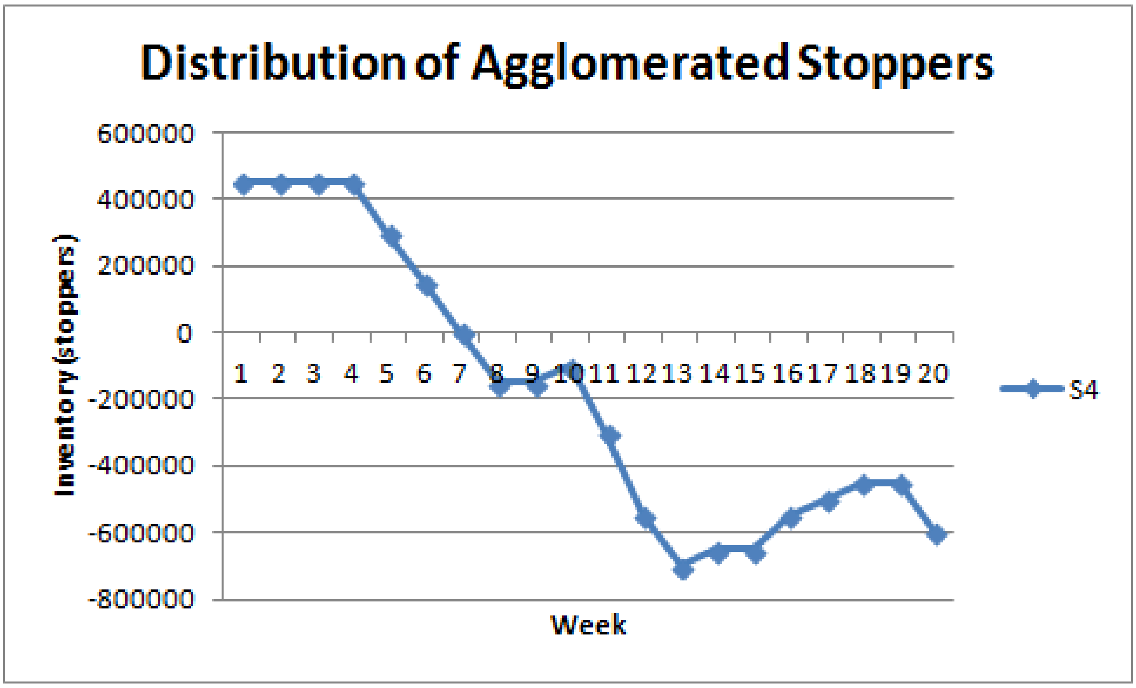


Figure D.9: Effective Inventory of S4 in Distribution of Agglomerated Stoppers in Scenario A

D.1.2 Graphs of Orders Placed

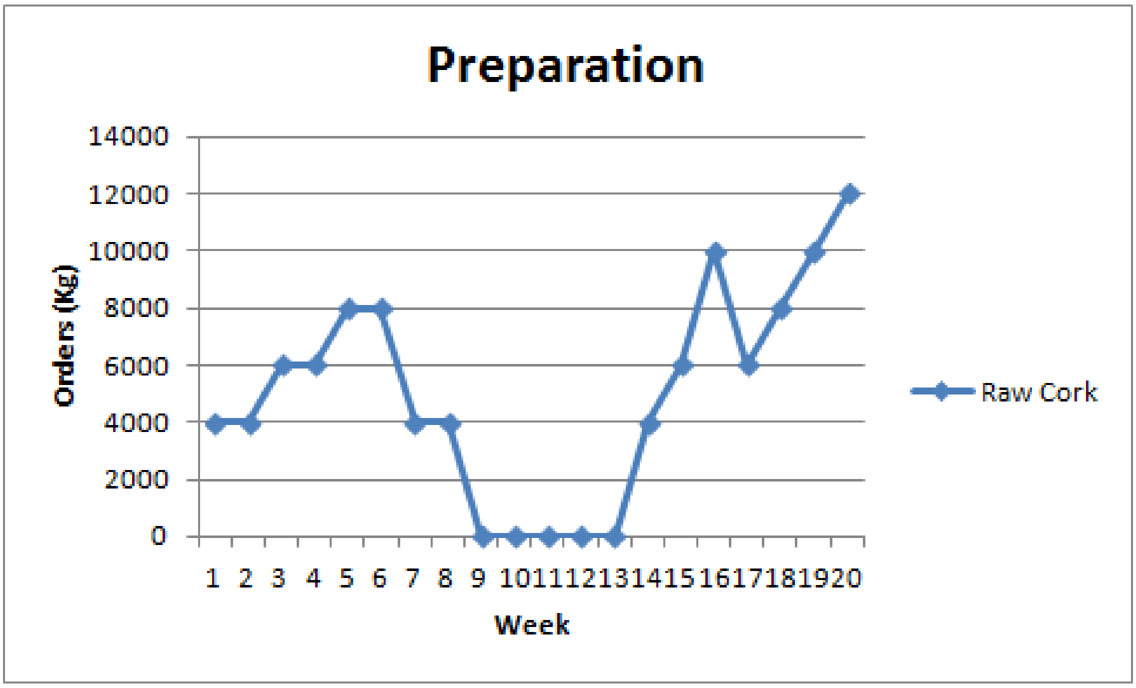


Figure D.10: Orders for Raw Cork Placed by Preparation in Scenario A

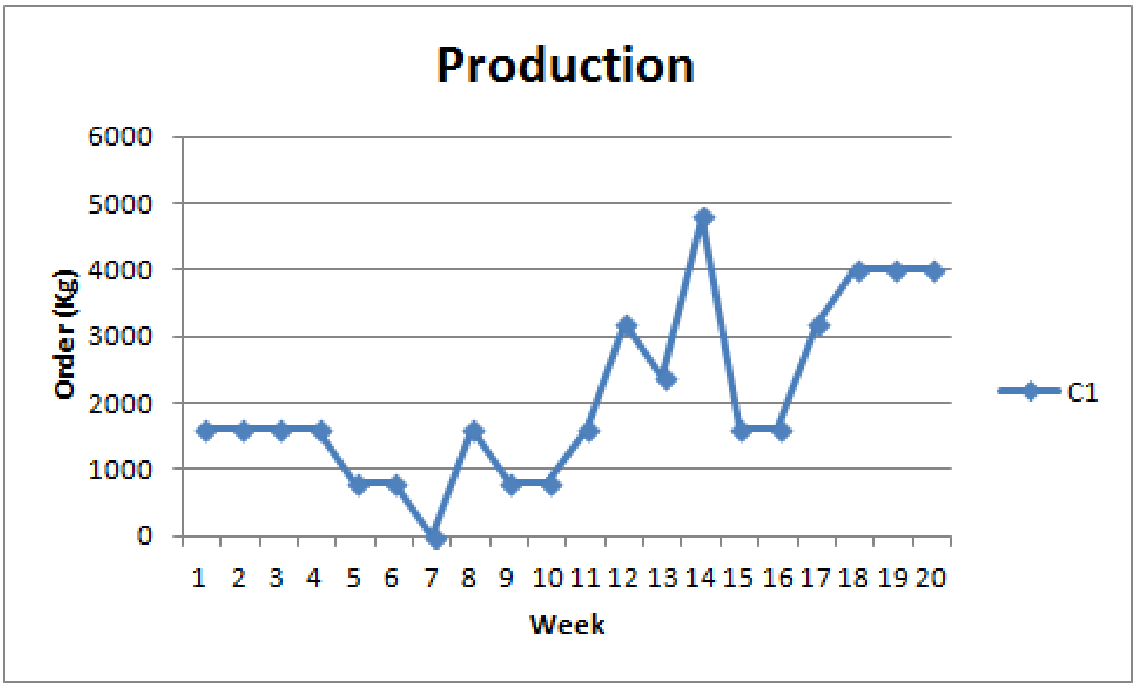


Figure D.11: Orders for C1 Placed by Production in Scenario A

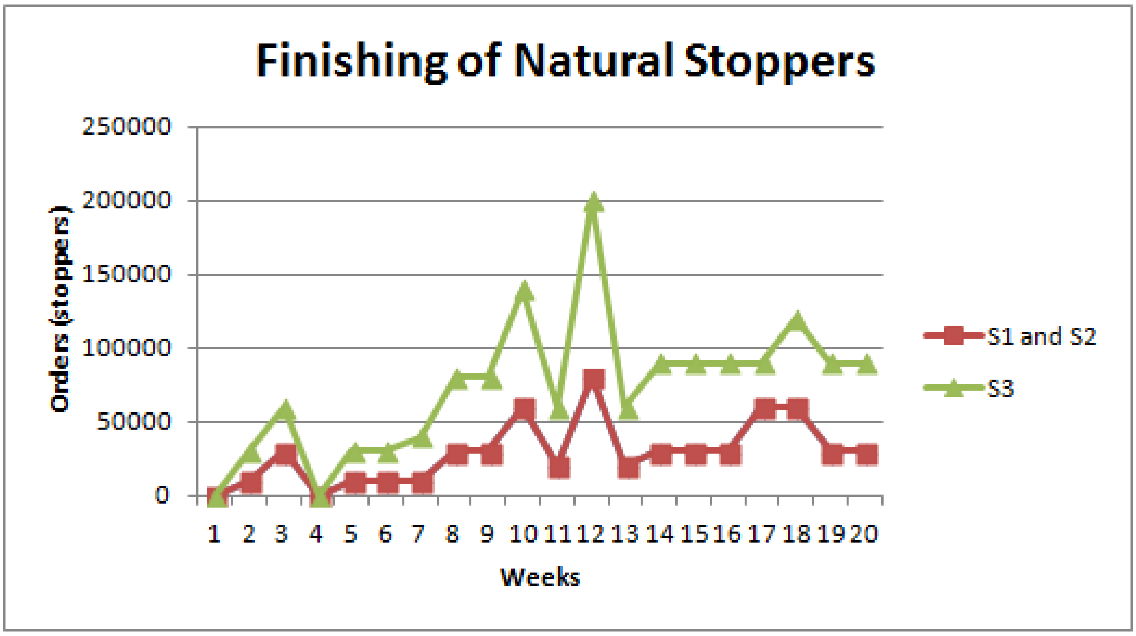


Figure D.12: Orders for S1, S2 and S3 Placed by Finishing of Natural Stoppers in Scenario A

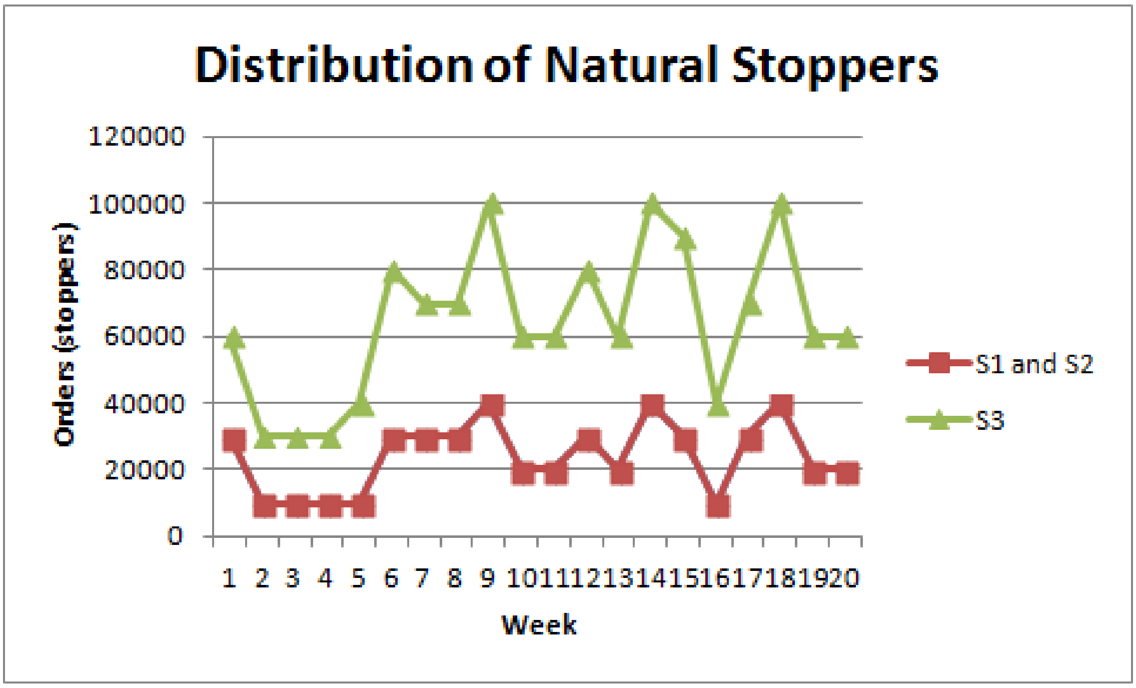


Figure D.13: Orders for S1, S2 and S3 Placed by Distribution of Natural Stoppers in Scenario A

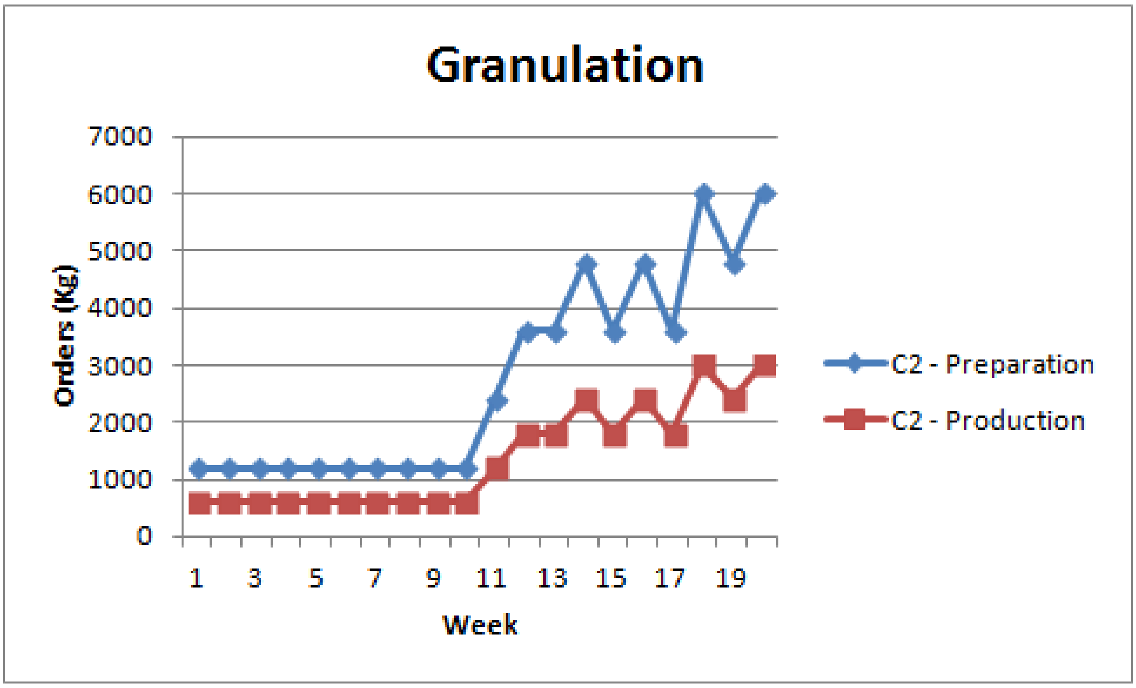


Figure D.14: Orders for C2 Placed by Granulation in Scenario A

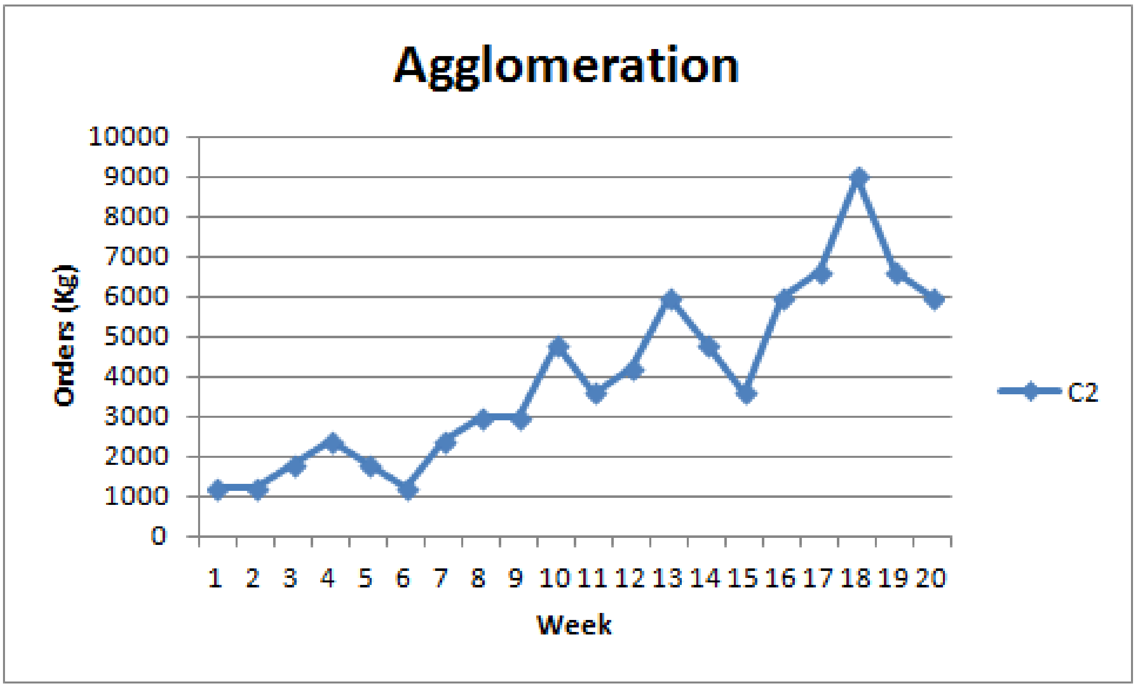


Figure D.15: Orders for C2 Placed by Agglomeration in Scenario A

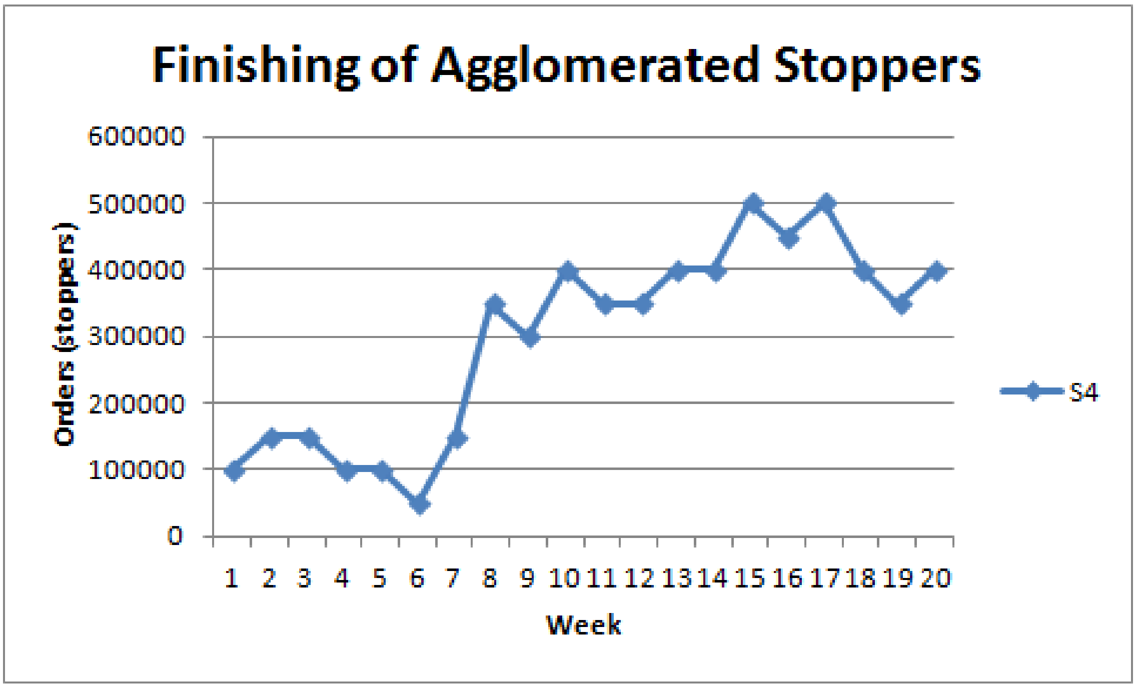


Figure D.16: Orders for S4 Placed by Finishing of Agglomerated Stoppers in Scenario A

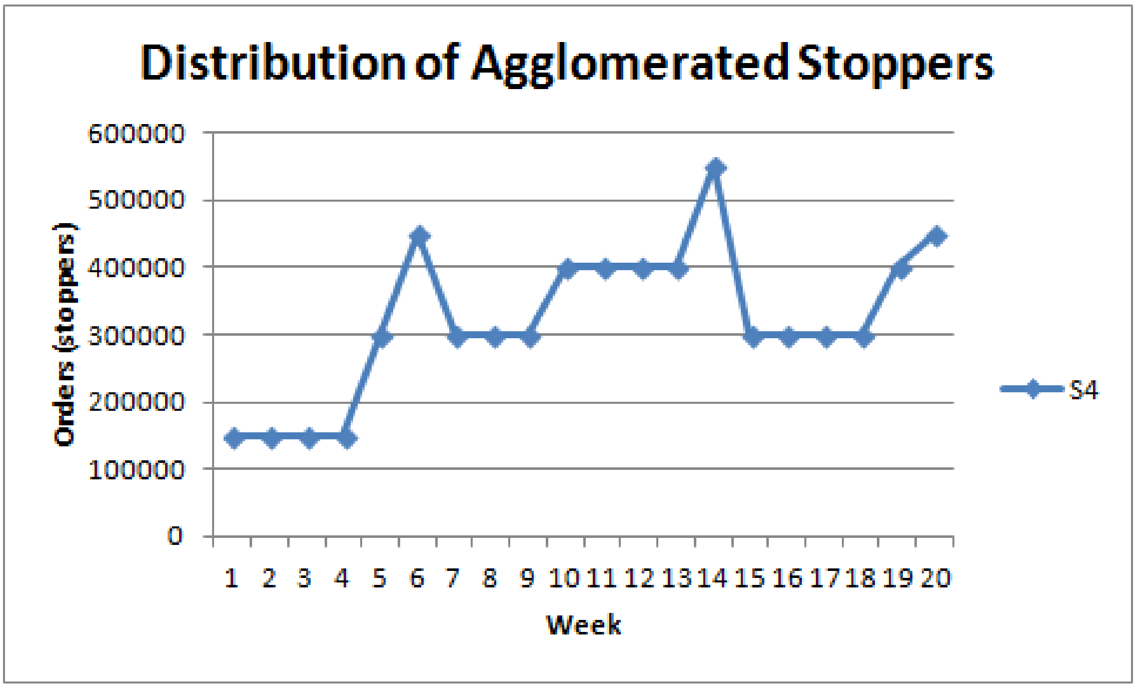


Figure D.17: Orders for S4 Placed by Distribution of Agglomerated Stoppers in Scenario A

D.1.3 Costs

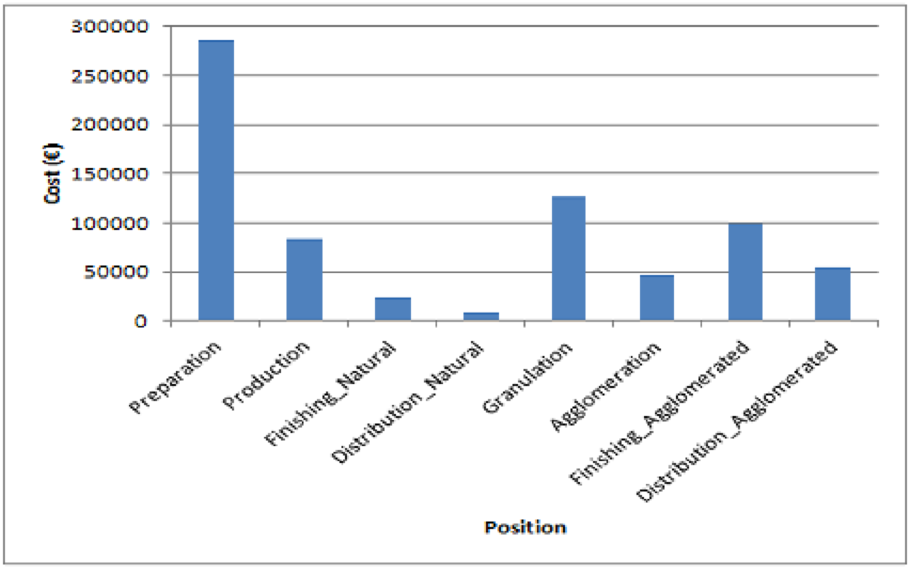


Figure D.18: Absolute Costs by Stage in Scenario A

D.2 Results of Scenario B

D.2.1 Graphs of Inventories

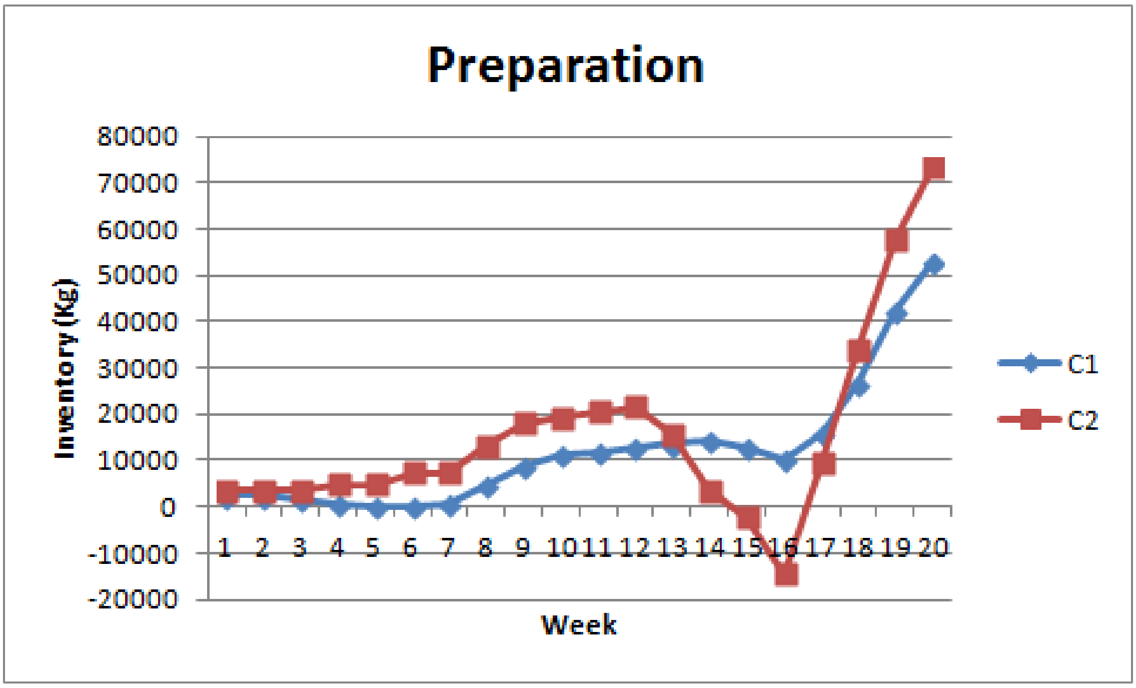


Figure D.19: Effective Inventory of C1 and C2 in Preparation in Scenario B

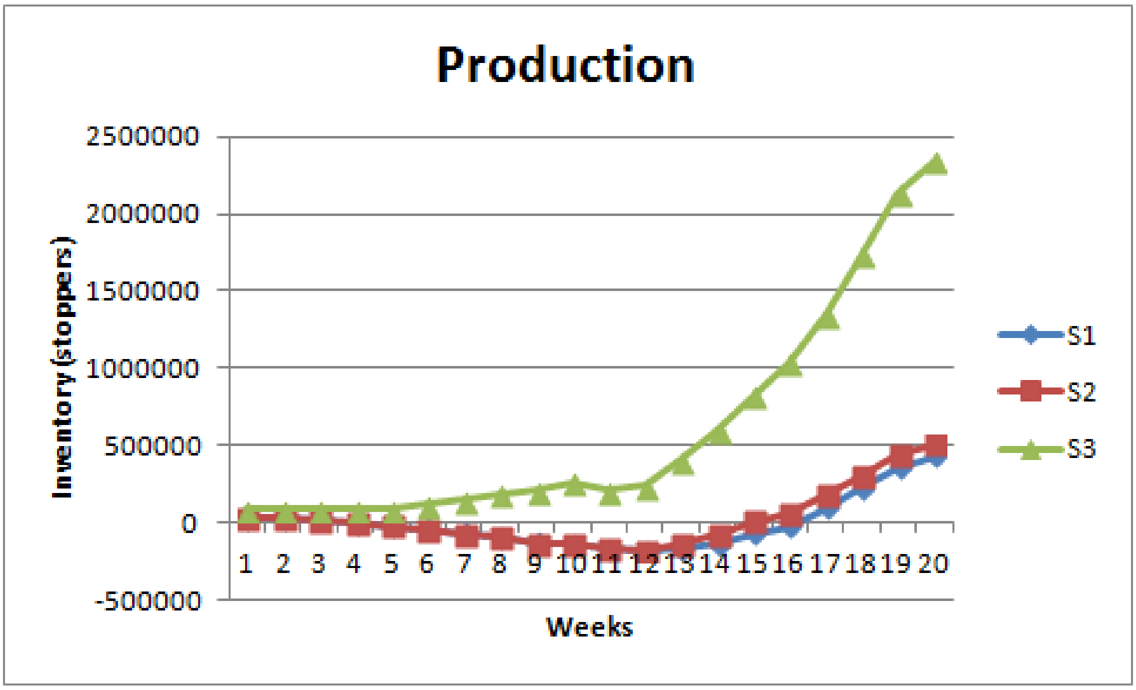


Figure D.20: Effective Inventory of S1, S2 and S3 in Production in Scenario B

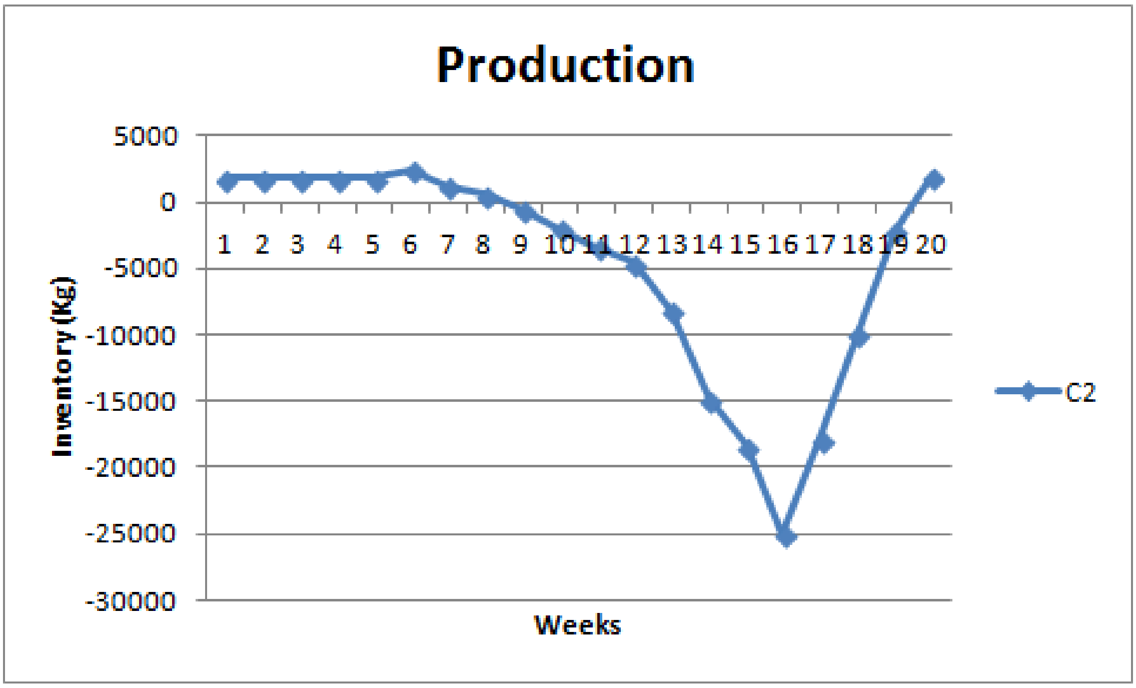


Figure D.21: Effective Inventory of C2 in Production in Scenario B

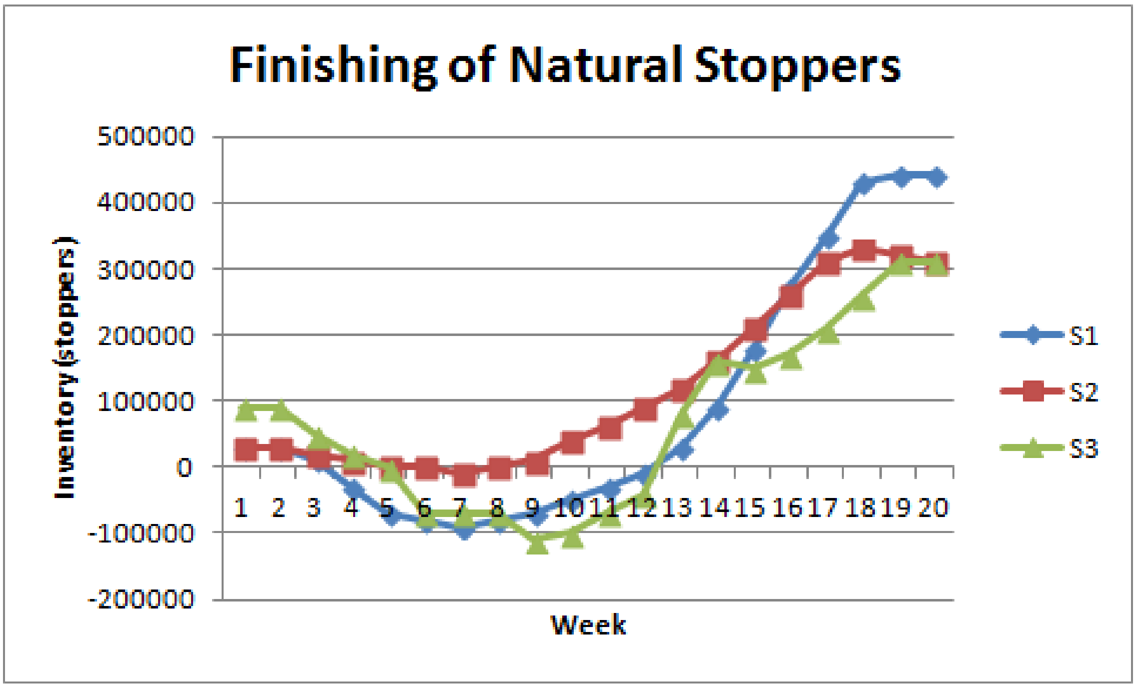


Figure D.22: Effective Inventory of S1, S2 and S3 in Finishing of Natural Stoppers in Scenario B

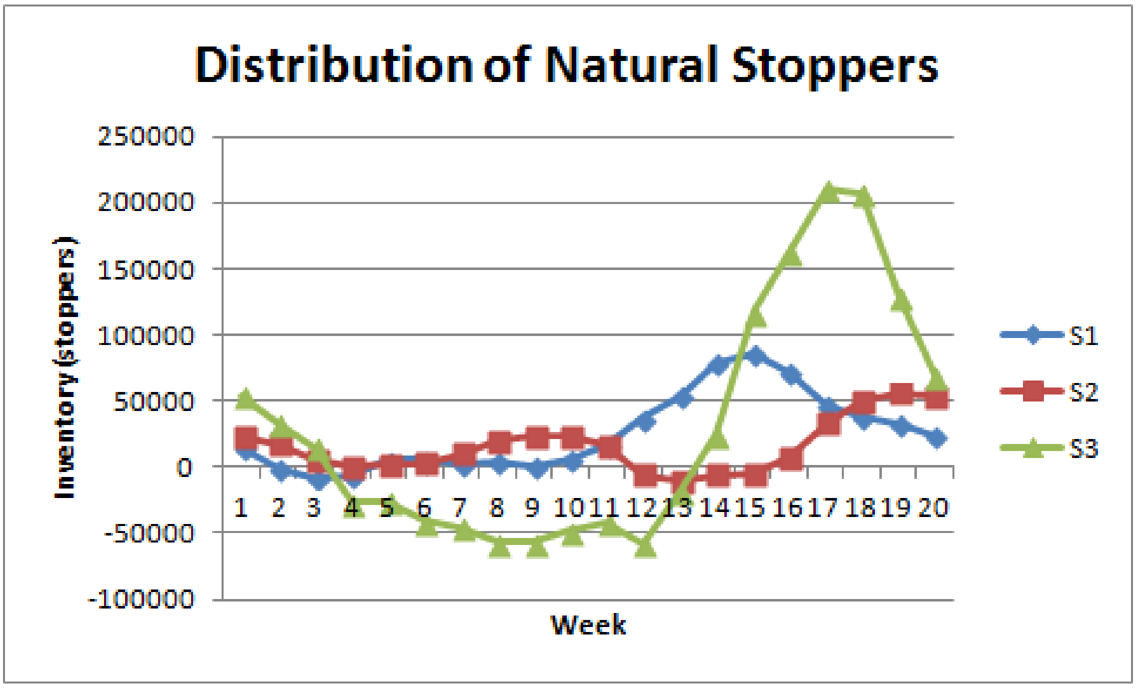


Figure D.23: Effective Inventory of S1, S2 and S3 in Distribution of Natural Stoppers in Scenario B

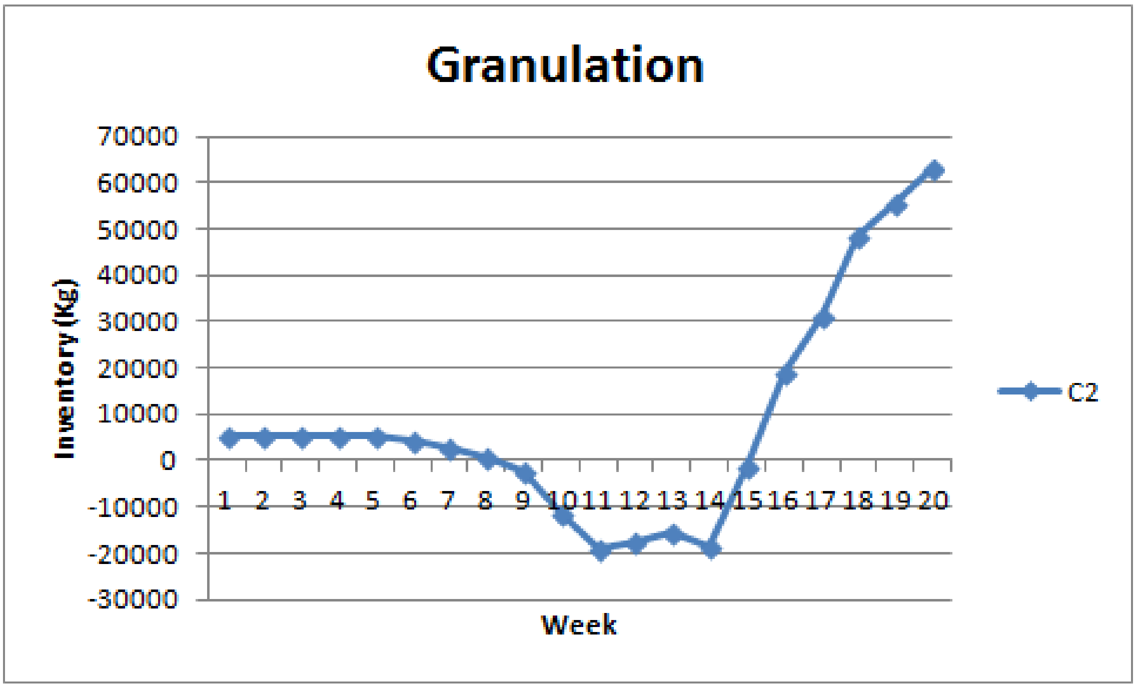


Figure D.24: Effective Inventory of C2 in Granulation in Scenario B

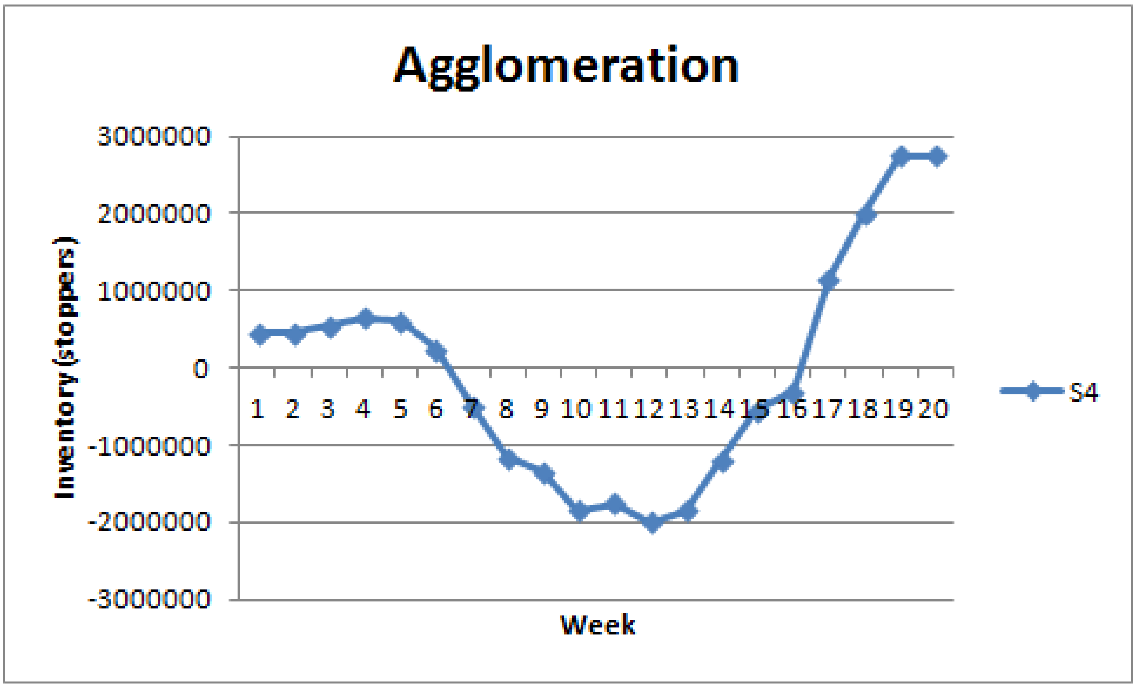


Figure D.25: Effective Inventory of S4 in Agglomeration in Scenario B

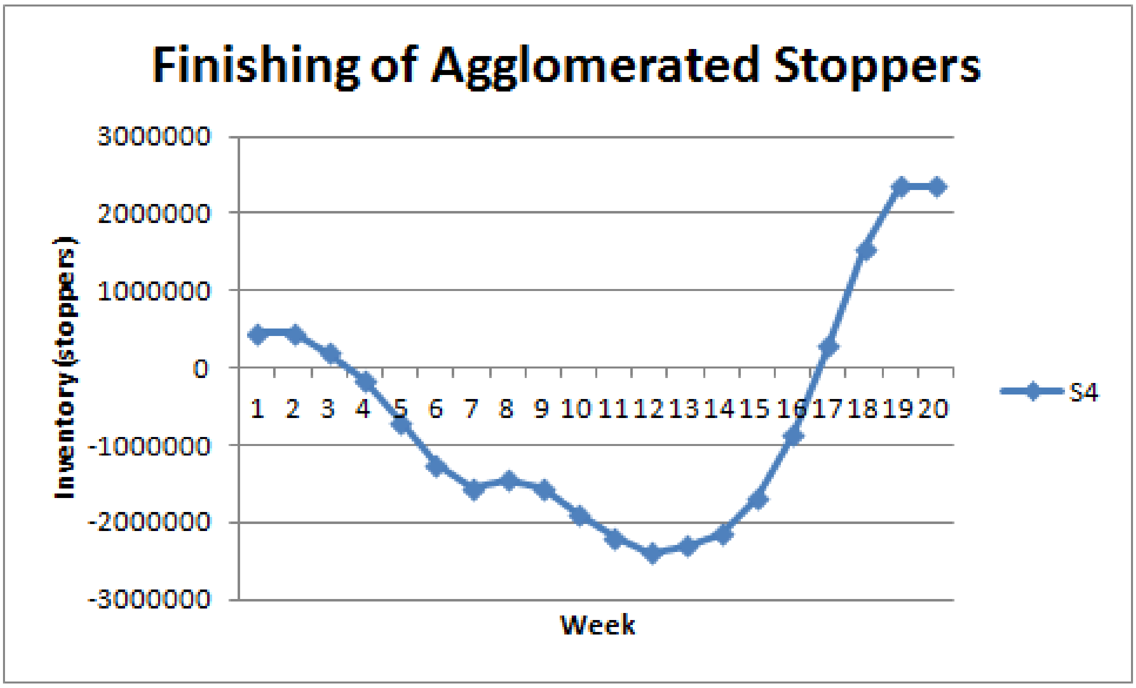


Figure D.26: Effective Inventory of S4 in Finishing of Agglomerated Stoppers in Scenario B

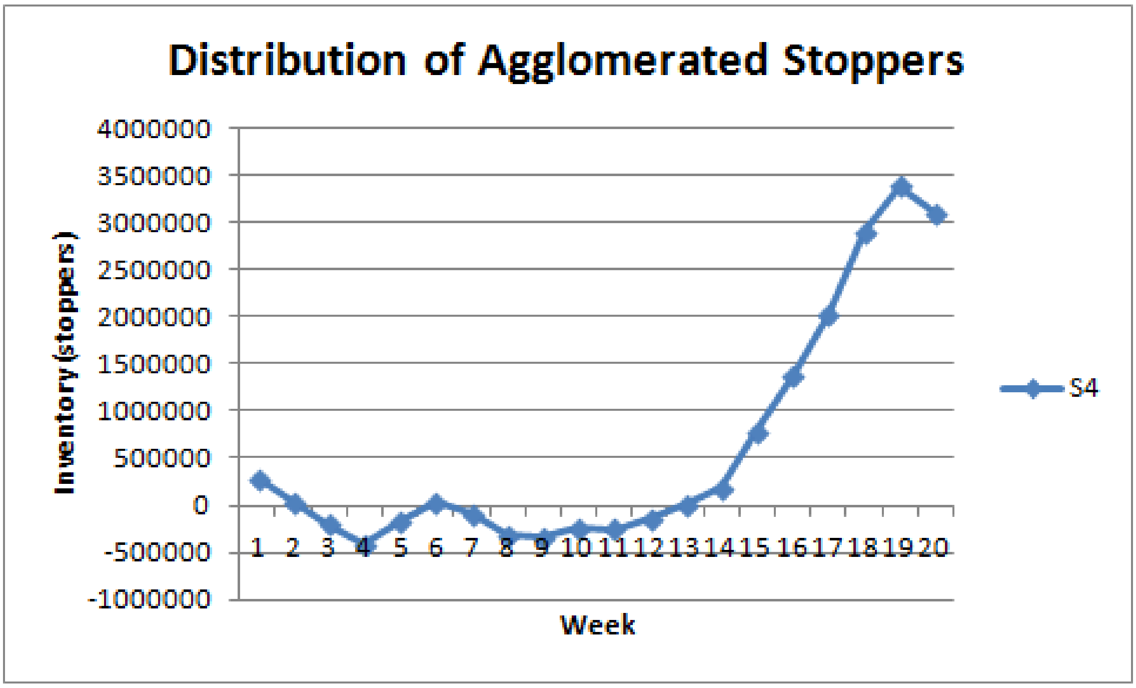


Figure D.27: Effective Inventory of S4 in Distribution of Agglomerated Stoppers in Scenario B

D.2.2 Graphs of Orders Placed

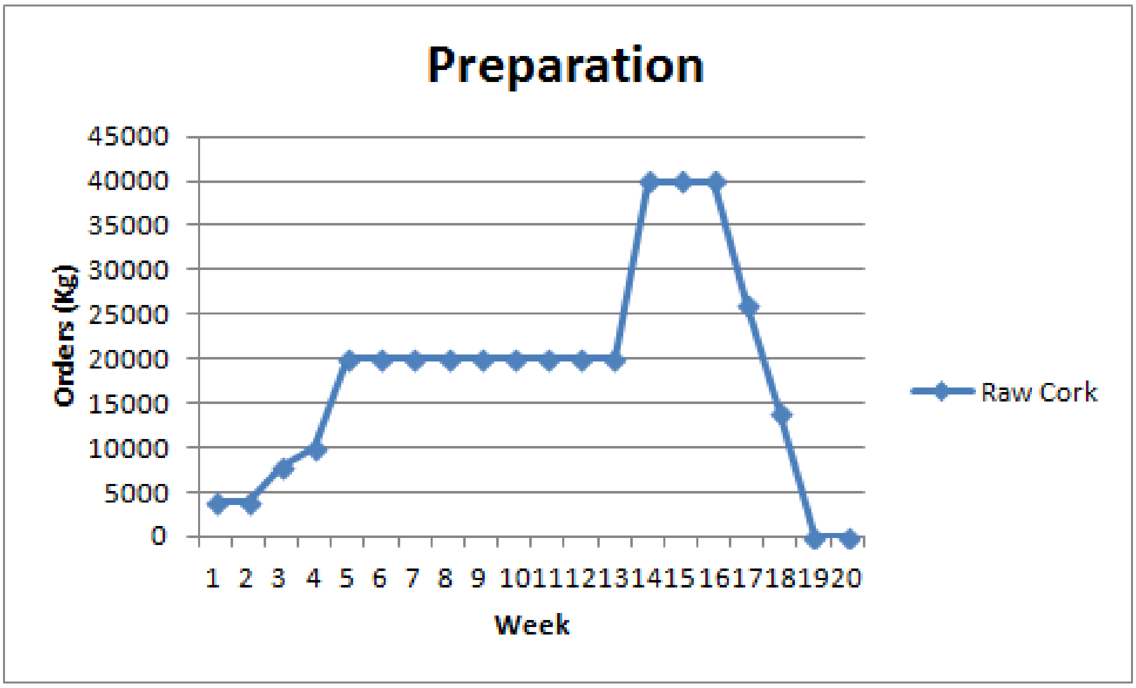


Figure D.28: Orders for Raw Cork Placed by Preparation in Scenario B

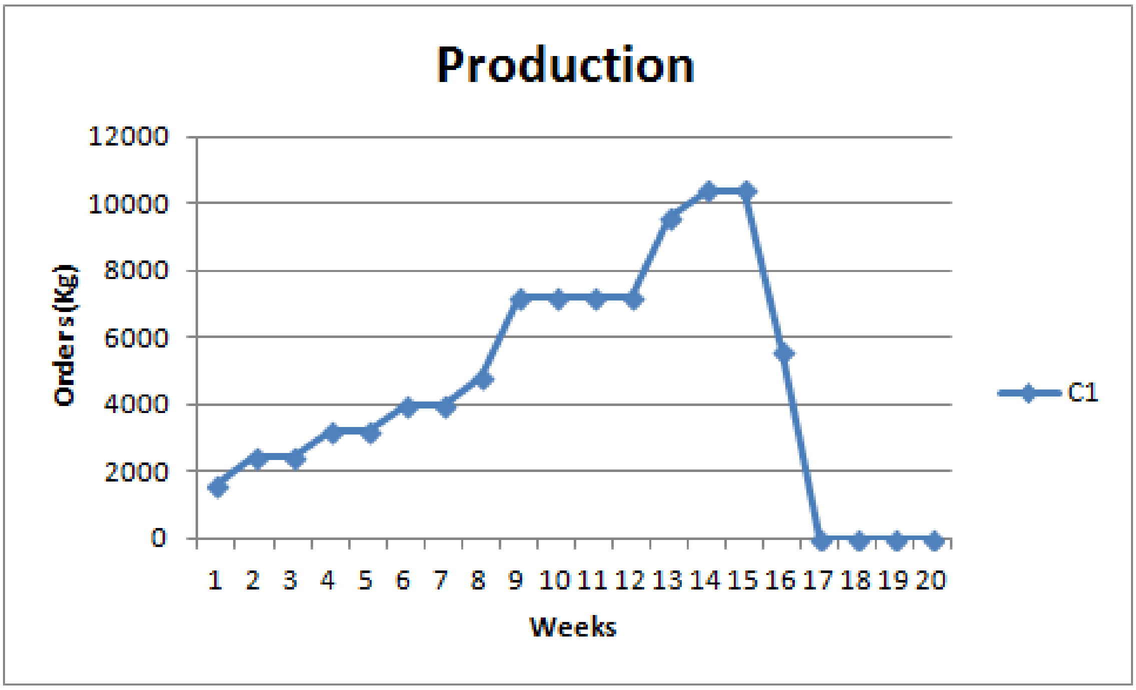


Figure D.29: Orders for C1 Placed by Production in Scenario B

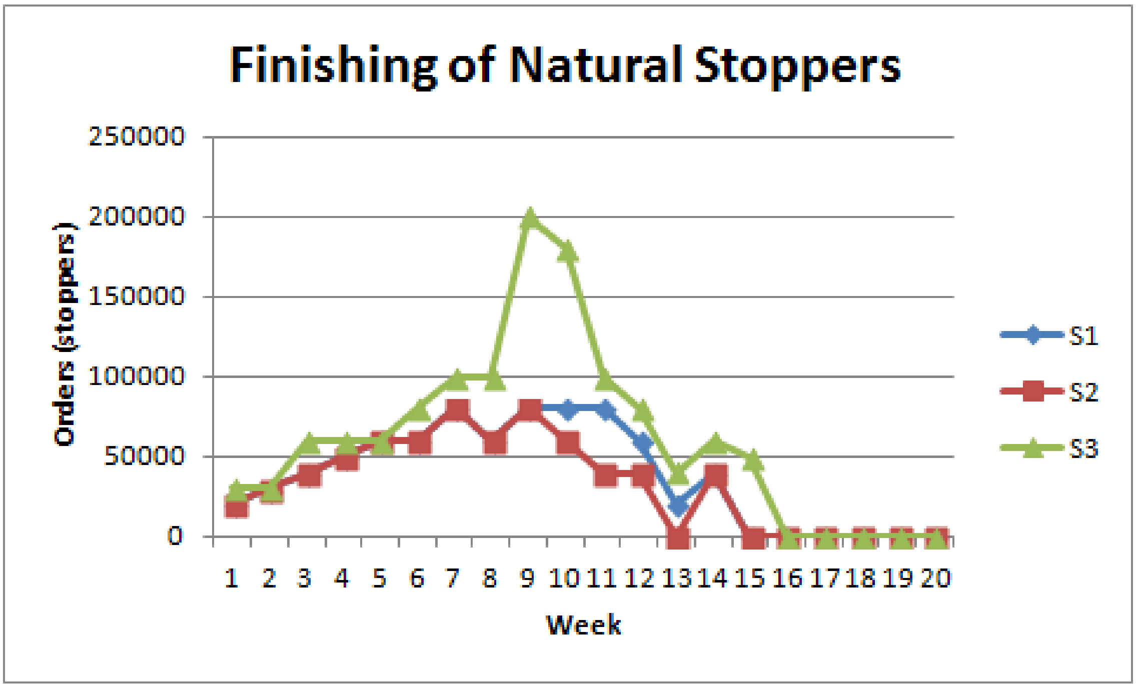


Figure D.30: Orders for S1, S2 and S3 Placed by Finishing of Natural Stoppers in Scenario B

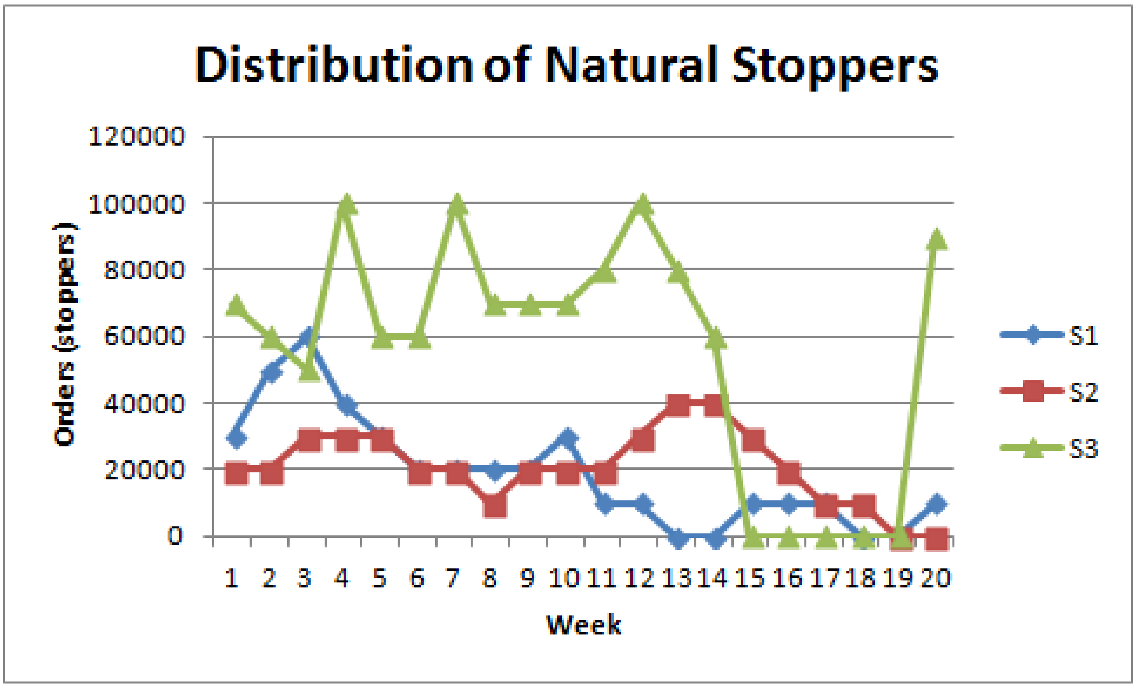


Figure D.31: Orders for S1, S2 and S3 Placed by Distribution of Natural Stoppers in Scenario B

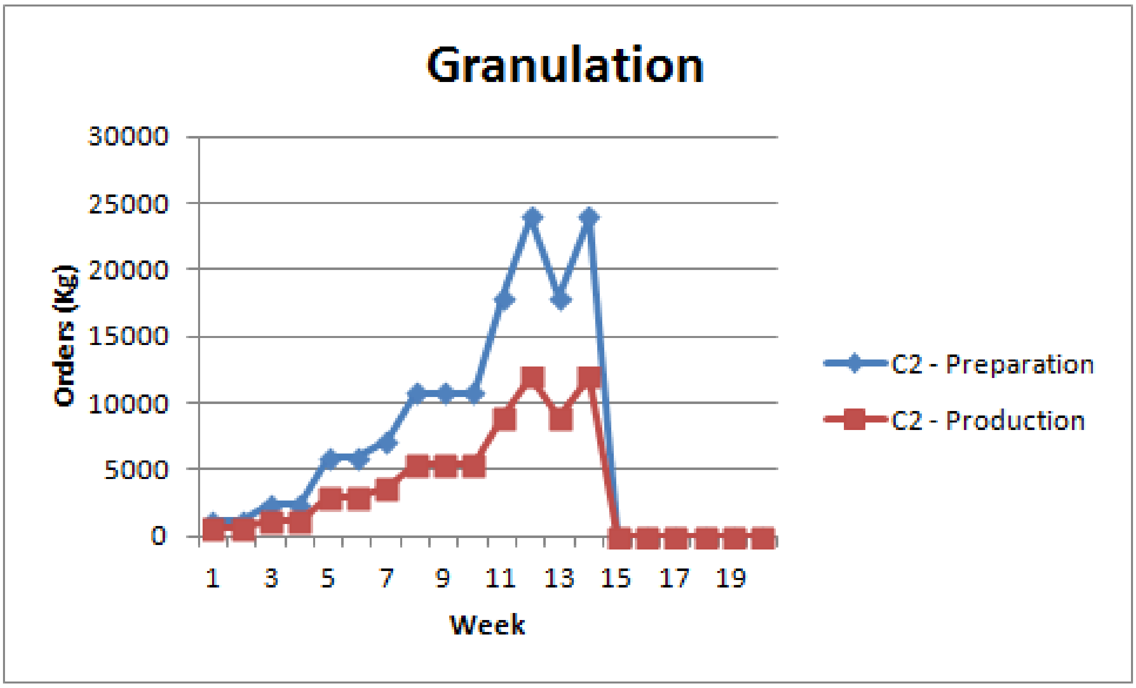


Figure D.32: Orders for C2 Placed by Granulation in Scenario B

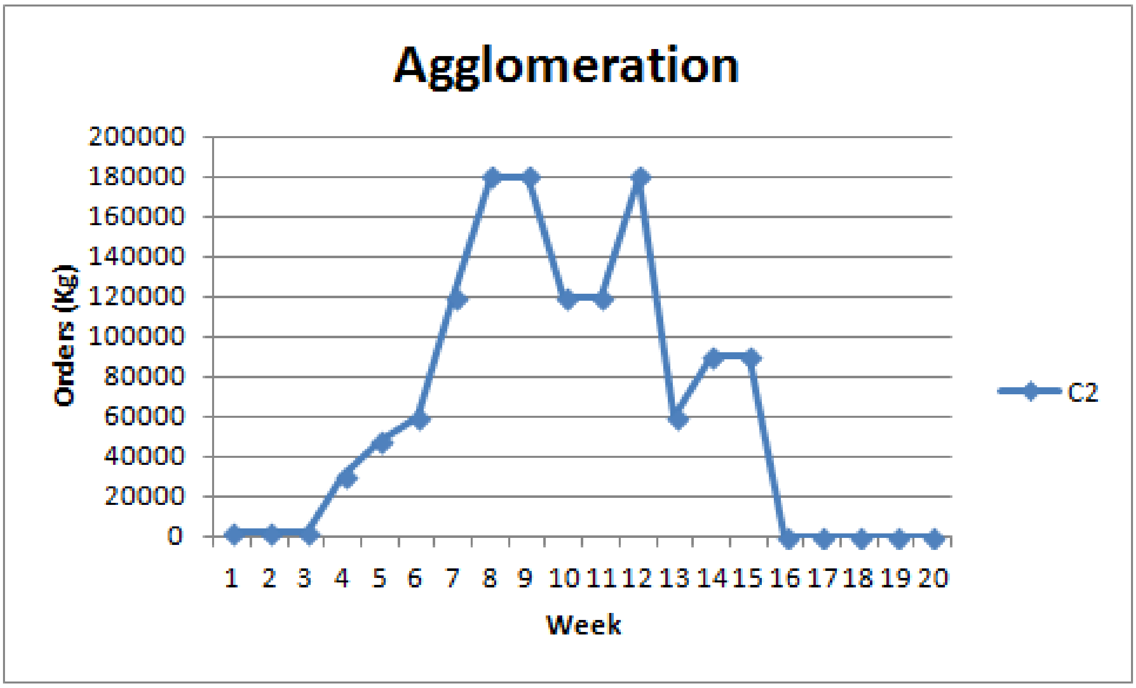


Figure D.33: Orders for C2 Placed by Agglomeration in Scenario B

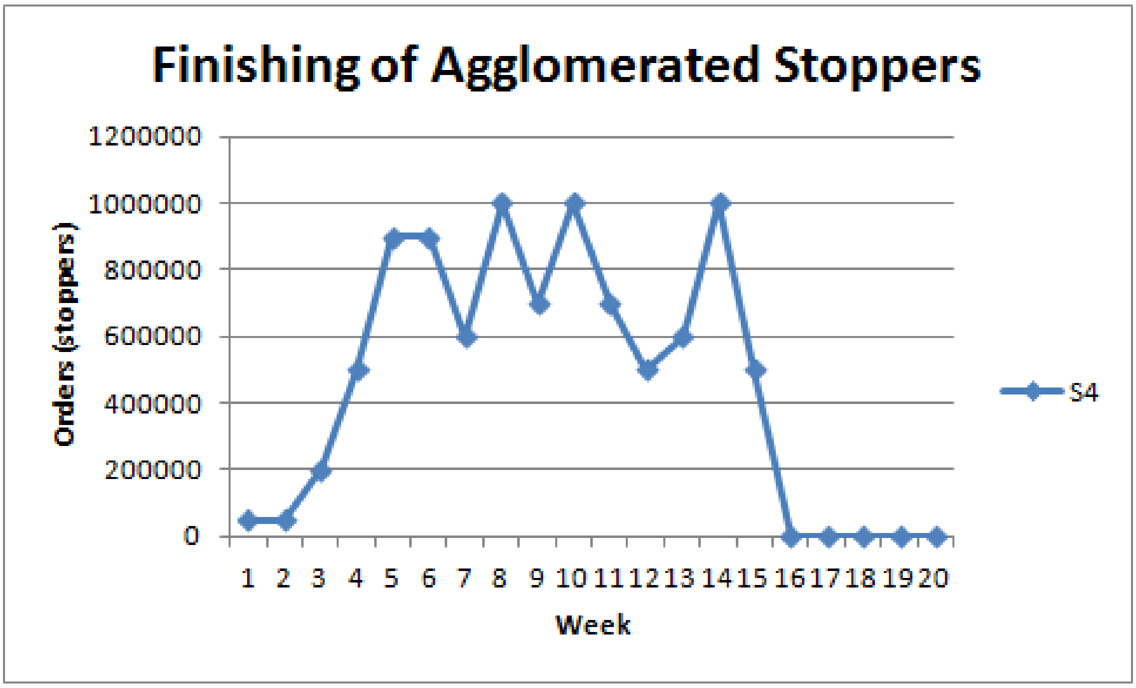


Figure D.34: Orders for S4 Placed by Finishing of Agglomerated Stoppers in Scenario B

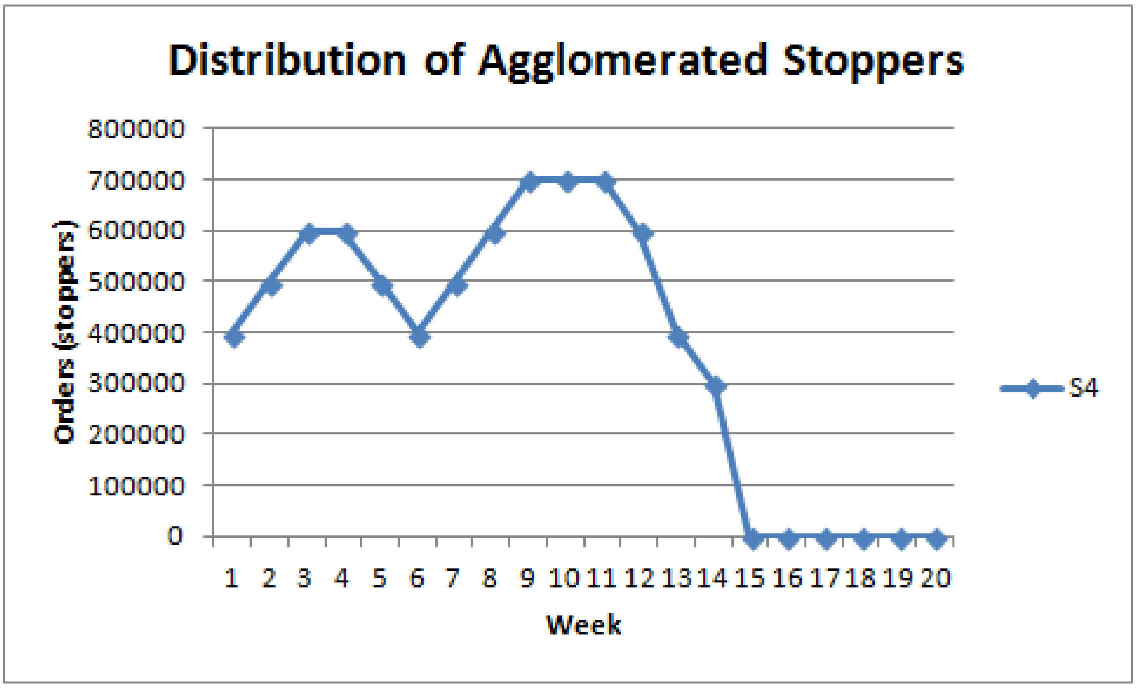


Figure D.35: Orders for S4 Placed by Distribution of Agglomerated Stoppers in Scenario B

D.2.3 Costs

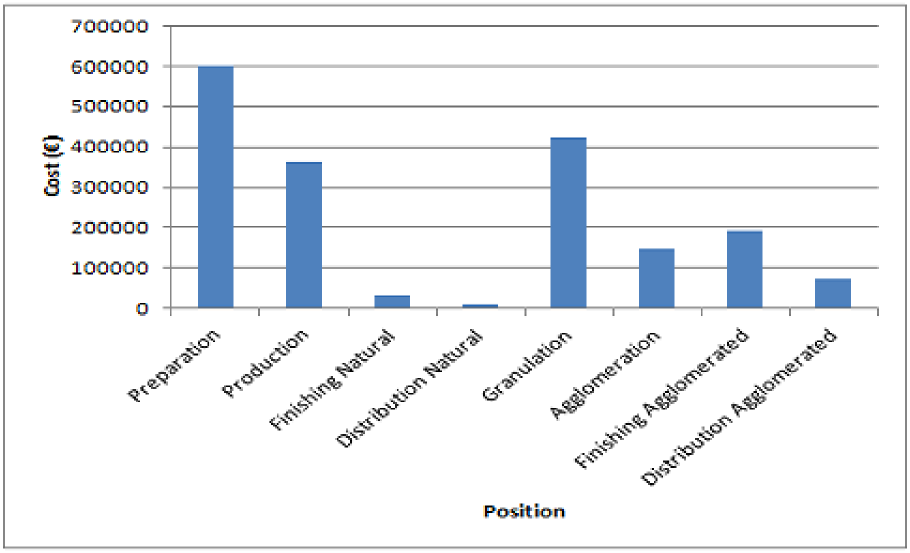


Figure D.36: Absolute Costs by Stage in Scenario B

D.3 Results of Scenario C

D.3.1 Graphs of Inventories

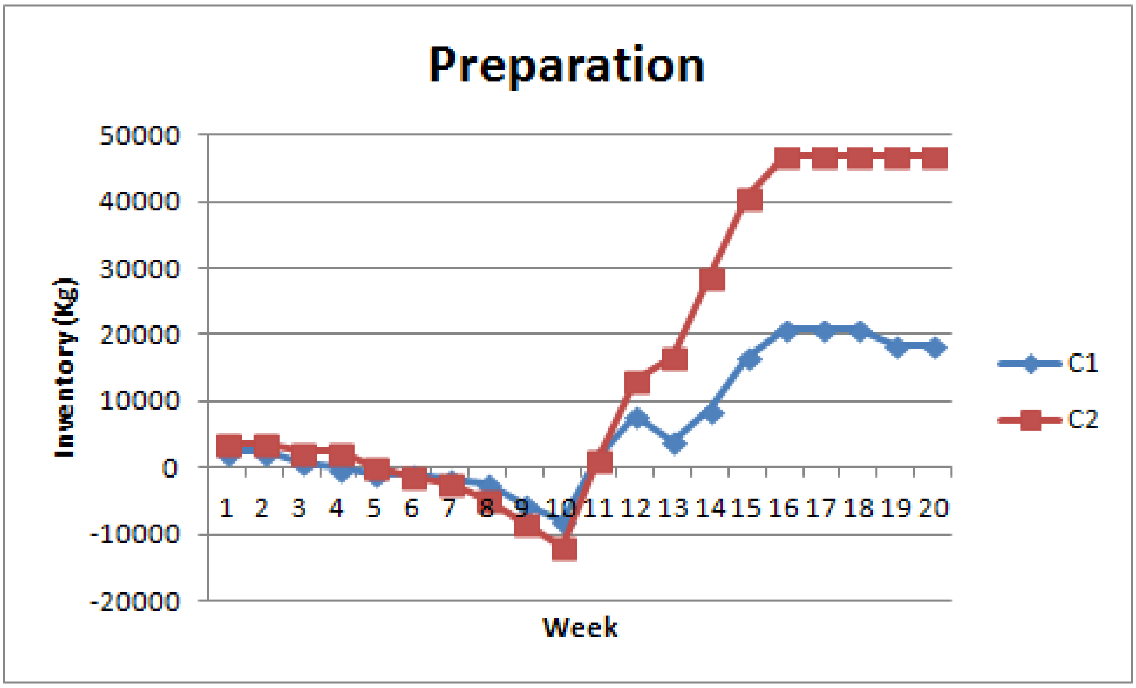


Figure D.37: Effective Inventory of C1 and C2 in Preparation in Scenario C

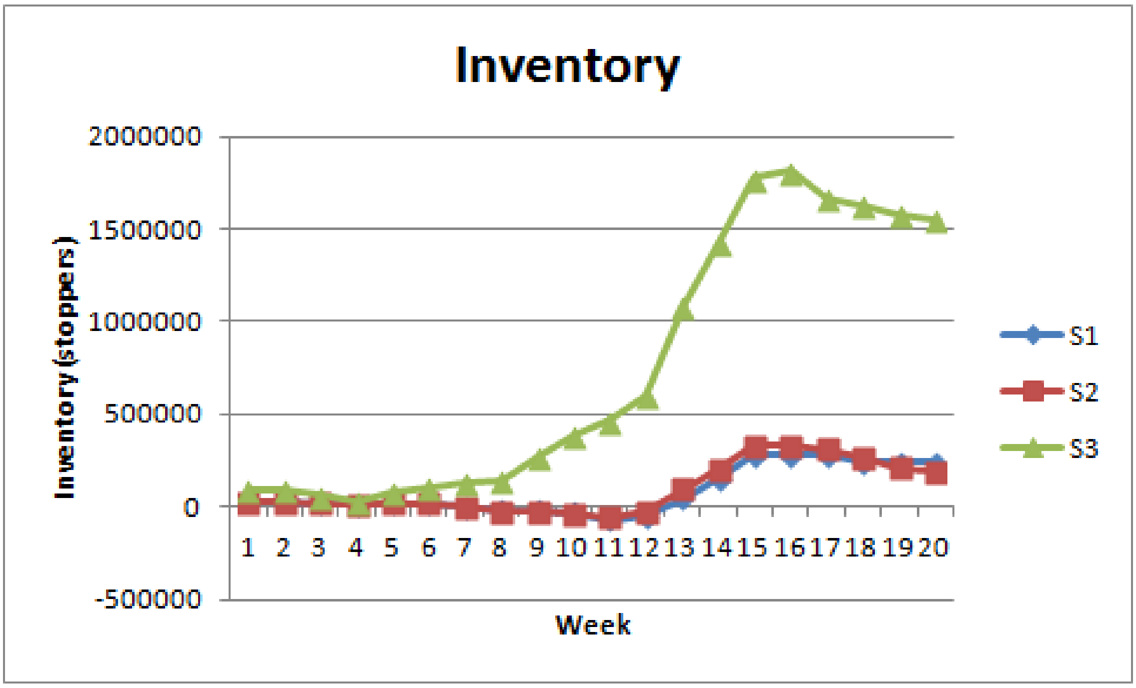


Figure D.38: Effective Inventory of S1, S2 and S3 in Production in Scenario C

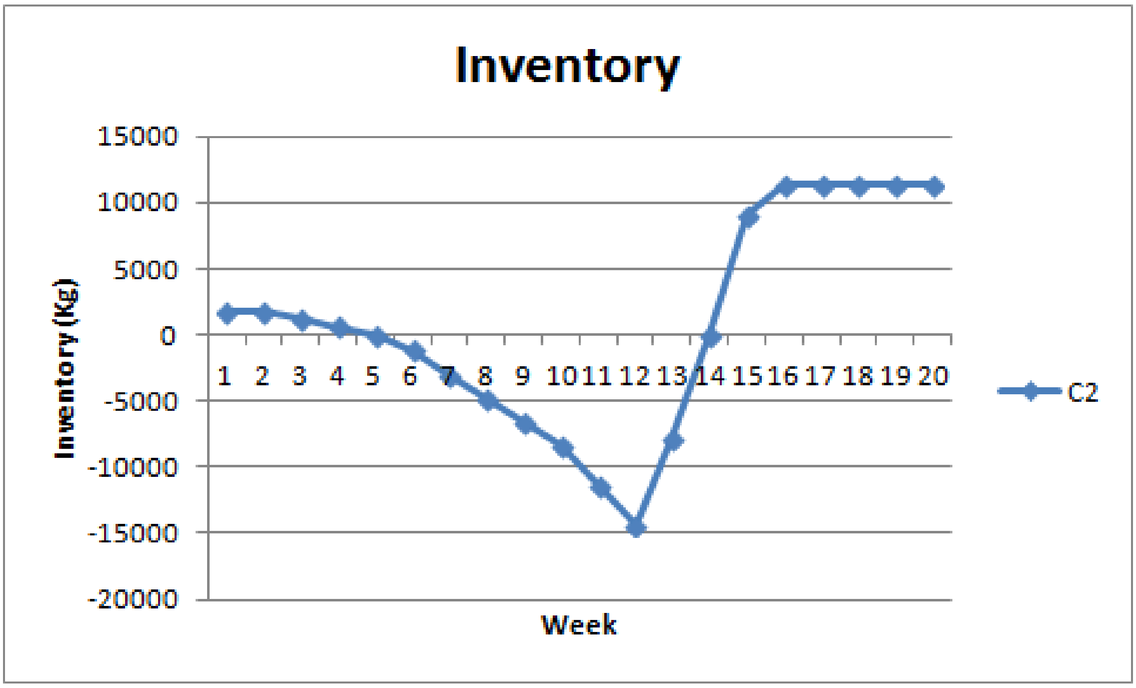


Figure D.39: Effective Inventory of C2 in Production in Scenario C

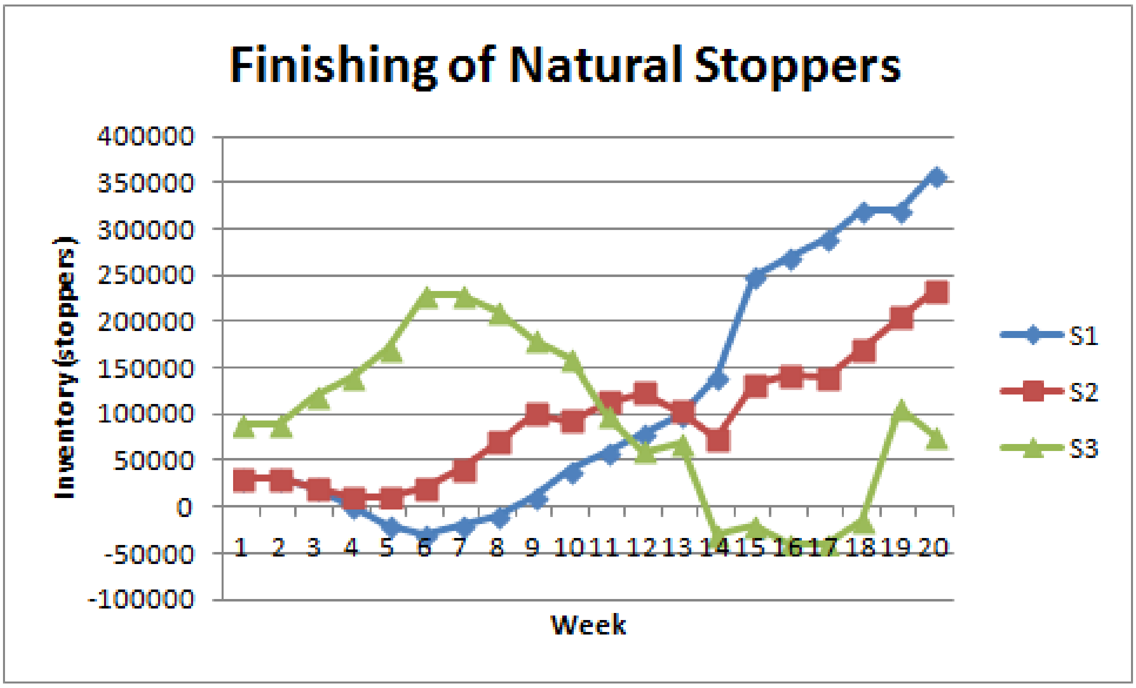


Figure D.40: Effective Inventory of S1, S2 and S3 in Finishing of Natural Stoppers in Scenario C

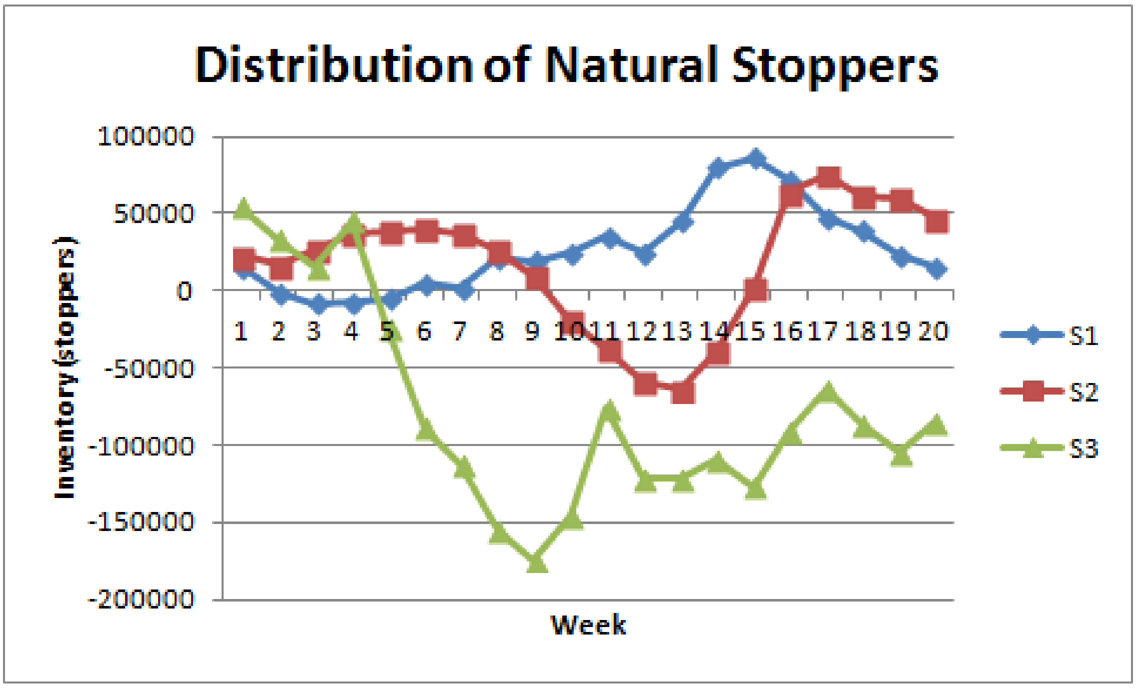


Figure D.41: Effective Inventory of S1, S2 and S3 in Distribution of Natural Stoppers in Scenario C

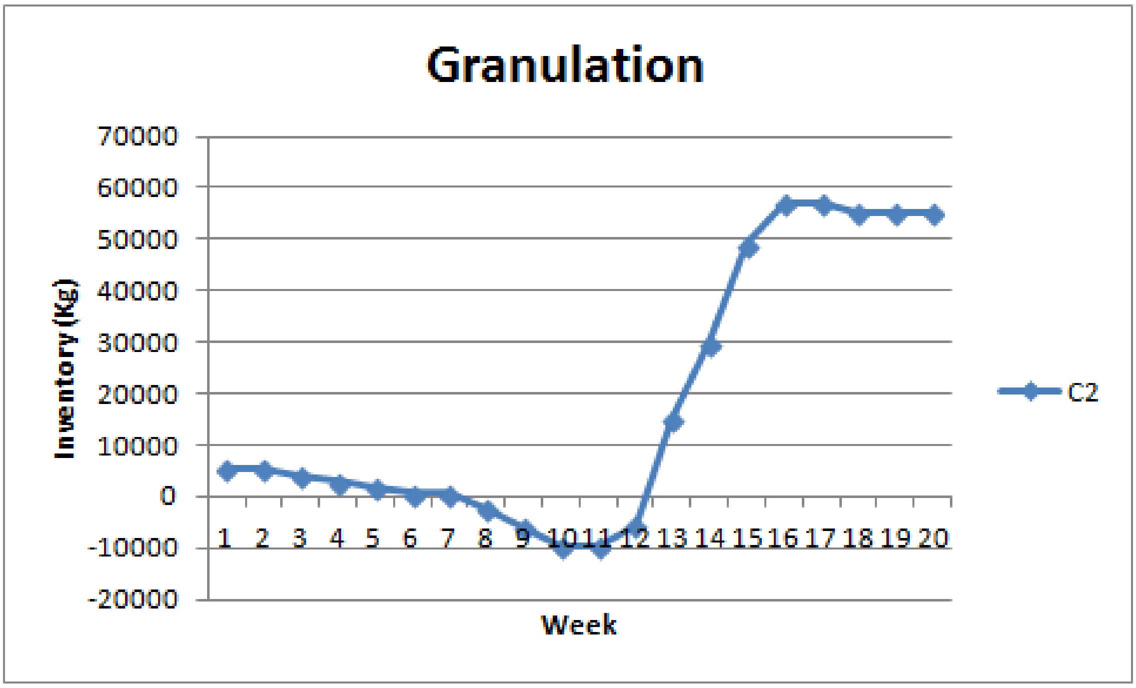


Figure D.42: Effective Inventory of C2 in Granulation in Scenario C

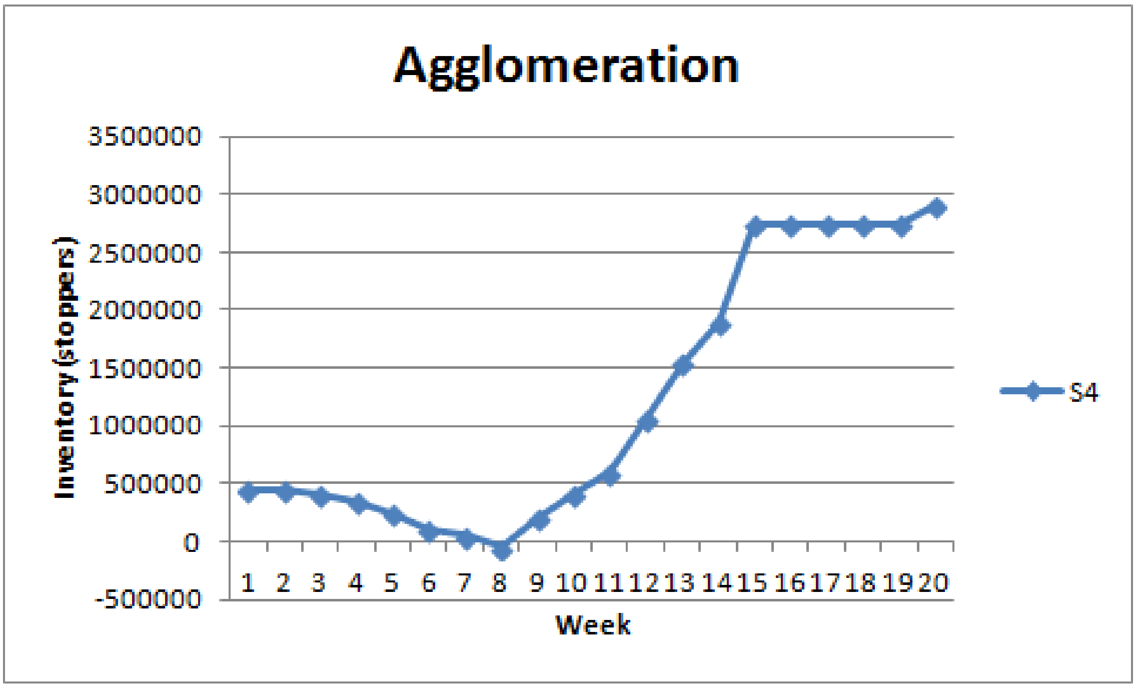


Figure D.43: Effective Inventory of S4 in Agglomeration in Scenario C

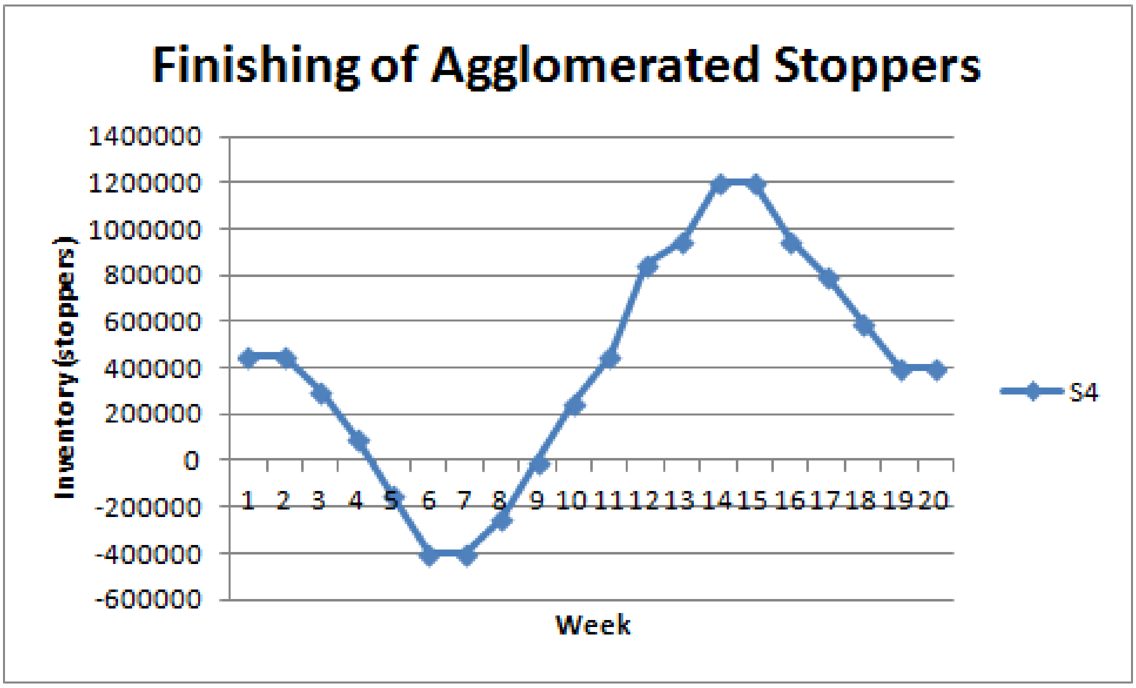


Figure D.44: Effective Inventory of S4 in Finishing of Agglomerated Stoppers in Scenario C

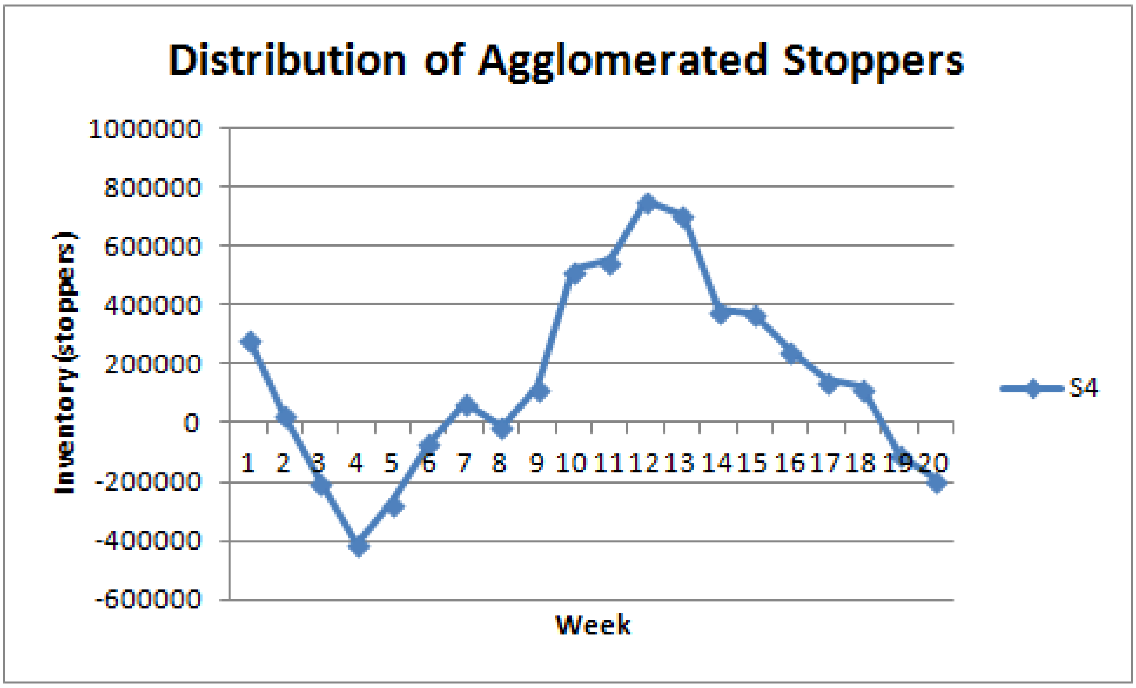


Figure D.45: Effective Inventory of S4 in Distribution of Agglomerated Stoppers in Scenario C

D.3.2 Graphs of Inventories of Special Stoppers

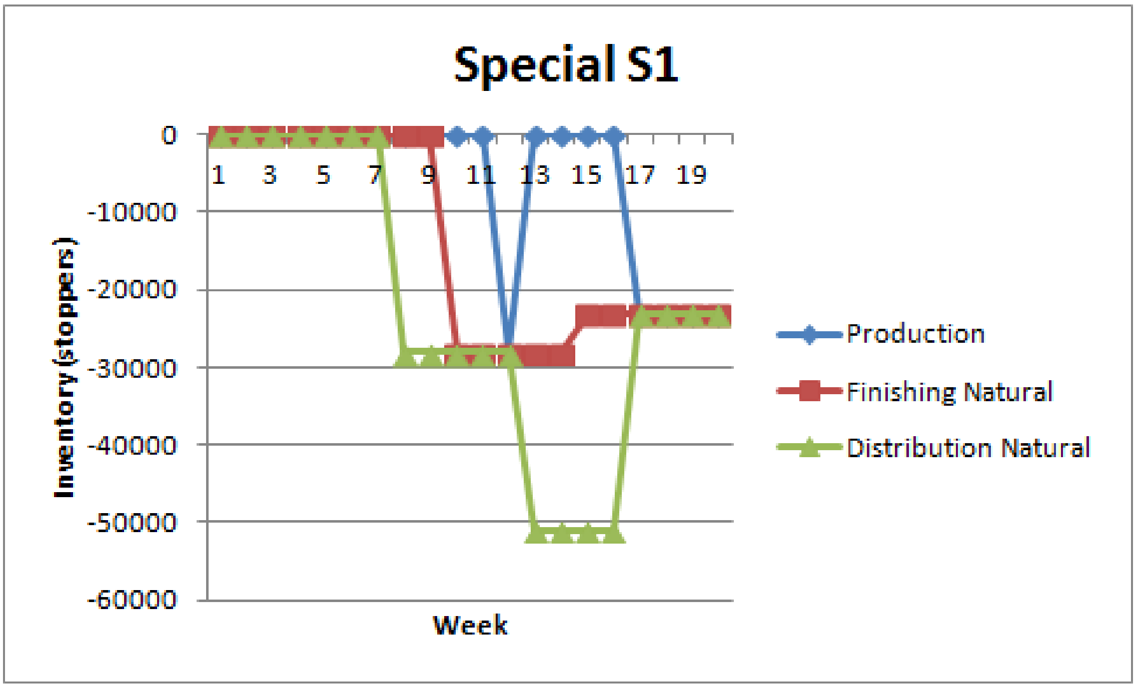


Figure D.46: Effective Inventory of Special S1 Stoppers

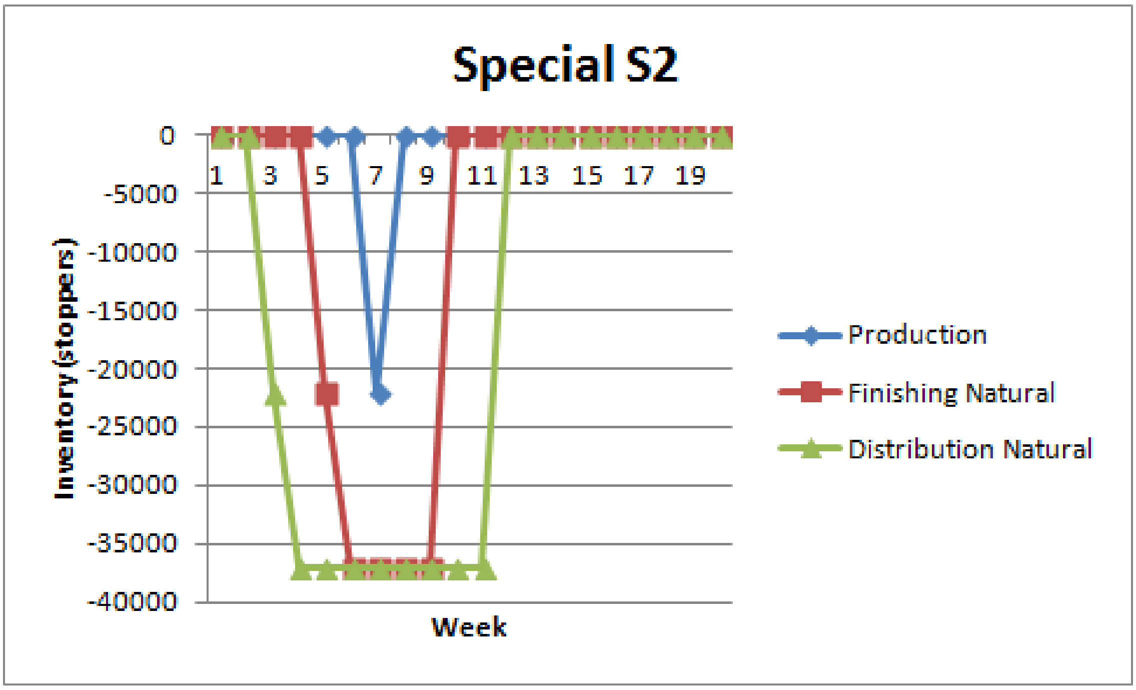


Figure D.47: Effective Inventory of Special S2 Stoppers

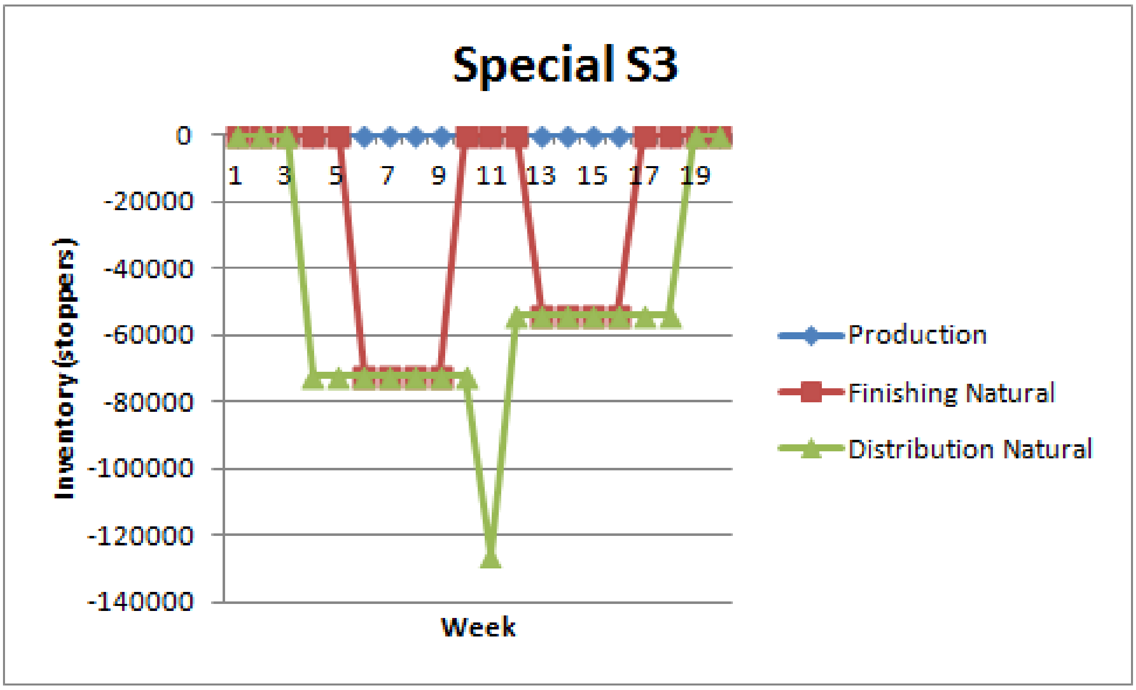


Figure D.48: Effective Inventory of Special S3 Stoppers

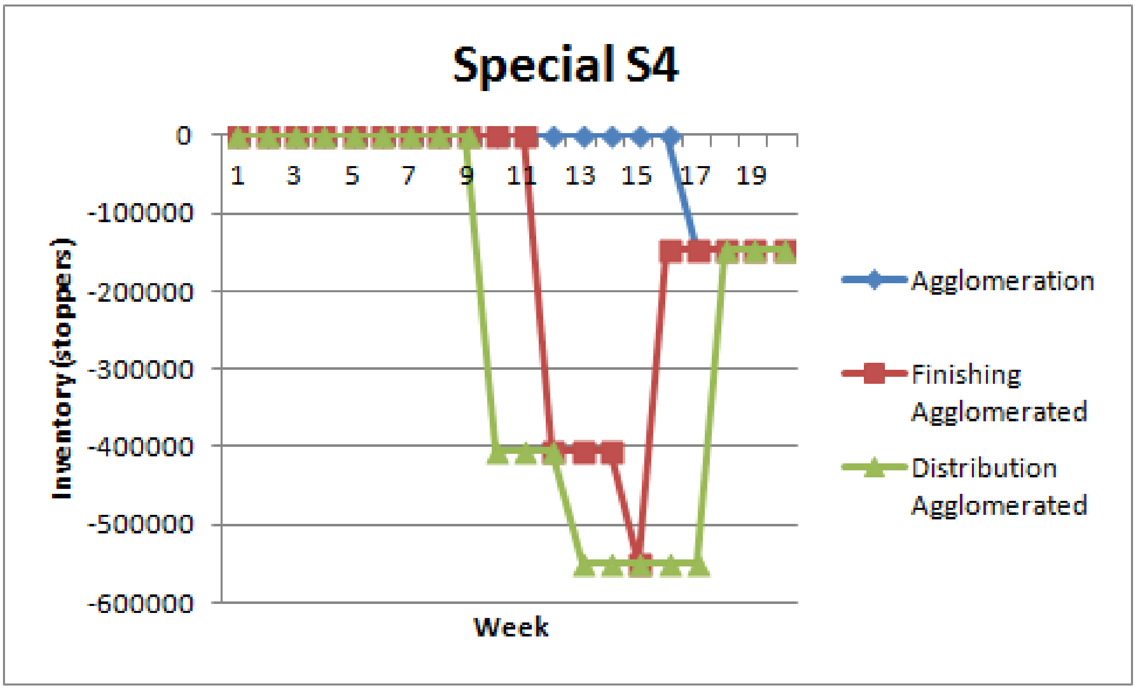


Figure D.49: Effective Inventory of Special S4 Stoppers

D.3.3 Graphs of Orders Placed

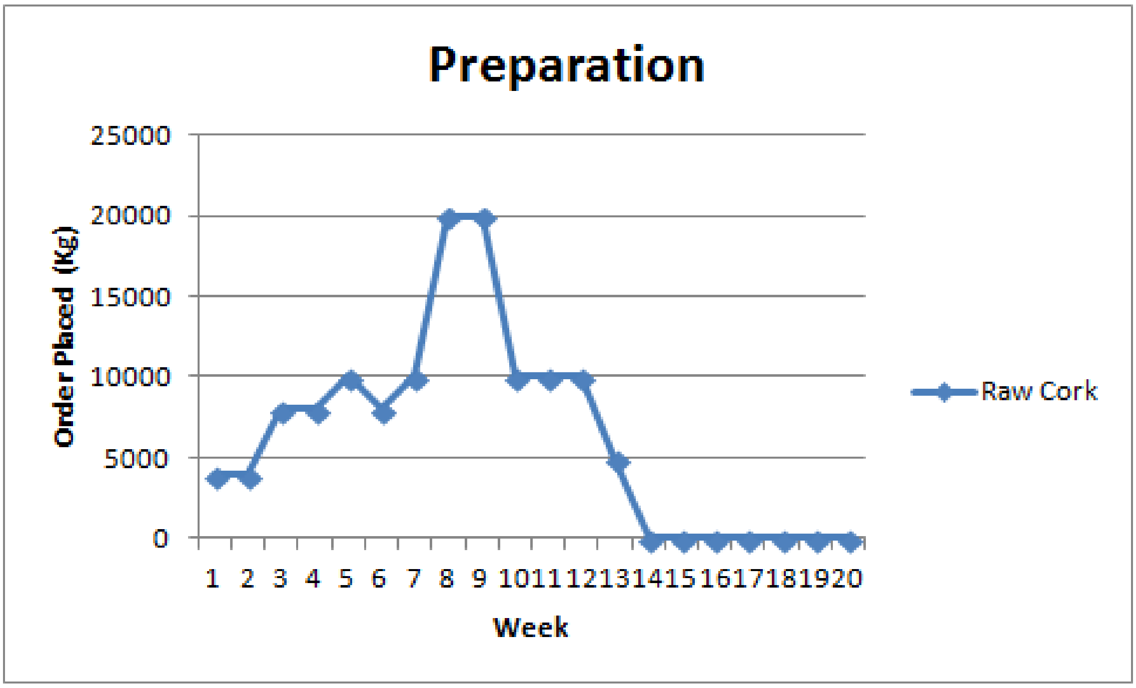


Figure D.50: Orders for Raw Cork Placed by Preparation in Scenario C

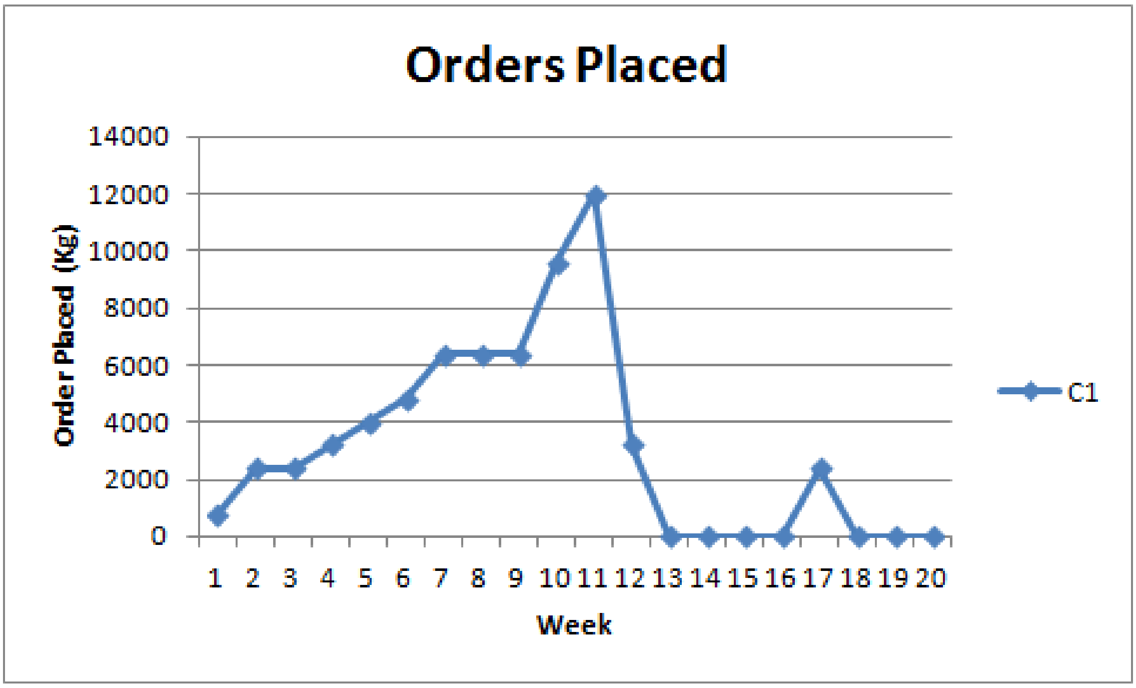


Figure D.51: Orders for C1 Placed by Production in Scenario C

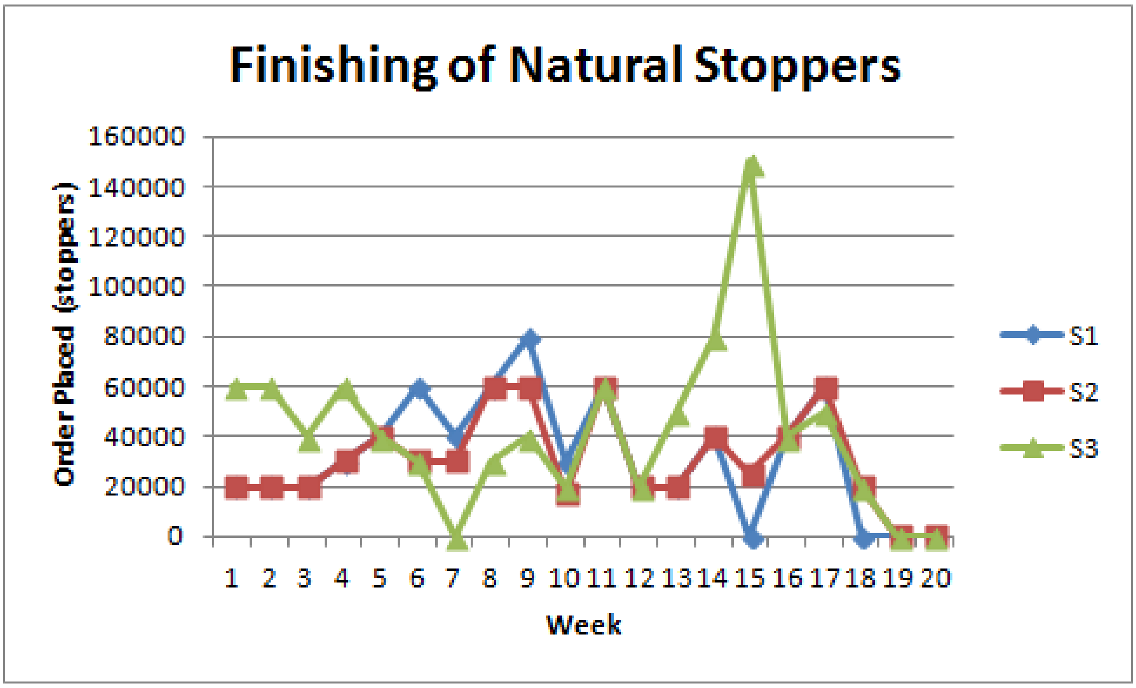


Figure D.52: Orders for S1, S2 and S3 Placed by Finishing of Natural Stoppers in Scenario C

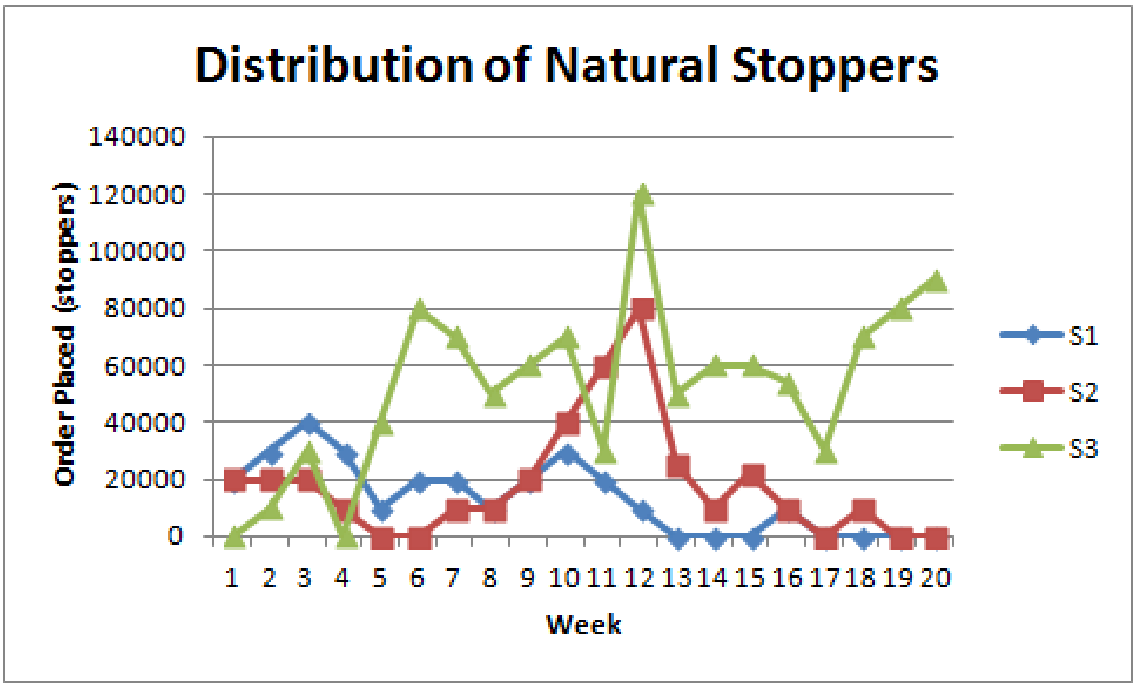


Figure D.53: Orders for S1, S2 and S3 Placed by Distribution of Natural Stoppers in Scenario C

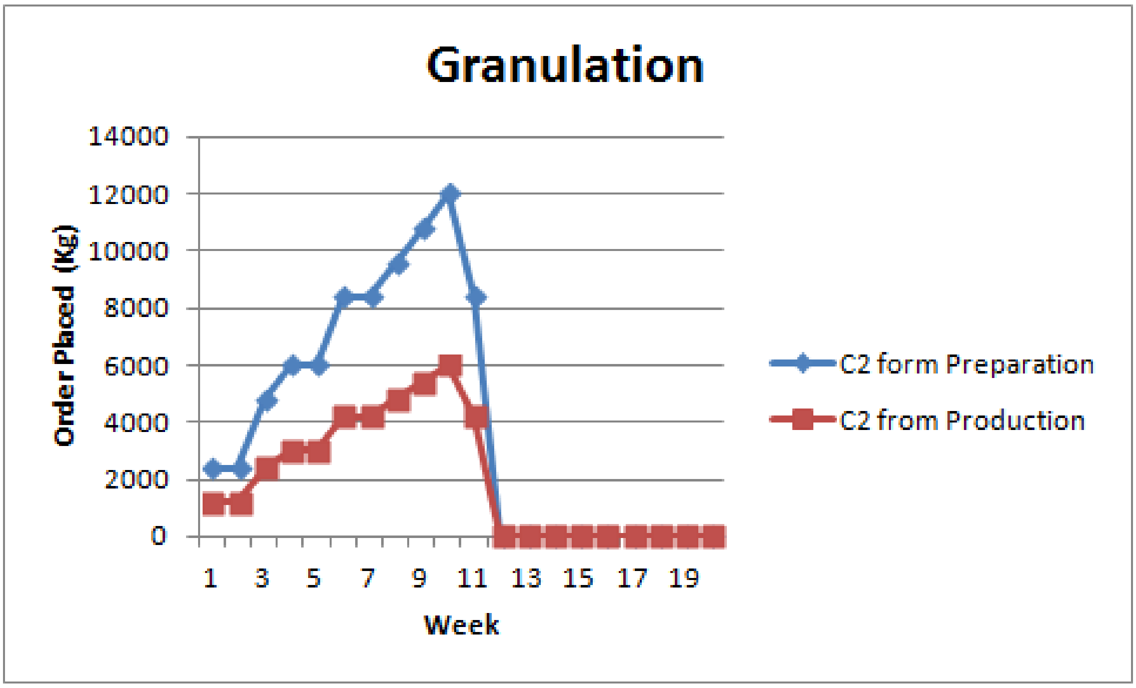


Figure D.54: Orders for C2 Placed by Granulation in Scenario C

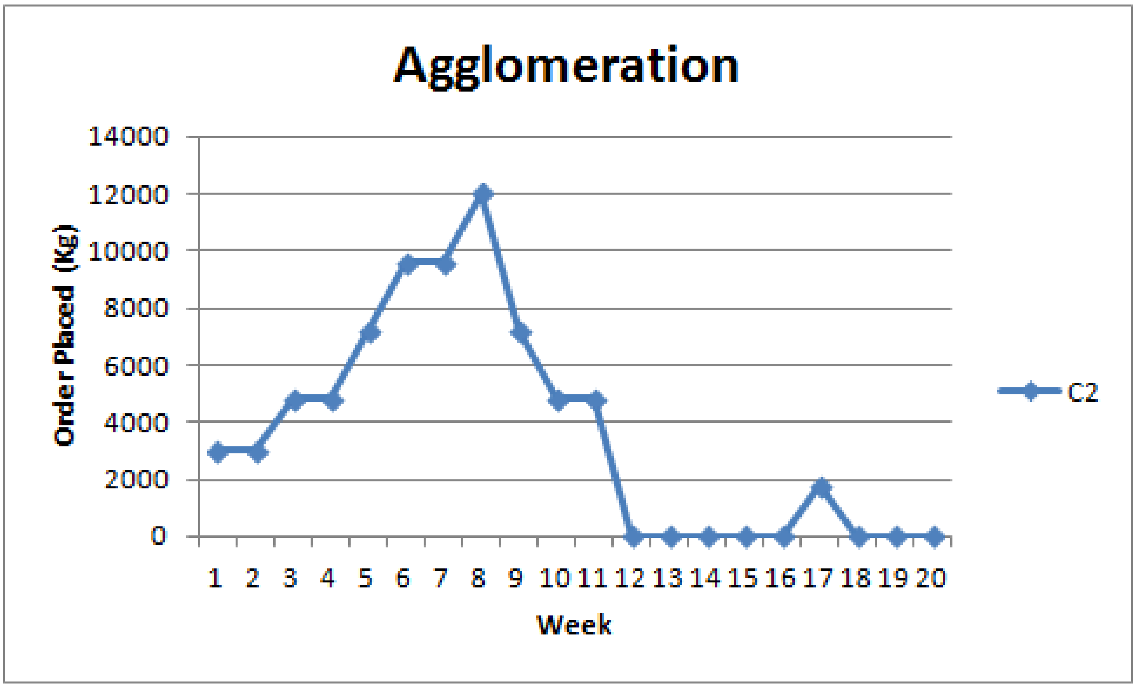


Figure D.55: Orders for C2 Placed by Agglomeration in Scenario C

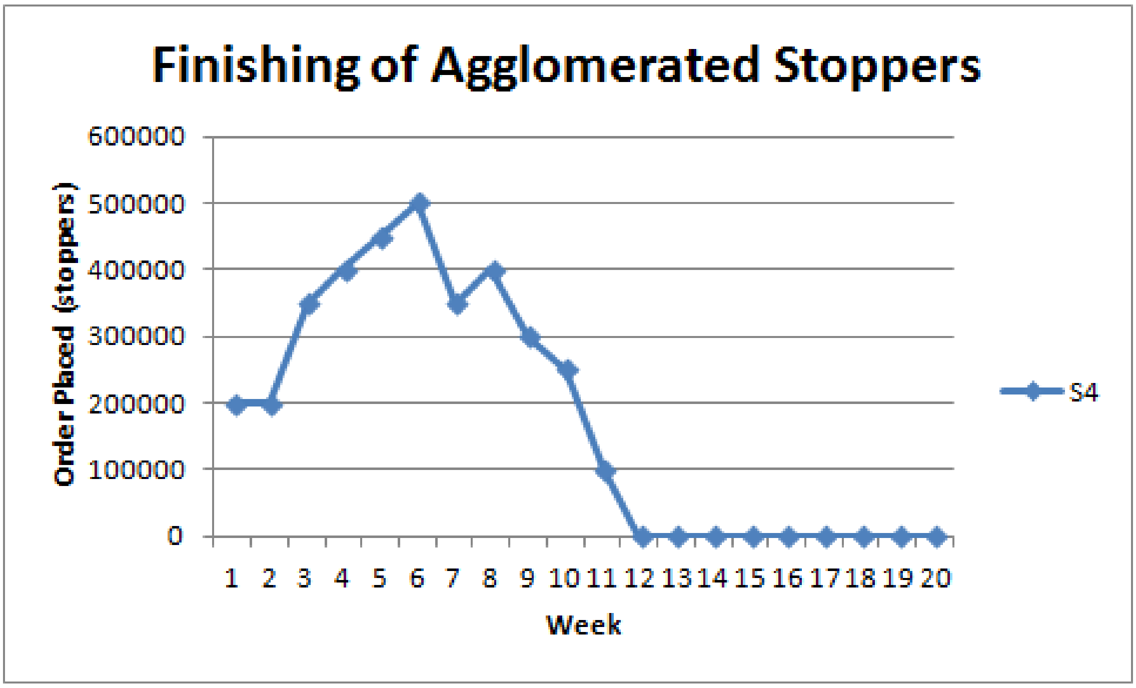


Figure D.56: Orders for S4 Placed by Finishing of Agglomerated Stoppers in Scenario C

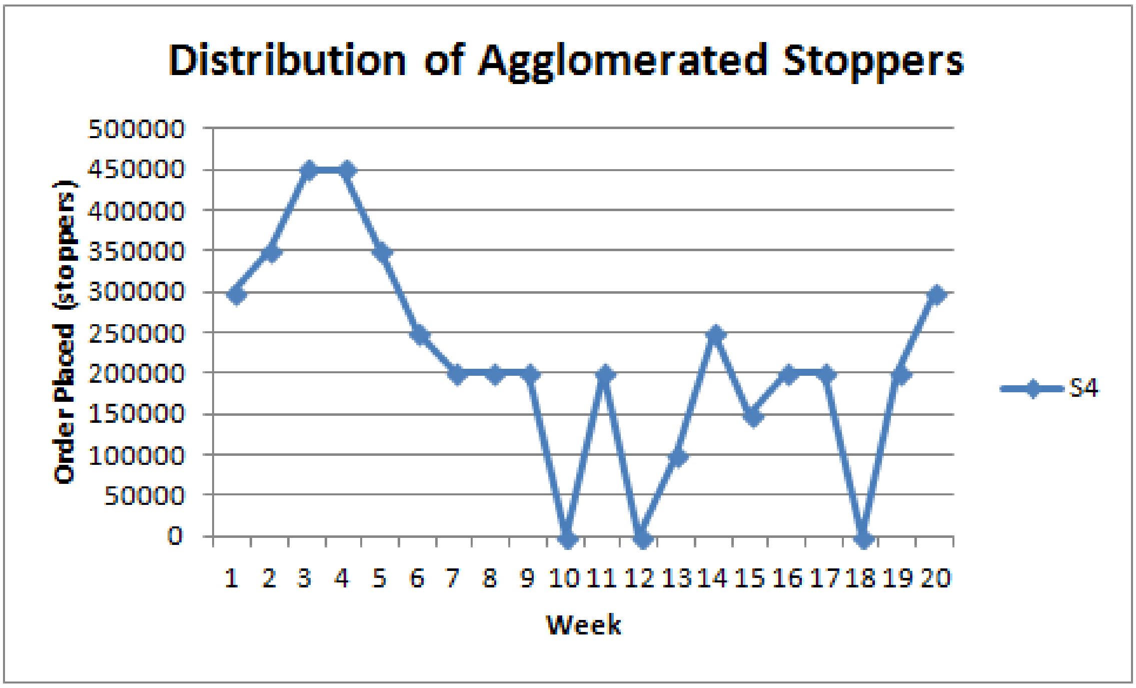


Figure D.57: Orders for S4 Placed by Distribution of Agglomerated Stoppers in Scenario C

D.3.4 Costs

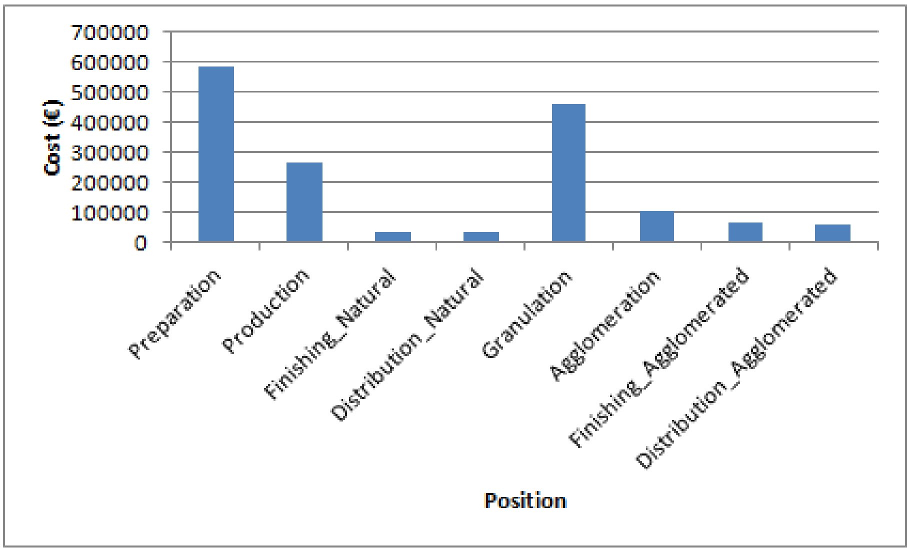


Figure D.58: Absolute Costs by Stage in Scenario C

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