Cost impact analysis of rush orders using line simulations

JÚLIA MOIX

Cost impact analysis of rush orders using line simulations

Author: Júlia Moix

Supervisors: Daniel Hellström
        Carl-Magnus Bertilsson

Acknowledgments

This thesis is the final step of a five years degree in Industrial Engineering from Barcelona Tech University and Lund University, and it has been written during the spring semester of 2013. Firstly I would like to thank Carl-Magnus Bertilsson for trusting in me and giving me the opportunity of writing the thesis at Tetra Pak. Also for proposing several topics so that I could choose the one that motivated me the most. In addition I would specially like to thank Sebastian Ferrada for his dedication, interest and advices. He has been a very helpful *buddy*. Besides them, both Anna Bellini and Haris Omeragic have always been offering support which I appreciate very much. I would also like to thank Daniel Hellström for the support given and the constructive feedback provided. It has helped me to always be on the right track. Finally, I would like to thank all those who have kindly answered my questions and have helped me to achieve a good understanding of the systems and processes. Also to my family and friends who have always shown their faith in me and have never stopped encouraging me.

Júlia Moix

Lund, June 2013

II

Abstract

Title	Cost impact analysis of rush orders using line simulations
Author	Júlia Moix
Supervisors	Carl-Magnus Bertilsson (Manager at the Virtual Engineering Department – Tetra Pak) Daniel Hellström (Asst. professor at the Packaging Logistics Department – LTH, Lund University)
Purpose	The purpose of this thesis is two folded. The first purpose is to propose, define and validate a process for Tetra Pak to evaluate the cost impact of a rush order using simulation. The second purpose is to conduct some analysis to understand the impact different kinds of rush orders' scenarios have, by analysing the costs that they entail in the Arganda factory.
Design/Approach	To provide information on how to insert a rush order so that the impact is minimum, a good understanding of the converting line machines set-ups, of the block production strategy, and of the planner procedures, is required. A process has been defined to be able to run the simulation model once the rush order has been inserted, so that its impacts can be evaluated.
Originality/Value	The process provided in this thesis will allow managers in Arganda evaluate the cost impact that inserting a rush order entails. Also, the report will inform them about how much money are the rush orders currently entailing. Besides, this project is valuable for the VE Dept. since it continuous proving the value of simulation capabilities. Finally the report includes a wide description of the converting line, what can become useful documentation to keep modelling factories.
Limitations	The scope of this project is limited to one of the company's factories, which is the one in Arganda (Spain).

Findings   The proposed evaluation process succeeds on providing a cost assessment report about the impact the insertion of a rush order has. The way a rush order is inserted in the planning definitely makes an impact on efficiency and cost. A good understanding of the blocks' specifications is essential to minimize these impacts. The impacts can be translated into costs for the factory.

Keywords   Rush orders, production planning, production blocks, converting line, set-up, waste

Executive Summary

Introduction

Background – Nowadays, if companies aim to stay competitive and remain as market leaders, they have to stay updated to new technologies and keep improving their organizations every day. Also, in order to ensure an efficient performance, they need to have a holistic approach along the whole process whenever an organizational decision is made. One way of ensuring efficient performance in manufacturing companies is by using simulation capabilities. The packaging company started building line simulation capabilities for some of its converting factories a few years ago. Since then the company has proved the value of this tool, and therefore is now planning to extend its usage in potential projects.

Problem discussion – Factories sometimes get requests for running rush orders. Customers are asked to place their orders with a certain margin of time so that the factory planners can organize the production efficiently. However, customers not always do it. This has an impact on cost, on efficiency, and on lead times for other orders. Thus, it is essential to consider and evaluate these impacts on whether to accept the rush order or not.

Purpose – The purpose of this thesis is two folded. The first purpose is to propose, define and validate a process for the packaging company to evaluate the cost impact of a rush order using line simulations. The process has to fulfil several requirements, such as: explain how to define and insert a rush order into a data base, indicate how to do simulation runs, find out which are the relevant KPIs to measure, and provide a cost assessment report. The second purpose is to conduct some analysis to understand the impact different kinds of rush orders' scenarios have, by analysing the costs that rush orders are currently entailing in Arganda.

Focus – The scope of this project is limited to one of the company's factories, which is the one in Arganda del Rey (Spain).

Methodology

Since the process defined in this thesis uses a simulation tool, it is relevant to understand the simulation methodology that was used to build the factory

model. In addition, the lasts steps of the simulation methodology are part of the thesis work and therefore have been explained in the report. To acquire a good handling of *Flexsim* (simulation software) the author of the thesis attended a training course. The aim was to understand the model´s behaviour and discover upon what fields of the input data the model is functioning. The input data for the model is stored in a data base Access file. A good handling of the file has been required to be able to work with the data and insert rush orders into the plan. The method followed to learn to use the tool has been by working with it and by asking to data experts. With the purpose of gathering knowledge related to the relevant topics of this thesis and be able to picture a meaningful frame of reference, the author read some literature regarding *Advanced Planning and Scheduling*, simulation and rush orders. Besides reading literature, in order to get familiar with all the factory performance, some interviews have been done to factory managers. With the information gathered from these interviews and plus some knowledge gathered from reading *PowerPoint*-presentations, it has been possible to write a wide description of the real system. Finally, in order to make the thesis work trustworthy, it has been explained how the requirements presented at the first stage of the thesis have been achieved, and how the defined process has been validated.

Frame of reference

This chapter sums up all the knowledge gathered from existing literature tackling about topics relevant to this thesis. First, an insight into packaging logistics is given. Then, the concept of simulation is presented, and Advanced Planning & Scheduling systems are introduced. Last, rush orders are discussed.

System Description

The system composed by all the machines in the converting line, by certain processes and by informatics softwares, is what this chapter tries to picture. First of all though, a brief introduction to the company is provided, so that the reader gets a holistic overview (see figure below). Then the machines in the production line are presented one by one. Later, it is explained how customers place orders in the factory, and also which is the procedure the planner follows to allocate the order in the production plan. Finally, some information regarding production strategy and machine's set-ups is provided. The chapter finishes explaining the factory simulation model functioning.
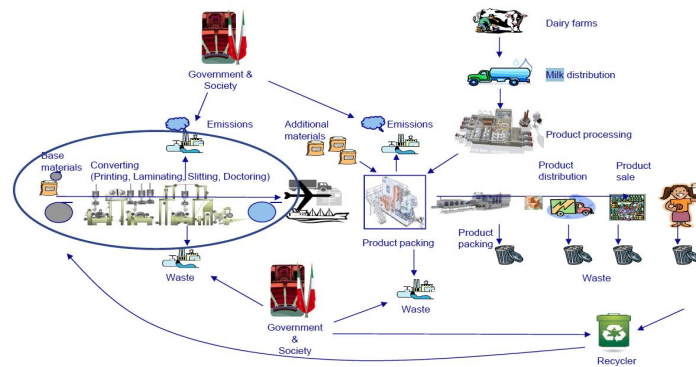
Rush orders in Arganda

At Arganda factory of the packaging company, they consider an order to be a rush order when it offers less than 14 days between its *Order Date Time* and its *Due Date*. This master thesis will only study orders with a lead time shorter than 7 days, because despite not being the most frequent, they are the ones with greater impact and thus worth to be analysed the most. The Arganda´s rush-order will be categorized depending on its size, on its urgency and on its lamination block definition. When a rush order is to be inserted in the planning, the planner has to follow a specific procedure which is mapped in a flowchart in the thesis report. After identifying the factors on which the rush orders have more impact, it has been concluded that the outputs needed to study the rush order impacts are: machine's efficiency, machine's % of set-up state, machine's waste, buffer levels and % of orders perfectly delivered. In order to achieve a sensitive analysis, the outputs have been translated into costs by using the following sensitive figures: machine hour cost, inventory storage cost, paperboard cost, aluminium foil cost, and PE cost.

Process for evaluating the cost impact of a rush order

The process has three main steps. The first one is the insertion of the rush order in the planning. The second step is to do simulation runs (using the modified planning as input data) and to gather the desired KPIs. The third step is to evaluate the KPIs obtained and to deliver a cost assessment report to inform about the rush order's impact.

STEP 1	STEP 2	STEP 3
Insertion of the RO in the planning	Simulations runs	Analysis of the results and evaluation of the RO impact

Analysing rush order scenarios

Analysis 1: **Impact of the rush order AOS** – The results of three different scenarios are presented and compared to a base line scenario. Scenario1 has a RO of 4 rolls, scenario 2, a RO of 11 rolls, and scenario 3, a RO of 16 rolls.

Analysis 2: **Impact of a RO depending on whether a new lamination block needs to be created or not** – The results of three different scenarios are presented and compared to a base line scenario. In scenario 0 a RO is inserted in an existing block; in scenario 1 a RO is inserted in a new block which will be placed between 2 existing blocks, and in scenario 2 a RO is inserted in a new block which will be placed breaking an existing block.

Analysis 3: I**mpact of a RO depending on its urgency** – The results of two different scenarios are presented and compared to a base line scenario. In scenario 1 a RO with a lead time of only 2 days will be introduced in the planning, while in scenario 2, the RO added to the plan will have a lead time of a week.

Conclusions

First, it is the author beliefs that the first purpose has been achieved since the process defined fulfils all the requirements and succeeds on evaluating the cost impact of a rush order. Second, the conclusions extracted from the analysis conducted in the previous chapter are:

1. Rush orders bigger than the AOS have a positive impact on the printer efficiency
2. When it comes to STOs' perfect delivery, the insertion of a new lamination block generally has more impact than the rush order size
3. The impact of a rush order strongly depends on its QSV, especially when inserting lamination blocks

4. Widening a lamination block too much might imply a short stop
5. Rush orders with an urgency of a week, have many chances of finding a block of its kind
6. The cost is concentrated in the laminator rather than in the printer
7. The more costly rush order scenarios are those requiring the insertion of a new block. They will have index cost about 116.

Concluding remarks

Recommendations – The first recommendation is to use simulation capabilities to better understand rush orders impact. Using simulation, certain events which are not obvious and which are harmful, can be detected and be taken into consideration. Besides, some general advises have been given on how to insert a rush order in the block planning. Always try to seek existing blocks where the rush order can be placed. If the block we are looking for is already full, before extending it, is always convenient to check if a switch of orders is possible. In the case where no block is found, then there is no option but to create a new block. It is usually more convenient to place the new block between existing ones, than breaking an existing one. Also, rush orders have to be inserted in the planning the most lately as possible, so that the fewer STOs' lead time are affected, and so that the printed rolls' buffer doesn´t raise much (and so doesn´t the cost it entails).

Potential future studies – 1) Conduct the analysis again with another DB extraction which has a greater content of orders. 2) Put a price on the acceptance of a rush order and base it on a categorization of customers. 3) Make the process more accurate by validating completely the factory simulation model (to be done by the VE Dept.).

Contribution to the rush orders' theory – The empirical study of this thesis has found out that: 1) The perfect delivery of STOs strongly depends on whether the planner schedules the production activities allowing a security margin of time or not. 2) Because STOs spend longer times in the production line (due to longer interoperation times due to the rush order prioritization), the WIP buffer levels will increase. Therefore, it can be said that rush orders have impact on inventory storage costs. 3) The rush order impact strongly depends on the complexity handled in the factory. Rush orders in factories with high complexity will have a relevant impact on set-up waste material.

x

Abbreviations

APS - Advanced Planning and Scheduling

CL – Converting Line

DB –Data Base

DSO – Development & Service Organization

FGI – Finishing Goods Inventory

GUI – Graphical User Interface

KPI – Key Performance Indicator

LamWIP – Laminated (rolls) WIP

MES – Manufacturing Execution System

PM – Packaging Material

QSV - Quality Size Variance

RO – Rush Order

SCO – Supply Chain Organisation

STO – Standard Orders

TP – Tetra Pak

VE – Virtual Engineering

WIP – Work In Progress

Table of contents

1. Introduction

This chapter introduces the master thesis by defining the background, the problem discussion and the objectives. Also, the project delimitations will be stated and the target group will be identified.

1.1. Background

Nowadays, if companies aim to stay competitive and remain as market leaders, they have to stay updated to new technologies and keep improving their organizations every day. Also, in order to ensure an efficient performance, they need to have a holistic approach along the whole process whenever an organizational decision is made. Through operational efficiency companies can perform with the most cost-effective manners, and therefore can save money, raise benefits, reduce waste and offer better services to their clients. One way of ensuring efficient performance in manufacturing companies is by using simulation capabilities. Simulation tools are very powerful as they can be used to visualise, analyse and optimize manufacturing processes and organizations virtually. All kind of systems can be modelled such as machines, resources, waste or people, so that an accurate picture of the reality is created. Before using simulation capabilities though, the requirements of the system have to be properly identified and the aim of the study has to be clear. Once this is done, simulation tools can be used to improve the systems' operational efficiency by analysing the desired key performance indicators (KPI).

Tetra Pak is currently using virtual engineering, which helps the company stay competitive and remain a market leader in its field. The company started building line simulation capabilities for some of its converting factories a few years ago, but the VE Dept. (in Lund) wasn't created until Sept 2011. As of today parts of factories have been modelled and the first valuable conclusions from analyses have been drawn. Since the company has proved the value of this tool, is now planning to extend its usage in potential projects.

So far, the Virtual Engineering (VE) Department of the company has only modelled some work areas from certain factories. However, the company's long-term aim is to complete the existing simulation models so that they can

embrace the whole factory. Also, they hope to model as many as requested of all the company factories around the world. Because of that, they are currently working on the creation of a customized library of sub-systems and equipment used in the factories. Also, they are developing processes for how and when to work with line simulations, that is which areas or events in the factory can also be modelled apart from production lines or inventories. Their aim is to add value throughout their organization (DSO PM & SCO PM) by using simulation. To sum up, the coming step for Tetra Pak is to extend the production line simulation capability to a factory simulation capability, and as well to continuously extend the usage of simulation to areas found valuable.

1.2. Problem Discussion

Factories sometimes get requests for running rush orders. Usually, customers are asked to place their orders with a certain margin of time so that the factory planners can organize the production efficiently. Despite knowing that, clients sometimes place an order too late and consequently the planner has no choice but to plan the rush order production in a confirmed order sequence. This has an impact on cost and efficiency, and on lead times for other orders. Thus, it is essential to consider and evaluate these impacts on whether to accept the rush order or not.

At Tetra Pak's factories requests for running rush orders are frequent. Therefore, the company has found out that it might be valuable to extend the usage of simulation capabilities to the study of ROs. A simulation method would help to understand the impact on cost and efficiency when accepting different kinds of rush orders, and also would provide information on which is the best way to schedule a new order in an existing order sequence to avoid internal costs to rise too much. As a consequence, the company has considered valuable to develop a project on this issue. The company considers interesting to do research on how much money the rush orders are currently entailing.

To proceed with the design of this evaluating process, first of all, all kind of existing RO must be studied, classified and defined. As well, a good understanding of the converting line must be achieved. This way, it will be possible to identify which are the relevant factors to look at. Afterwards, the planning system will have to be analysed and understood, so that the user of

the process can understand how to introduce a new order. Finally, through the usage of an existing simulation model, it will be possible to run different scenarios and then study how the acceptance of ROs affects the performance of the production line. The factors which receive more impact due to the RO will be identified, will be analysed through KPIs, and finally translated into costs to be evaluated from an economical perspective.

1.3. Purpose

The purpose of this thesis is two folded. The first purpose is to propose, define and validate a process for Tetra Pak to evaluate the cost impact of a rush order using simulation. The process has to fulfil several requirements. It needs to explain how to define and insert a rush order into a data base, indicate how to do simulation runs, find out which are the relevant KPIs to measure, and translate the KPIs into costs. In the end, the process also must achieve a cost impact analysis of the rush order. The second purpose is to conduct some analysis to understand the impact different kinds of ROs' scenarios have, by analysing the costs that rush orders are currently entailing in Arganda.

1.4. Focus and Limitations

The scope of this project is limited to one of the company's factories, which is the one in Arganda del Rey (Spain). The main reason of this choice is the fact that Arganda factory is the only one that has a factory model so far. In addition, managers of the factory seem to be highly interested in the study of the efficiency and cost impact of rush orders. Although the simulation model that will be used is defined as a factory model (since it includes all processes in the converting line: printers, laminators, slitters, doctor machines and palletizing station), only part of the model will be used (from printers to laminators). At the time this project is being developed, the modelling of the last stations of the converting line is still to be improved. Therefore it has been decided to restrict the simulation to the printers and the laminators, which happen to be the machines where the RO's impact is greater, according to the factory managers.

1.5. Target group

This project is in firsthand valuable for the VE dept. at Tetra Pak since it continuous proving the value of simulation capabilities. Also, the report provides a wide description of the converting line, what can become useful documentation to continue modelling factories. Secondly, the master thesis is of great interest for managers in Arganda, since they can use the process to find out how much money are the rush orders currently entailing in their factory. Finally, the thesis can be useful for students aiming to do research on topics related to rush orders or planning systems, since this document can be a sort of inspiration or knowledge.

2. Methodology

This chapter tackles about all the activities carried out along the thesis time, and also about the methodology used to develop them. First, an introduction to simulation methodology is provided. Later, it is indicated which literature research has been done, and how the data has been collected. Also the data base used in this thesis will be commented. Finally, it will be explained what has been done to validate the process.

2.1. Project methodology and management

This thesis started with a project plan, in February 2013, which aimed to introduce the project itself and provide information on which tasks were going to be developed and when. In general, project plans are considered of great importance for the achievement of future results, although it is highly likely that insights gained along the way alter the content of them and the timing scheduled. This master thesis' project plan was complied and discussed with the two supervisors, LTH supervisor and company supervisor.

During the first weeks it was mainly about getting to know the company, the packaging material production line (converting line), and the planning system. While doing this, the author started to realize what kind of literature had to read in order to become familiar with the project´s topic, and so that she was able to picture a good frame of reference about it. Therefore she read about Packaging Logistics, Planning Systems, Simulation, and Rush Orders. The information gathered made it easier to proceed with the thesis afterwards.

Also, during one of the first weeks the author took a one week simulation training course with other colleagues at Tetra Pak. Besides this, she did some visits to Lund´s factory and to its planner, so that she would be more prepared to go to Arganda's factory (the one this project focuses on) weeks after. Next she started dealing with the simulation factory model and its input data. The aim was to understand how the model´s behaviour was and upon what fields of the input data was the model functioning. For that she got help from both Jason and Sebastian. Parallel she started to think about a potential process flow, and as well about potential analysis to conduct.

In the first week of April she went to visit the factory in Arganda. There she got to speak to the planner and to the managers of the converting line main activities. After coming back a proper system description was written, rush orders were approached accurately, and experiments were defined. In May, the data was finally received, and the author started to conduct the analysis. After that the results were analysed and some conclusions were drawn.

2.2. Simulation methodology

2.2.1. Building the factory model

Simulation is much more than drawing a picture of a system in your computer and afterwards make it run. To simulate a system or a process, the first thing to do is to create the pertinent model. In order to build a simulation model, a long and rigorous methodology needs to be followed. Although this master thesis will not build the simulation model that will be using in the process (since it already exists), it has been considered important to give a brief explanation of which was the methodology followed when the model was created from scratch. To build the Arganda factory model the engineers at the VE Dept. tried to approach the methodology flow chart shown below (figure 1). The three main parts of the whole process are: pre-model, build the model and analyse the model (see different step colours) (Brooks Automation, 2003).
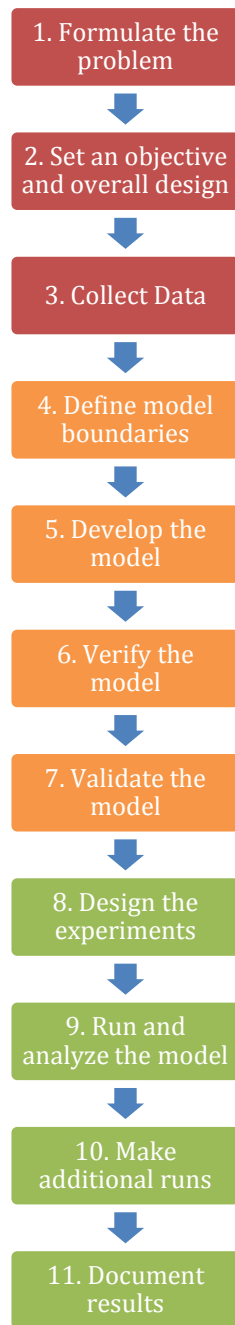
Figure 1: Steps in a simulation process

Steps 1 to 6 have been briefly described in Appendix I.

At present time, steps from 7 to 11 in the flowchart still haven't been completed. The VE Dept. is currently working with step number7: Validation of the Model. However, by the end of this master thesis period, the model is expected to be almost validated. Therefore it will be quite reliable to use it in the process that this project will define. The last part of the whole methodology process (analyse part), which include steps from 8 to 11, will be specifically developed for this master thesis, and therefore will be part of the master thesis work. It includes design the experiments, run and analyse the model, and evaluate results.

2.2.2. Simulation software: *Flexsim*

Flexsim is a powerful modelling tool which Tetra Pak uses to simulate its factories. At the very beginning of the project, the author of this thesis got the chance to attend to a whole week training course in *Flexsim* and Packaging Material simulation models. During the first three days, Ralf Gruber –*Flexsim* trainer-, trained in standard Flexsim, and the last two days the group went through the understanding of Tetra Pak's existing models such as the *PrePress* model and the *Finishing* model. Those two last days the explanations were given by Sebastian Ferrada and Haris Omeragic - Development Engineers at Tetra Pak (TP)-. The value of learning how to use *Flexsim* interface is really high as it has been indispensable for developing this project.

2.3. Database

A database is an organized collection of data stored in a file. In order to run a simulation model, input data is required. For the factory model of Arganda the input data is introduced to the model through an Access file database. It contains both *Order data* & *Configuration data*, and is loaded from *Manufacturing Execution System* (*MES*). The file is composed of different objects: tables, queries, macros and modules. The author had never used this software before, and therefore was forced to learn to use it in order to be able to work with the data and insert rush orders to the plan.

2.4. Literature Research

With the purpose of gathering knowledge related to the relevant topics of this thesis, the author read some literature regarding *Advanced Planning and Scheduling* (APS), simulation and ROs. All the learning is reflected in the following chapter, *Frame of Reference*. The databases used to find articles tackling the subjects mentioned above have mainly been: *Emerald*, *Science Direct* and *Lovisa*.

2.5. Data Collection

Besides reading articles, in order to get familiar with all the factory performance, some interviews have been done (see Appendix II). With the information gathered from these interviews and plus some knowledge gathered from reading *PowerPoint*-presentations facilitated by the work colleagues, a description of the real system has been written in chapter 4, *System Description*.

2.6. Validation of the process

The purposes of this thesis are: to propose, define and validate a process, and to conduct some general analysis. In order to make the methodology used to achieve both purposes more trustworthy, it will be explained how the requirements presented at the first stage of the thesis have been achieved, and how the defined process and the second purpose have been validated.

The main requirements were: to gain a good understanding of rush orders in Arganda, and to figure out which are the main factors the ROs have impact on. The first one has been achieved by talking to the planner in Arganda and by analysing some historical data. The categorization of ROs, and the flowcharts for the planning processes, have been discussed and approved by the planer in Arganda. The second requirement has been achieved by talking to the machine's managers in Arganda. This has provided a wide understanding of the machines in the CL and of the block planning strategy. This second requirement has also been achieved by talking to virtual

engineers at the company who are very familiar with the factory simulation model, and therefore with the CL process.

The definition of the process has been supervised by virtual engineers who are very familiar with the factory model and also with the data base. The feedback received from them has enabled the author of the thesis to validate the process. Regarding the first step of the process, which is the insertion of an extra order in the data base, a specific validation activity can be conducted every time the process is used. See section 6.2.2. Since the factory simulation model is still being validated, the author of the thesis has been helping the virtual engineers at the company with the task. It has consisted of ensuring that the visual representation of the model was acting like the real system. For instance, it has been checked that the machines were doing the appropriate set-ups, that the order sequence stated in the input data was being followed, that the machines were switching to the desired states after certain events, etc. Besides this, the model results and the real system results have been compared. The throughput obtained from the model after running it for 5 days has been compared to the real throughput provided by a factory report. The input data used to run the model was the real data of the system in week 19. Obviously, the report used to check the real throughputs was the one of week 19.

3. Frame of reference

This chapter sums up all the knowledge gathered from existing literature, which tackles about topics relevant to this thesis. First, an insight into packaging logistics is given. Then, simulation is presented. Finally, Advanced Planning & Scheduling system are introduced and ROs are discussed.

3.1. Packaging Logistics

Since this master thesis is supervised by the Department of Design Sciences - Division of Packaging Logistics at LTH, and what is more important, it develops a project at a company devoted to produce packages, it has been considered appropriate to discuss about Packaging Logistics. The Division of Packaging Logistics at LTH is considered one of the world's leading research and educational institutions in the embracing field of packaging and logistics. The institution focuses on the knowledge of interlinked areas such as packaging, logistics, product development, and marketing, and aims to integrate these areas into product, process and innovation (LundUniversity, 2013).

According to Saghir, the packaging of a product can be defined as a "coordinated system of preparing goods for transport, distribution, storage, retailing, and end use" (Saghir, 2002). It is usually considered a system as it is composed of different levels, i.e., the primary package (the one in contact with the product), the secondary package (the one designed to contain several primary packages), and the tertiary package (the one used to assemble several secondary packages in a pallet or container). A package system has several functions to fulfil along the different actors of the SC, and therefore many aspects of a package can be relevant. For example: machinability, product protection, flow information, volume and weight efficiency, handleability, product information, selling capability, safety, use of resources, amount of waste that generates, packaging cost, stackability or unwrapping facility (Pålsson, 2012).

The packaging system can interact with many factors such as logistics, marketing, production, production development or environment. When it comes to the interaction between packaging and logistics, is when the concept of *packaging logistics* arises. There are several definitions for *packaging logistics*, and below, three possible ones are shown (each one according to a different author):

"An approach which aims at developing packages and packaging systems in order to support the logistical processes and to meet customer/user demands" (Dominic, C. et al., 2000).

"The interaction and relationship between the logistical system and the packaging system that add value to the combined, overall, system – the enterprise" (Bjärnemo, R., Jönson, G. & Johnson, M., 2000).

"The process of planning, implementing and controlling the coordinated packaging system of preparing goods for safe, efficient and effective handling, transport, distribution, storage, retailing, consumption and recovery, reuse or disposal and related information combined with maximizing consumer value, sales and hence profit" (Saghir, 2002).

Because of the emphasis putted on gaining a good logistics performance, then appear some packaging's cost trade-offs. The role of packaging in logistics is critical because packaging normally accounts for 8% of the cost of logistics, and when talking about international logistics it can raise up to 15-20% of the cost (Richard A. Lancioni, Rajan Chandran, 1990).

Packaging systems are constantly developing in order to satisfy customer's demands, market requirements, and safety issues, and in order to ensure an efficient logistics performance. Packaging innovation is driven by these trends (Sonneveld, 2000): business dynamic of the packaging industry trends, consumption trends, legislative trends, and distribution trends. Situations that push developers to innovate might be: when the product physical dimension has impact on handling, when special transports are needed, when product cost is a major part of the final cost, or when the shipping of products is exposed to water, dirt, air, temperature, etc.

3.2. Simulation

3.2.1. Introduction to simulation

Nowadays, simulations are present in many different contexts of our daily lives; for instance: in computer games, in healthcare, in weather forecast, in safety engineering, in flight simulation, in education and training, in manufactories for analysing the logistics performance, in natural and human

systems, and in many others (Gruber, 2012). Since simulation is used in various fields the concept can be defined differently. However, a general definition could be the following: "*simulation is the process of creating a model (i.e., an abstract representation or reality) of an existing or proposed system (e.g., a project, a business, a mine, a watershed, a forest, the organs in your body) in order to identify and understand those factors which control the system and/or to predict the future behaviour of the system*" (GoldSim Technology Group, 2011).

3.2.2. The purpose of simulation

The main goal of simulation is to clarify which are the mechanisms that control and describe the behaviour of a system. Once this is achieved, the practical purpose of simulation is to predict future behaviour of systems, and find out what can be done to control these future behaviours. In other words, simulation can be used to predict how the system will develop and respond in certain potential scenarios, so that we can discover which are the factors that need to be addressed in order make the system perform in a certain way (GoldSim Technology Group, 2011). Simulation offers the opportunity to experiment virtually before implementing in reality. If alternative designs, plans, or machines were to be implemented without being simulated, that would cost money, time and efficiency. Simulation is considered a highly valuable tool because it provides information on "What if?" scenarios, avoiding testing them on actual systems. This tool help analysts to make the proper decision because it allows them to evaluate, compare and optimize all the future scenarios beforehand. Furthermore, it is always a very successful resource for justifying potential plans to stakeholders (GoldSim Technology Group, 2011).

3.2.3. When to use simulation

Simulation is used when the consequences of a possible plan are not evident or easy to foresee. Simulation must be implemented in those systems which are complex (as they are built out of many different sub-systems) and that have a lot and unpredictable input. By defining behaviour of all the simpler parts and the relation between them, simulation models can help us to gain insight in the behaviour of the whole system (GoldSim Technology Group, 2011) (VE_TetraPak, 2013).

3.2.4. A simulation model

While the broad concept of simulation refers to an imitation of a real system, a simulation model is also a representation of a real system but with the important difference that this representation has been designed with the purpose of solving a problem or understanding the system behaviour. For this reason, simulation models don't put emphasis on detail, but emphasize both the importance of identifying the requirements of all parts of the system, and the importance of defining the desired outputs, whenever a model is going to be built (Gruber, 2012).

3.2.5. Simulation models classification

Theoretically speaking, the models that we build to describe our real systems can be static or dynamic, deterministic or stochastic, and discrete or continuous (see figure 2).
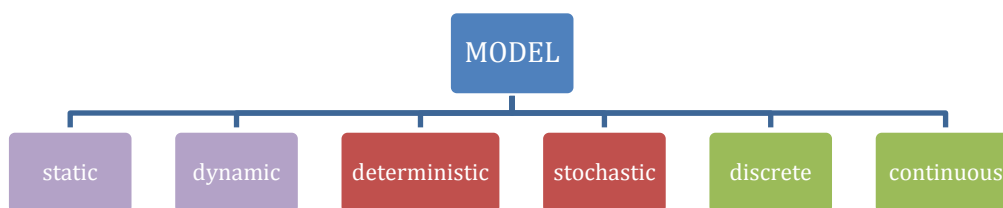
Figure 2: Simulation models classification

Regarding the time period during when the system is evaluated, models can be classified into static and dynamic. Static models define systems upon what is happening at a particular point of time, while dynamic models analyse systems over time. Models will be defined as deterministic or stochastic depending on the kind of input they receive. Deterministic models use input parameters that are single values (they are often believed to be "the best guest"), while stochastic models use probability distributions to specify their inputs (GoldSim Technology Group, 2011). Taking into account that, in everyday life, inputs are generally not predictable anymore, a probability distribution is an accurate and explicit way of representing uncertainties. Statistical distributions can introduce randomness to a simulation model so that they more closely resemble the real world system they are modelling (Gruber, 2012). In this context it is interesting to present Monte Carlo

method, which can be described as a method that transfers input uncertainties to output uncertainties. The methodology that it follows is the usage of statistical distributions to define the input data in the system. It states that, in an uncertain system, whereas the result of a deterministic simulation is a qualified statement, the result of a stochastic simulation is a quantified probability (GoldSim Technology Group, 2011). Finally, models are classified according to whether they are discrete or continuous. Continuous models define systems that evolve over time following equations. Contrary, discrete models evolve over time going through several events. The so-called "discrete-event" simulation is that one represented by a series of chronological events, which cause corresponding state changes in the system. An *event* is something happening, a change in the system while it is evolving over time (Gruber, 2012). For instance: a part arrival, a product movement, a machine process start/finish or a machine breakdown. A *state* is something on-going in the system while it is evolving over time and can be applicable to all kind of objects. Machines states can be: idle, set-up, processing…; queues states can be: empty, full… ; operators states can be: utilized, idle… etc (VE_TetraPak, 2013). The factory simulation model built for Arganda factory is dynamic, stochastic and discrete. The model is dynamic because the factory behaviour will be analysed over time; it is stochastic because its input will consist of provability distributions; and it is discrete because events will happen at specific points of time and will make change the element´s states.

3.2.6. Input and output variables

Simulation tackles two kinds of variables: input and output variables. It is important to understand that in a system, inputs generate outputs, but not vice versa. Simulation aims to find out which are the input variables that have most impact on the performance measures, so that they can specifically be controlled in order to obtain the outputs wanted. Thus, it is important to ensure that models are not missing the relevant inputs (Gruber, 2012).

3.2.7. The reason why Tetra Pak uses Simulation

Simulation in Tetra Pak is used from an engineering perspective. The aim of using it is to understand the systems behaviours and test *what if?* scenarios. Plus, simulation is currently being used to verify the need of investments as a support to the business cases. In figure 3 the main applications of simulation in Tetra Pak are highlighted (VE_TetraPak, 2013).

Factory optimisation: -throughput analysis -bottleneck analysis	Optimization of buffer´s and inventory´s location and size	Test of new equipment
Evaluation of operation procedures: -planning -production scenarios	To quantity equitment and operators & evaluate current equipment utilization	To train operators: -overall system behaviour -job related performance

Figure 3: Applications of simulation at Tetra Pak

Tetra Pak considers highly valuable the usage of virtual engineering because provides several benefits to the company such as the ones shown in figure 4 (VE_TetraPak, 2013):

simplify	highlight risks	reduce costs	visualize	capture knowledge

Figure 4: Benefits of using simulation

3.3. Advanced Planning & Scheduling systems

Advanced Planning and Scheduling (APS) systems are tools that help companies to meet customer's demand by using planning software that considers material availability and plant resource capacity. Material availability, factory capacity, distribution and transportation, among others, are integrated in the system. The fact that both suppliers and customers are included in the planning procedure makes it possible to optimize a whole SC structure. This tool enables organizations to make decision upon SC structures, to do long term supply plans, and to define detailed operational schedules along the job floor. APS are softwares that follow both a constrained-based planning algorithm, and an optimization algorithm. The plans provided by APS are near optimal and feasible. This is achieved by

16

seeking potential bottlenecks whenever a plan is to be built. APS optimize plans according to financial or strategic objectives settled down by the company. There are two kinds of models: descriptive models, i.e. those forecasting demand and which are used to make decisions upon SC databases, and optimisation models, which allow managers to identify effective plans by exploring what if scenarios and considering constraints (Hvolby, Hans-Henrik; Steger-Jensen, Kenn, 2010).

A Supply Chain is a network of companies that encompasses raw material suppliers, manufacturers in charge of transforming the raw materials into intermediary and finished goods, and distributors who are in charge of delivering the products to the final customers (Lee, H. & Billington, C, 1993). Each actor in the SC has specific requirements and objectives, which are usually different from the others actors' objectives. This fact makes the flow along the SC quite complex. Because of that, modelling and simulation techniques are often used to understand the behaviour of SC systems (which encompass many actors). The purpose of modelling and simulation is, by the usage of models and the development of data, become a useful tool for making technical, organisational and managerial decisions. A holistic approach through simulation is required to be able to propose the best way to exploit a system. In the context of SC planning, simulation deals with relevant problems such as: dynamic scheduling and shop floor job assignment, planning and scheduling integration problems, information sharing, SC control structures, among several (Santa-Eulalia, Luis Antonio; Halladjian, Georgina; D'Amours, Sophie; Frayret, Jean-Marc, 2011).

During the last 5 decades, there has been an evolution when it comes to manufacturing planning and control systems. *Manufacturing Resource Planning* (MRP) was one of the first relevant systems to exist. Its main functionality was to explore which were the components required for building a certain finished product, and to time and report the orders of these individual components. Then, MRP evolved and two new systems appeared: *Enterprise Resource Planning* (ERP) and later on, *Advanced Planning and Scheduling* (APS). They were better than MRP because the integration of the materials and capacity requirements, and also the material and capacity planning, were notably improved. ERP differed from the previous system because integrated some new applications such as forecasting, long term planning and critical resource planning. APS stood out because was providing a highly developed scheduling and planning functionality. Also, a relevant

aspect of APS is the ability to simulate potential planning scenarios before launching them. Thus, APS has become a spectacular and significant tool within planning and control. Besides the evolution just recounted, it is interesting to know that lately, a software aiming to cover a wider approach of the SC has appeared: *Supply Chain Planning* (SCP). SCP supports logistic functions such as forecasting, production, transportation, delivery and distribution (Hvolby, Hans-Henrik; Steger-Jensen, Kenn, 2010).

"One of the key factors for successful implementation of APS systems is correct and consistent modelling" (Zoryk-Schalla, Fransoo, & de Kok, 2004). The implementer must have a good understanding of the core APS functionality, and be skilled enough to set up the appropriate planning parameters. Also, previous to implementing the APS, the implementer has to become very familiar with the reality he/she wants to model. APS software is built following *planning process* based on standard and theoretical *modelling process*. It's interesting to notice that when (big) companies invest up to hundreds of thousands of Euros in licensing the software, a significant part of this amount is spent on software implementation, i.e., hiring external consultants and making internal people available to make the implementation run smoothly. Despite putting special commitment on the implementation of the software, some studies (Zoryk-Schalla, Fransoo, & de Kok, 2004) suggest that still: "APS tools may not be capable of assisting the modeller in properly defining the planning process and planning model. Extensive support from highly trained modellers is necessary". APS present high complexity and thus its usage currently entail some problems such as lack of understanding and training among the users, low-data accuracy, and lack of support during the implementation phase (Hvolby, Hans-Henrik; Steger-Jensen, Kenn, 2010).

Nowadays, the greatest shortcomings in APS systems are the collection and maintenance of the data, and the investment cost when implementing the system (Hvolby, Hans-Henrik; Steger-Jensen, Kenn, 2010).

Regarding theory, planning processes are generally ordered hierarchically. Schneeweiss proposed a formal modelling framework for describing hierarchical planning processes (Schneeweiss, 2003) in which the interactive process of decision-making between two levels was modelled. Generally, APS software is based upon a hierarchical structure which consists of three levels

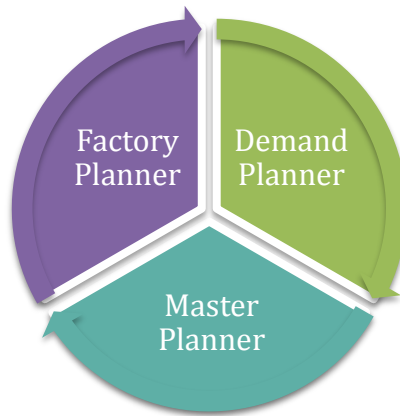(represented in figure 5): Demand Planner, Master Planner, and Factory Planer.

Figure 5: Levels of APS

- The Demand Planner module is in charge of building a forecast of all the orders expected in the near future. It is based on historical or statistical data, on market strategies, or on clients provided forecast. It offers a multi-dimensional representation of the demand as it includes customers, geography, quantity, kind of products and delivery date.

- The Master Planner module generates a plan for the whole company SC while considering the market demand received, the business policies, and also the SC capabilities. Basically, the planner has to update the operational base plan -which was defined upon the Demand Planner forecast, and also upon material and resources capacity-. The result is a real plan that is capacity-feasible and that provides scheduling -in all the machines- to all orders. This plan differs from the standard one due to the differences between the forecast and the real demand.

- The Factory Planner schedules all the manufacturing operations that one customer's order needs to go through. As well, it indicates the resources required for all the tasks. The result is a factory wide plan that will be used as input in the production plans of each machine of the factory. The machines need to have a detailed scheduling in order to be able to perform efficiently and also to be able to organize the procurement.

Business processes operate under the planning scheme just explained. The idea is that, based on a sales plan, the planner defines a feasible production plan with the help of APS software. However, the planner must be capable of analysing and detecting plans proposed by the system that are not executable, and therefore need to be rejected or modified. Planners should have insight in the correspondent SC, as they are finally the one in charge of the decision-making (Hvolby, Hans-Henrik; Steger-Jensen, Kenn, 2010).

3.3.1. Proplanner

Proplanner is an APS application leader in process engineering and management softwares for assembly manufacturers. It is a tool that automates, streamlines and integrates engineering activities with the purpose of designing and planning production systems. The application imports external information, that once integrated, allows the system to estimate activity and operation times, balance work across the assembly line, process routings, define plan layouts, place work instructions and do overall in-plan logistics. Once all this information is processed and optimized, *Proplanner* can then export all the time-phased information to APS systems. That leads to a fast and optimal production (Proplanner, 2002).

3.4. Rush Orders

Regarding rush orders literature there are still a lot of aspects that need to be investigated and be given a more extensive understanding. However, some facts regarding rush orders have already been stated. Plossl's research (Plossl, 1973) in PPC (Production Planning and Control) stated that there is a clear relationship between the share of RO and the delay of standard orders. He found out that an increasing share of RO would lead to higher delays of standard orders. Another issue that the literature regarding RO has been dealing with is whether rush orders revenue is or not worth it taking into account the tardiness cost that they evoke for standard orders. A balance between these two aspects should be done in order to make a decision on whether or not to accept the incoming rush order (Wu M. C.; Chen S. Y., 1997) (Chun-Lung Chen, 2010). The main questions arising regarding RO are "which is the critical RO share that can be handled by a production?", "which are the RO most influencing variables?", "which are the RO effects?", and

"upon which characteristics should RO be defined whenever they have to be integrated into PPC?".

Some research has been conducted aiming to define the throughput time for RO. It must be taken into account that RO have shorter throughput times than standard orders, due to the prioritization that they are given at the shop floor. An equation has been modelled in order to get to know to what extent RO prosecution can be accelerated (in other words, which the minimal achievable RO throughput time is). To model the equation the following assumptions have been taken: there cannot be more than one RO at a time at a work system, pre-emption at work systems is forbidden, and RO are transported batch wise. The influencing variables on RO throughput times suggested are: utilization of the work system, number of parallel workstations, and structure of work content of all kinds of orders. The two first variables are classified as structural variables, whereas the last one is classified as an operational variable. To gain a better output (low RO throughput time), the work system utilization level must be kept down, and this is not likely to happen as companies usually try to operate close to 100% utilization. Also, raising the number of workstations working in parallel is normally not a typical option because it is expensive. However, something feasible that can be done in order to obtain a better output, is to modify the structure of standard orders work content. The equation developed by Wiendahl (Wiendahl, H.P., 1995), that aims to model orders throughput times is shown in figure 6.

$$TTP_i = TOP_i + TIO_i$$

TTP_i	throughput time of order i [SCD]
TOP_i	processing time of order i [SCD]
TIO_i	interoperation time of order i [SCD]

Figure 6: Order throughput time equation

When this equation is applied to a RO, weighted values are used. To obtain the weighted TIO_i it needs to be studied how much time the RO has to wait at the workstation queue until the previous standard orders are finished. This amount of time depends on the influencing variables mentioned above.

A study (Trzyna, D.; Kuyumcu, A.; Lödding, H., 2012) was conducted to quantify to what extent standard orders can be delayed due to RO. It suggests the following influencing variables on STOs' throughput times: mean WIP at the work station, structure of the RO's work content, and share of RO.

Besides, the study suggests using logistic operating curves to visualize the impact that the influencing variables have on different kinds of throughput times, and also on the output rate. The following graphic (figure 7) shows the impact of the variable "mean WIP at the work station" on the different groups:
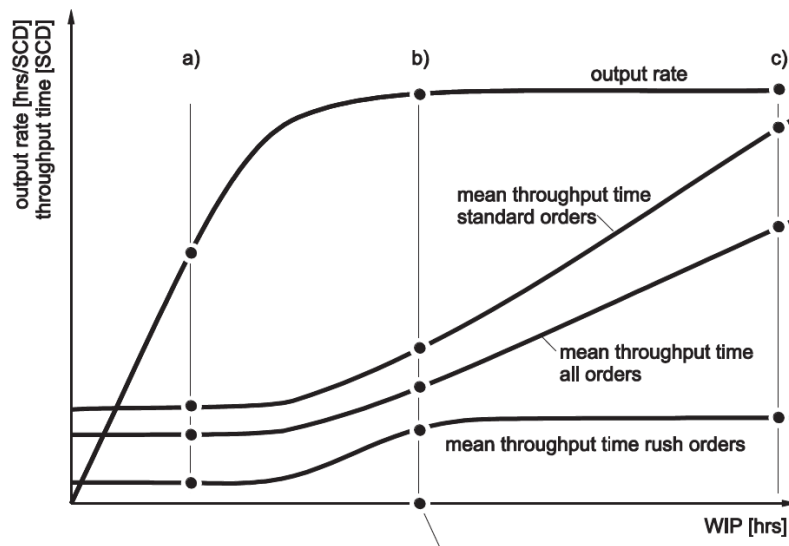
Figure 7: Logistic Operating Curves

The a) level corresponds to a situation where the processing time (WIP) is low, and therefore there is no difference between the queuing times of any kind of order. However, the output is lower for RO than for STO (standard orders) because they are expected to have faster operating times. The b) level is the transitional operating zone that is where the capacity reaches the maximum (utilization tends to a 100%). At this point RO have lower output due to both their lower operating time and the fact that they have priority at the queues (lower inter-operating time). The c) level represents the situation at which workstations are running with overload. STO are affected by the overload because that makes their inter-operating times to rise a lot.

Following Windahl model, another equation (figure 8) was defined (Trzyna, D.; Kuyumcu, A.; Lödding, H., 2012) for "STO' weighted throughput times", as a function of the influencing variables mentioned above.

$$TTP_{stdw} = \frac{TTP_w - TTP_{rw} \bullet \sigma}{(1 - \sigma)}$$

TTP_{stdw} weighted throughput time of std. orders [SCD]

TTP_{rw} weighted throughput time of rush orders [SCD]

σ rush order share

Figure 8: STO weighted throughput time[1]

Trzyna et al. also provided a method to determine the critical share of RO (Trzyna, D.; Kuyumcu, A.; Lödding, H., 2012). The influencing variables on RO's critical share suggested are: structure of RO's work content, structure of standard orders' work content, variation of RO's share, and number of parallel workstations. The 2 first are specially expected to have great influence on the output.

Simulation is used for the evaluation of the critical RO share because the modelling of operation times is defined as a statistic distribution. Mainly two situations are expected. For each side of the transitional operating zone there will be a certain handling of the RO. For low WIPs (left side) there will be no competition for capacity, while for high WIPs (right side) the impact of the RO's share, on ROs' throughput time, becomes noticeable. The following graphic (figure 9) shows the ROs' throughput time as a function of RO share and mean WIP level.

---

[1] TTP_w (weighted throughput time of any kind of order) can be calculated based on historical data
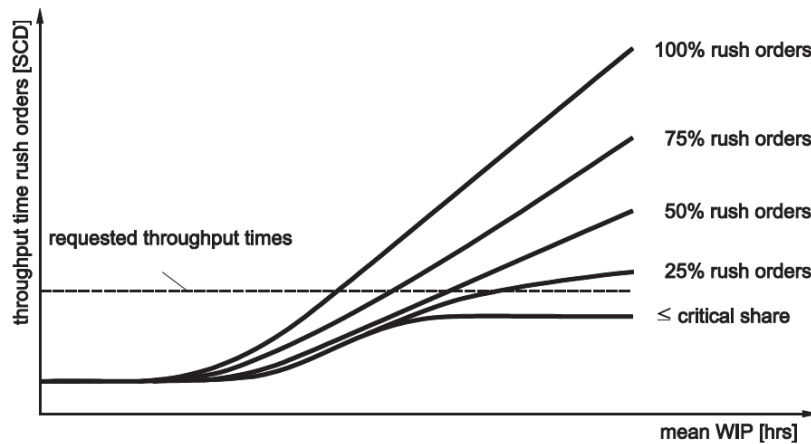
Figure 9: Graphic representation of RO throughput time for several RO shares

Finally, Trzyna et al., provided some suggestions for management decisions at companies (Trzyna, D.; Kuyumcu, A.; Lödding, H., 2012). They believe that when a factory has to handle a too high RO share, WIP levels must be reduced. In this way, there will not be such strong competition for capacity and the critical rush order share will be possible to handle.

In summary, a rush order is an order that has been placed very close to its due date and therefore needs to be handled within a short time. One of the greatest impacts they have on the production line is the delay they cause on standard orders (STOs have to wait longer to get into a work station because the RO is always prioritized). RO also have an impact on WIP levels. The more ROs there are in a system or the bigger they are, the longer STOs' lead times will be, and thus, the higher the inventory storage cost will become. Finally, RO don´t allow factories to follow the ideal production plans properly, and this has an impact on cost and efficiency when it comes to production performance. Figure 10 shows graphically how ROs are prioritized at the work stations of a production line.

ⓐ ⓒ ⓔ : prioritization of rush order
ⓑ ⓓ ⓕ : processing of rush order

- - - -► : throughput rush order   WS : work system   ⊘ : standard order   ⌐———⌐ : buffer
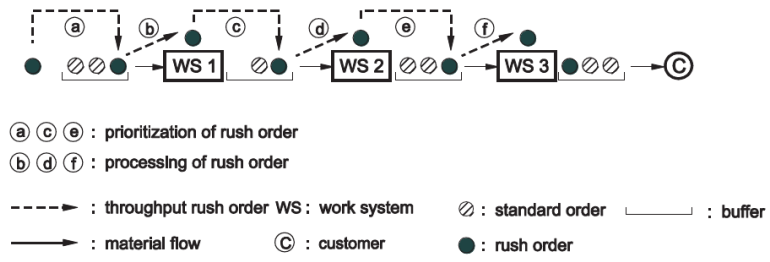———► : material flow   Ⓒ : customer   ● : rush order

Figure 10: Behaviour of ROs (Trzyna, D.; Kuyumcu, A.; Lödding, H., 2012)

4. System Description

This chapter´s purpose is to accurately describe the converting line. First of all though, a brief introduction to the company will be provided, so that the reader gets a holistic overview. Then the machines in the production line will be presented. Later, an order placed by a client to the factory is explained, and also which is the procedure the planner follows to allocate the order in the production plan. The objective is to get a good understanding of the order flow. Finally, some information regarding production strategy and machine's set-ups will be provided. The chapter will finish by explaining the factory model functioning.

4.1. Tetra Pak´s company and Tetra Pak´s value chain

Tetra Pak's organization is represented in figure 11. It is composed of two businesses that work as one in order to reach optimal effectiveness. The *Packaging Solutions* area is in charge of developing, manufacturing and selling the packaging material, while the *Processing Systems* area is responsible for developing and manufacturing processing machines.
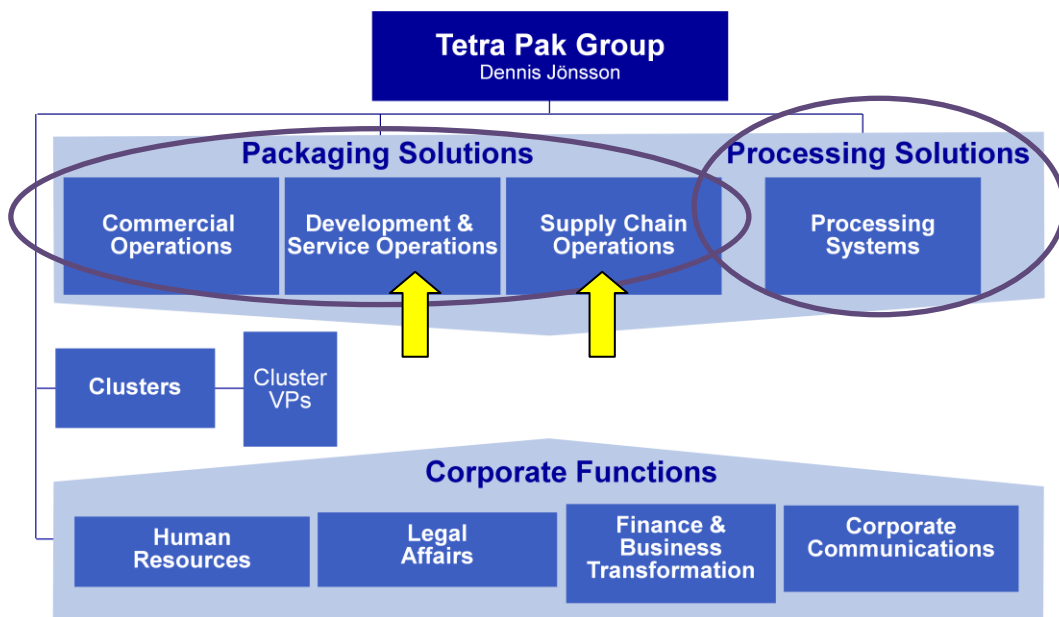

Figure 11: Tetra Pak´s organization

The blocks relevant to this project, that is, relevant to packaging material production, are *Development & Service Operation* and *Supply Chain*

Operations. The first block includes two sections: *Packaging Material* and *Technologies & Service Products*. Both are approached from a perspective of research and development. The point is that, besides constituting a container, and giving the steadiness needed to shape and maintain the shape of the package, the packaging material protects the product from being affected by the environment. Furthermore, the packaging gives information about the contents of the package, and makes it easy to handle and transport. For all these reasons, the packaging material of the package becomes so relevant and is constantly trying to be improved. The second block, *Supply Chain Operations*, deals with the logistics of industrial bases, which are: *Supply Chain Packaging Material & Base Materials*, *Packaging Material Operations*, *Additional Materials* and *Capital Equipment*. To get a better understanding of the logistics involved in the whole manufacturing process, figure 12 shows Tetra Pak´s Value Chain.
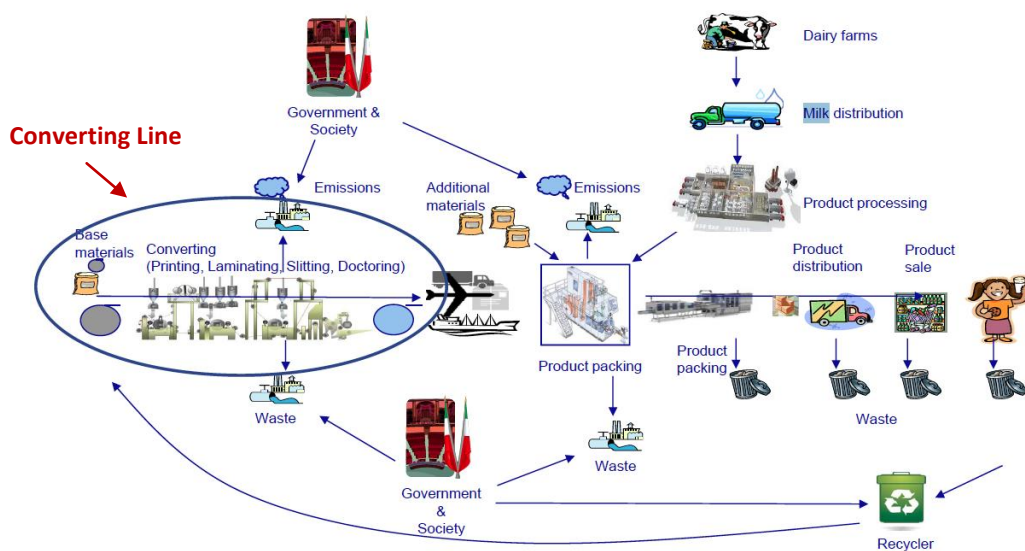
Figure 12: Tetra Pak´s Value Chain and placement of the CL

As viewed in the figure, the main activities along the value chain are the production of packaging material, the production of food products at the customer´s sites, the packaging process of the product, and then the distribution and sale of it. As said before, this thesis is going to look into the packaging material production, that is, the converting line (circle on the picture above).

28

4.2. The Converting Line

The converting line process is placed at the first stage of the supply chain as seen in the picture above. Its purpose is to convert base material (paper board rolls) into packaging material (packages rolled in reels). The output of it is sent to the customer´s filling machines, which fold and fill the packages.

The main activities in the converting process are *Printing, Laminating, Slitting* and *Doctoring*. Between one activity and the following the rolls are stored in buffers (named WIPs in the thesis). Before the converting process starts, the rolls and the base materials are warehoused. Just before printing, there is a *Prepress* area that is in charge of creating specific sleeves for each design (to later be used in the printing activity). Once the converting process is over, after doctoring, the reels are palletized and warehoused as FGI until they are called to be delivered. Although at first sight, the process may seem simple, it is actually quite complex since the factory has to handle different customers, produce different packages models, different packages sizes, different openings, different printing techniques, different packaging materials – depending on the liquid it contains-, it also has to deal with short orders (small size), flexible orders and rush orders.

Next, the mentioned main activities in the CL are described. Be aware of that these activities' descriptions are specific for Arganda factory. Other TP factories may not match this description since they have either other machine models, or other procedures.

4.2.1. Printing

This is the first machine of the CL that the rolls go through, and its main inputs are: the paperboard rolls (which are transported from the warehouse), the sleeves for each design (made in the *PrePress* station) and the inks. The internal processes along the 3 printing machines of Arganda are shown in figure 13 and represented in figure 15.

1. Unwind → 2. Roll adjustment → 3. Ink units → 4. Creasing Tool → 5. Design Control → 6. Rewind

Figure 13: Printing machine internal processes

1. The roll is first unwound and spliced to the previous roll. There is a buffer so that the machine doesn't have to stop in-between rolls. However, when a new order roll comes then it is compulsory to stop the machine since at least the sleeves have to be changed.
2. The paper roll is adjusted to the machine depending on its width.
3. The roll paper goes through several units where the ink is added to the paper. In each unit there is a different basic colour. The ink chambers need to be cleaned sometimes (and therefore the machine has to stop); for example, when an incoming order uses different ink colours than the previous order. The superposition of all the colour layers will achieve the desired tonality on the paperboard. Machines *Printer14* and *Printer12* have 6 ink units, while *Printer16* has 7 units. With the sleeves manufactured in the *PrePress* area, the design will be engraved to the package.

    The printing technique depends, among others, on the way inks are added to the paper. It can be either FP (flexo process – creates all colours from the combination of cian, magenta, yellow and black), or FL (flexo line – which uses specific colours).
4. Once the coloured design has been printed on the paper, folding instructions are added to the package, as well as opening perforations and holes for straws and screw caps (see figure 14).
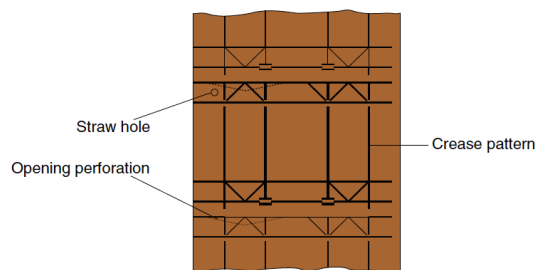
Figure 14: Piece of a paper creased

5. With a specific machine, it is verified that the printed design on the board matches with the expected one. It may occur that there is a lag between ink units, and therefore the picture is blurred. Or it may also happen that there is one ink unit which is not acting properly, or that the paperboard itself is damaged. When errors are detected the roll is manufactured again.
6. The roll is rewound so that it can be transported to either the WIP buffer or the following machine.
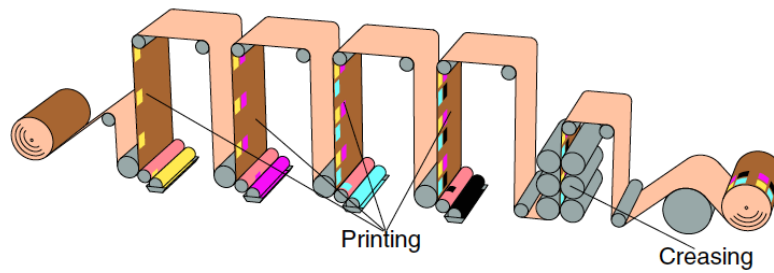
Figure 15: Representation of the printing machine

4.2.2. Lamination

Once printed and creased, the roll is transported to the laminator (also known as coating machine), where different layers are added to the printed paperboard. Depending on the future content of the package, the packaging material will consists of less or more layers. The internal processes along the 2 laminating machine of Arganda are shown in figure 16 and represented in figure 18.

Figure 16: Lamination machine internal processes

1. The roll is unwound and spliced to the previous roll. There is a buffer so that the machine doesn't have to stop in-between rolls.
2. The paperboard is pulled.
3. Then goes through a flame treating unit where the roll gets rid of dust and dirtiness, and increases its oxidation properties (that increases the adhesion between the paper and the polymer-which will be added in the following processes-).

Then all the required layers are added in three different stations (*lamination station, inside station* and *decor station*).

4. In the *lamination station* an aluminium foil is glued with LDPE to the paperboard. The aluminium foil is unwound at the same speed as the paperboard roll. The glue comes from an extruder.

   In this station there is a nip roller[2] that can be any of the following kinds: DD, DD1, or Teflon. Some *Quality Size Variance* (QSV[3]) types require the usage of a particular nip roller (for instance PLH packages), while other QSV are not restricted to one kind.

5. In the *inside station* an inside layer, which will be in contact with the product, is added to the paperboard already glued with aluminium foil. The inside layer is a superposition of three sub-layers. This is why the inside station is composed of three hopers (internal2 -D-, internal1 -C-, and internal3 -E-). Each hopper consists of an extruder that can be fed by one or two chambers. The content of these chambers might need to be changed depending on the specifications of the package. Each extruder will pour a liquid, and the joint of the three of them will be added to the paperboard. Figure 17 pictures the hoppers of the inside layer.

   In this station there is another nip roller that can be any of the following kinds: DD or DD2. Some QSV require the usage of a particular nip roller, while others don't.
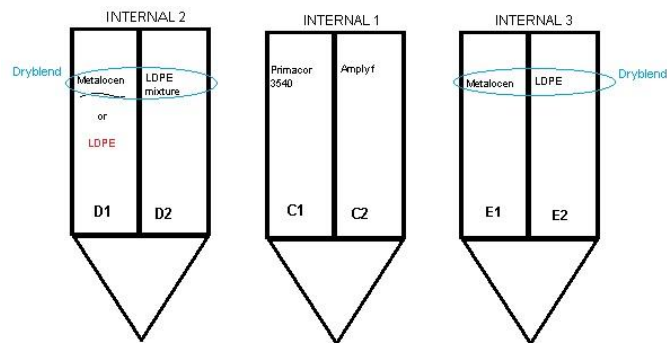

Figure 17: Representation of the hoppers that pour the contents of the inside layer

---

[2] The nip roller function is to press the polymer against the paper so that it adheres.
[3] A QSV is a code given to each package which defines the specifications of it. It contains 9 numbers: 4 belong to the *Quality*, 3 to the *Size* and 2 to the *Variance*.

- **Internal2** extruder has two chambers on top of it, one with either Metalocen pure or LDPE (D1), and another chamber with a LDPE mixture permanently (D2).
A set-up is required when changing the content of D1. A drooling is performed when emptying it.
For most of the packages, extruder internal 2 is required to pour a mixture of Metalocen (D1) and LDPE mixture (D2), which is called Dryblend. Contrary, PLH packages only require LDPE from chamber D1, and therefore chamber D2 is closed.

- **Internal1** extruder has two chambers on top of it as well: one with Primacor3540 (C1) and another with Amplyf (C2). Only one of them can be pouring liquid to the extruder at a time. The other chamber will be closed with a key. The first one is used for juice or wine, while the second one is used for milk.
For PLH packages, a set-up is required when changing production from milk packages to juice packages, or vice versa, since the locking key of the chambers needs to be switched suddenly. In the transition from one liquid to another, there will always be a mixture of the two liquids in the lower part of the hopper (cone shape). PLH packages are very sensitive to this mixture and therefore the extruder needs to be cleaned properly. This cleaning can be achieved by letting liquid flow for a while. This is called a flying set-up and involves wasting some meters of roll paper. However, if the machine is stopping anyway because of another reason (i.e. Teflon changes), no roll paper is wasted. In this case, the extruder is removed and a drooling is performed in order to clean it. For no-PLH packages, no set-up is required when changing production from milk packages to juice packages, or vice versa, since non-PLH packages aren´t sensitive to the mixture of Primacor3540 and Amplyf.

- **Internal3** extruder has two chambers on top of it, one with Metalocen (E1) and another with LDPE (E2).
The mixture of the two (DryBlend) is used for all packages. Since Internal1 is usually providing DryBlend as well, Internal1 and Internal3 layers are sometimes considered as one.
No set-ups are needed in this hopper, since the content of the chambers never changes.

33

6. In the *decor station*, a polymer is added to the exterior part of the paperboard. This layer´s function is protecting the printing from temperature and moisture.
7. Finally the surface pureness is checked.
8. The roll is rewound so that can be transported to either the WIP or the following machine.
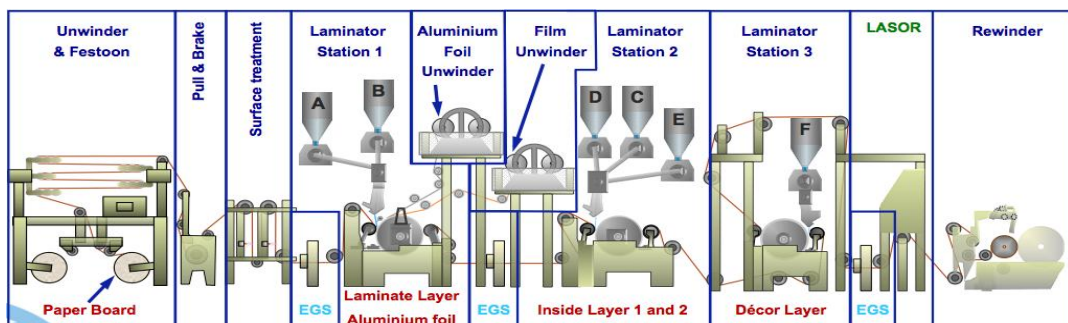
Figure 18: Internal processes along the laminator

Once the roll comes out from the lamination, it has the following layers (from outside to inside):

- Outer coating decor (added in *decor station* in the laminator)
- Printing (added in the printer)
- Paperboard
- Lamination glue (added in *lamination station* in the laminator)
- Aluminium foil (added in *lamination station* in the laminator)
- Internal coating 1 (added in *inside station* -extruder 1- in the laminator)
- Internal coating2 (added in *inside station* -extruder 2 and 3- in the laminator)

4.2.3. Slitting

This machine slits the rolls into several reels. The number of reels obtained out of a roll depends on the number of lanes of the roll, and on the reel diameter wanted. Rolls can have from 5 to 7 lanes. The reel diameter is limited by the pallet dimensions. In Arganda the maximum diameter allowed

for a reel is 1,13m (since the pallet width is 1,15m). The internal processes along the 4 slitter machines of Arganda are shown in figure 19.

1. Unwind   2. Adjustment   3. Evaluation of defects   4. Slitting   5. Wind the reels obtained   6. Send them to:
• doctoring
• palletizing

Figure 19: Slitter machine internal processes

1. The roll is first unwound and spliced to the previous roll. The machine has to stop every time reels are ejected.
2. The paper roll is adjusted to the machine depending on its width.
3. Operators look for defects, about which they take notes and enter in the system. They also evaluate the relevance of the defects archived in the system which were detected in previous machines. They will decide whether they have to be treated in the doctoring or not after the roll is cut into reels.
4. Cutting the roll into reels. There can be standard reels, or jumbo reels (bigger diameter), depending on the diameter of the reel desired by the customer.
5. Reels are rewound, and an adhesive is added to the tail of the reel to keep it strained.
6. Once the reels are ejected from the slitter machine, the reels which have defects are sent to the doctoring machine, while the approved ones are ready to be palletized. Reels are palletized together with other reels belonging to the same order, and wrapped in shrinking film. Some customers require wrapping reels individually before they are palletized together with others. The single wrapping station can become a bottle neck since its capacity is one, and its process time is considerable. Therefore, operators attempt not to send many of these individually wrapped rolls to the palletizing station at a same time, because this could generate a problem.

Figure 20: Images of the slitters

Figure 20 is composed of four images. The 1st image shows the load of a roll in the slitting machine, the 2nd image in the first row shows the cutting knives separating lanes, the 3rd image shows reels coming out of the slitter, and the 4th image shows a single wrapped reel going to the palletizing station.

4.2.4. Doctoring

Reels containing defects on the packaging material will be unwound, the faulty part will be cut off, and then they will be spliced again. As an average, around 16-17% of the reels need to be doctored. In figure 21 a reel is being doctored.
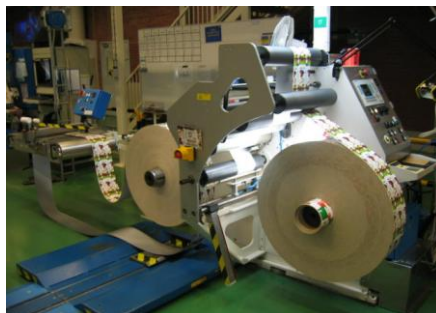
4.3. Definition of an order

What is an order? An order is a request, from a customer to Tetra Pak, of a certain number of packages, which have a certain packaging material characteristics, a particular volume and shape, a specific opening method, and a particular design. If any of these parameters changes from one set of packages to another set, then each set of packages will be a different order.

It can happen to have a co-production order, what means that in all of its rolls different designs from the same client are printed in alternated lanes (of course, the packages have to be made out of the same material, and share some other specifications as they belong to the same roll). In this context, it is important to distinguish between *Main Order* and *Production Order* (vocabulary used once in the factory). A *Main Order* is a set of rolls which are all equal in-between them (it might be co-production or not). A *Production Order* consists of a set of lanes that have the same design. Therefore, a *Main Order* which is a co-production, will have several *Production Orders* associated (as an example of a co-production roll of 6 lanes, see the 2nd image of figure 20).

Tetra Pak's customers place orders to the Market Companies. Roughly, there is one Market Company for each country and they are in charge of allocating the customer's orders in some of the company's factories within the cluster they belong to. A cluster is a group of market companies and factories that are located in a same geographical area. For instance, the South Europe Cluster of Tetra Pak consists of three factories (Arganda, Dijon and Rubiera) and several countries close to them. Not all the factories can produce all kind of packages, and thus it is reasonable for Company Markets to belong to a cluster instead of placing orders only to the nearest factory. If they were to do that, they wouldn't be able to satisfy all kind of customer orders. However, there are some specific factories, that due to their size and location, they export a lot to other clusters; i.e. Lund factory. Also, there are other factories that produce only for their regions, for instance China and India factories; and they don´t need to belong to a cluster.

4.4. Order flow

The total lead time of a packaging material (PM) order encompasses from the day that a customer launches an order to the day that the customer receives the order at his site (see figure 22). The tracking of the order is controlled by the Sales Department in order to evaluate and improve the system performance and efficiency. The main sources of information are *R/3* for Finished PM Order, and *MES* for Production Events.
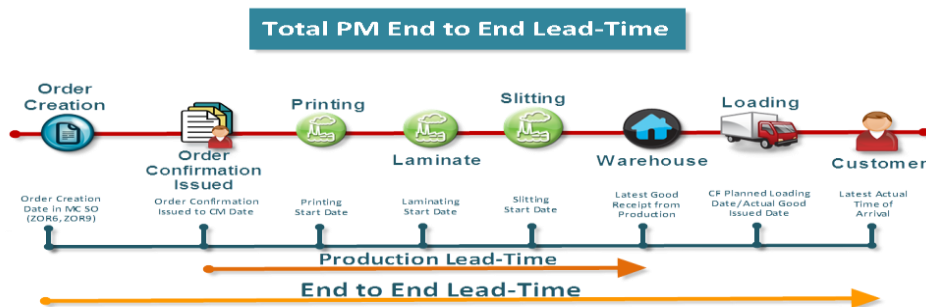
Figure 22: PM Order flow

4.5. Reception of orders and Production planning

4.5.1. Reception of an order

The Market Companies place order requests to the cluster they belong to, and the cluster then place the orders to the factories (in this case, Arganda) through the *R3 system*. These orders can be either accepted or rejected, depending on the factory´s capacity, on the availability of raw material, and on the requested lead times. Within the *South Europe Cluster*, Arganda factory is responsible for producing PM of certain specifications. There are some kinds of packages that cannot be produced in Arganda, but the cluster already sends those packages requests directly to the other factories inside the cluster. The order request is sent to the *C Plan System*, and in the *SO Confirmation Report* tab, orders are constantly being placed along the day and they wait to be accepted by the factory planner. Once the planner accepts the order, the market company receives the confirmation, and the order moves into another system called *Proplanner*. The accepted order remains in a tab called *LamPlan* until the planner schedules its production in

the block planning. Since the planner works with a 14 days planning (plus the factory in Arganda intends to approach a Direct Flow strategy to avoid big levels of WIP) orders in *LamPlan* are scheduled not before their DueDate margin is 14 days or less. *Proplanner* is the software used by the planner to schedule the orders along the machine´s production plans. Every now and then, the planner is responsible for exporting the production plan that is defining in *Proplanner,* to another system called *MES*. The aim is that *MES* is always updated to the last modifications. *MES* translates the visual production plan of *Proplanner* into production orders for each machine in the factory. The following schema represents the path an order follows.

The market company places the order requests to the cluster it belongs

The cluster places the order in a factory through the *R3 System*

The order is then imported to the *C Plan System*. In the tab '*SO Confirmation Report'* the order is waiting to be accepted by the planner. Once accepted, it will be placed in the LamPlan tab of *Proplanner*
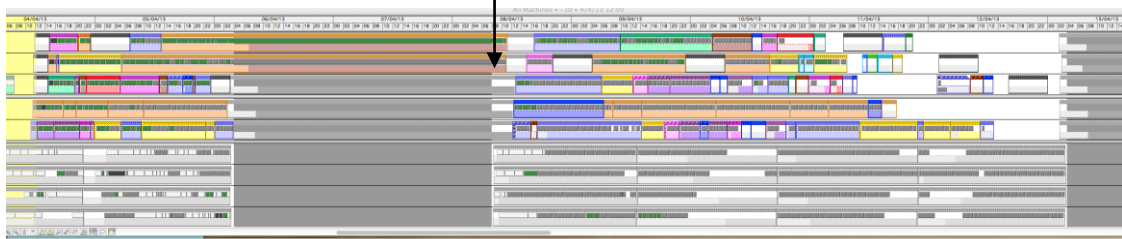
The order is scheduled in *Proplanner* -visual production planning (3 first lines belong to the printers, 2 second lines to the laminators)-

4.5.2. Production activities´ planning process

When a new order is accepted to be produced in the factory, the planner will seek in the draft production plan if the printing and laminating blocks, to which the new order belongs to, still have capacity. Blocks are a group of orders that present the similar specifications[4]. This is why a set of orders belonging to the same block can be handled in one go without having to stop the machines, or at least without having to do set-ups. There are three main machines that the roll has to go through in order to become packaging material: the printer, the laminator and the slitter. The bottleneck of this production line is the laminator. For this reason, when an order is to be introduced in *Proplanner*, the first production activity the planner schedules is the lamination. Once the order has been assigned a lamination block, then it is time to seek –inside the draft production plan- a printing block hole (sooner than the laminator). It is convenient to leave a security buffer time between the printing and the lamination in case there might be delays in the printers. Since the slitting is the last main activity in the CL and the slitter machines performance is quite simple, in Arganda, the slitting activity is not scheduled by the planner. The slitter operators in the factory organize the slitting activity of the rolls that are in the *LaminatedRolls* warehouse, according to the rolls urgency and of course trying to respect slitter blocks. Common orders, in Arganda, have an approximate size of 250.000 packages, which roughly corresponds to 2-4 rolls. The planner won't schedule an order until 14 days (or less) it has to be dispatched (the purpose is to avoid big FGI volumes). Figure 23 shows STO's planning process flowchart.

---

[4] As said, blocks are a group of orders that present the same specifications. These orders can be of different QSV, but since QSV belonging to a same block have the same printing/laminating/slitting specifications, no setups are required within a block. This is why all orders of a block can be handled in one go without having to stop the machines, or at least without having to do set-ups. There exist printing blocks, lamination blocks, and slitting blocks.
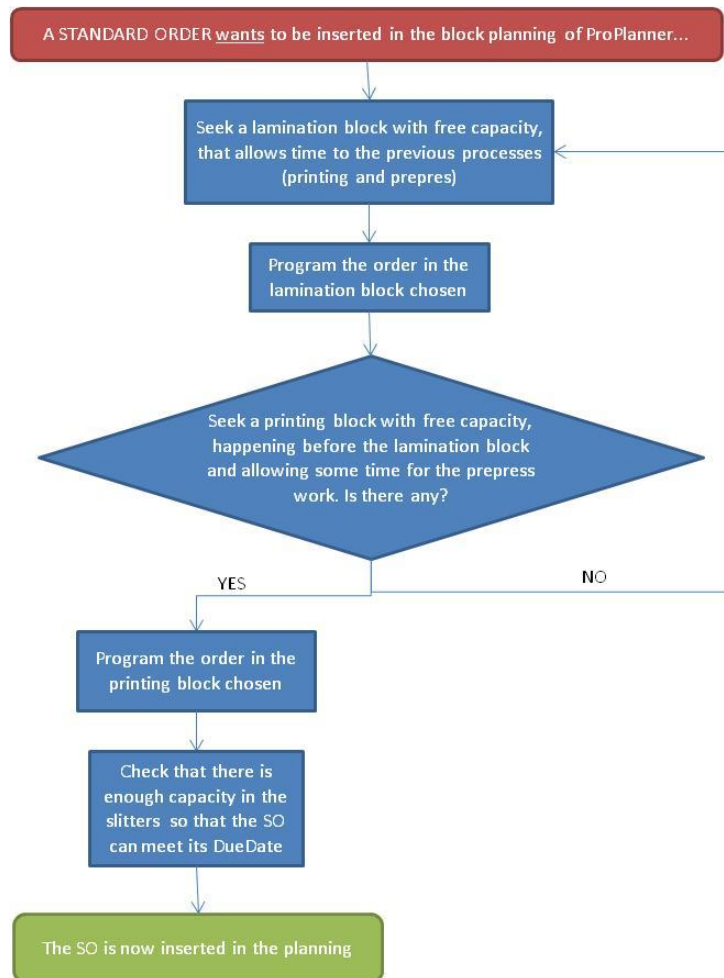
4.5.3. Draft production plan

The draft production block plan that the factory has for scheduling the production of all machines, is based on a forecast. Factories require all their clients to provide a rough forecast frequently, so that factories can plan how much and what kinds of raw materials need to be ordered to the suppliers, and when. Also allow them to plan how many workers are going to be needed. The forecast enables the factory to ensure production capacity and build an efficient block sequence.

41

The factory of Arganda has a draft production plan that lasts a week (and it keeps repeating week after week). The reason why is due to Cluster policy. The draft production plan is designed with the objective that the chosen block sequence has the minimum impact on overall set-up times and waste. There exists a lot of printing blocks and as well a lot of laminating blocks. However, factories don´t embrace all of them; each factory usually focuses on certain ones. Figure 24 shows the characteristics that orders belonging to the same block share. Orders belonging to the same printer block must have the same specifications regarding package size, opening, printing technique, and colours required. Orders belonging to the same lamination block must have the same specifications regarding the roll´s width, opening, kind of content, and PM quality. Finally, the features that must share orders belonging to the same slitter block are: package width[5] and the number of lanes.

Printers	Laminators	Slitters
• package size	• roll's width	• package width
• opening	• opening	• number of lanes
• printing technique	• kind of content	
• colours required	• PM quality	

Figure 24: Block specifications

In figure 25, it is specified what needs to be changed in the machines when they start producing packages with new specifications.

---

[5] It can be 174cm , 202cm, 322cm, 305cm or 260cm, depending on the "Size" QSV´s attribute.

Printers	Laminators	Slitters
• creasing tool • Anilox • doctor chamber	• side adjustments • insertion of teflons • add or remove specific layers • add, remove or switch nip rollers	• arm´s position • arm´s quantity

Figure 25: Changes required in the machines due to specifications changes

4.6. Factory goals and blocks' production strategy

The company´s (and therefore factory´s) main objective is to satisfy the client. This is achieved by fulfilling two requirements: deliver the order on time (that is to achieve its due date) and in full (that is when the customer receives the ordered quantity ±5%) Also, since one of the policies of TP is to do what the client wants at any time, factories end up accepting rush orders, and accepting claims on finished orders and remanufacturing them, among others. Besides this, the factory´s main aims are to maximize throughput (in order to maximize revenue), and to minimize costs. The objective is to perform the most efficiently and to generate as little waste as possible. See the factory's goals in figure 26.

Client´s satisfaction
Efficiency
Revenues

Costs
Total set-up time
Set-up waste
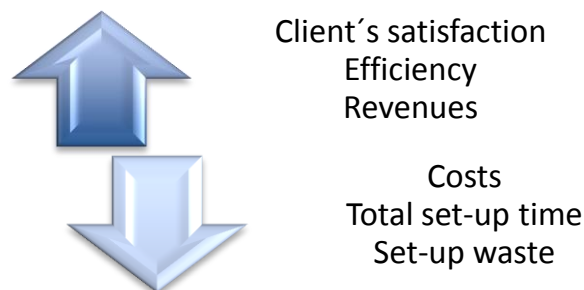
Figure 26: Factory´s goals

To achieve the goals, the factory follows a blocks production strategy. By scheduling the blocks properly, machines will have to be set up fewer times.

Set-ups entail a loss of production time, a waste of material, and, sometimes, having to stop the machines completely (which is very costly). The bottle neck of the CL would be the laminators, but with the current factory ideal production plan, and with the fact that there are 3 printers and 2 laminators, the laminators are not a bottle neck anymore. The laminators are the most complex machines and stopping them involves large amounts of waste material. Therefore, since they are the most costly to stop, the planner first schedules the lamination activity, and afterwards, the printing activity (as explained in the previous section). The overall CL objective, when trying to achieve good efficiency, is to set-up the laminators as rarely as possible. As a consequence, the printers sometimes are scheduled following lamination block conveniences, meaning that they have to break the optimal printing block sequence. The complexity of a factory can be measured with the quantity of QS (quality and size specifications of a package) the factory produces. It is obvious that the more complexity there is in the factory, the higher the factory costs become. The more different QS the factory offers, the more different blocks, for each machine, there will exist. The fact that the factory runs many blocks in one machine has an impact on the costs because there will be higher number of set-ups, more set-up waste material will be generated, etc.

4.7. Set-ups and other production stops. Time and waste related.

In this section machines' set-ups are defined. It is explained when they are required and what do they involve (regarding time and generation of waste). A set-up is an adjustment done to the machine every time it starts producing packages with new specifications (for instance, every time there is a block switch). Set-ups may entail stopping the machine completely, or instead, only lowering its speed a bit (those are known as flying set-ups). The waste generated in a flying set-up is the paper running while the machine speed is lower than the required to produce, and also the PE poured and the Aluminium foil loosed meanwhile. Besides set-ups, there are other occasions when production is interrupted (see figure 27). For instance: planned short stops, unplanned stops (for instance, a break down, or a paper breakage), or

maintenance or trainee shifts. Regarding 'planned short stops' in the laminators, they can be due to *teflon change*, or to *die cleaning*, and they always require to stop the machine completely. There exists a document[6] where it is stated how often these short stops happen, how much time they require, and how much paper and PE waste they generate (all these parameters depend on the QSV that is being produced). 'Unplanned stops' are very frequent in the printers.
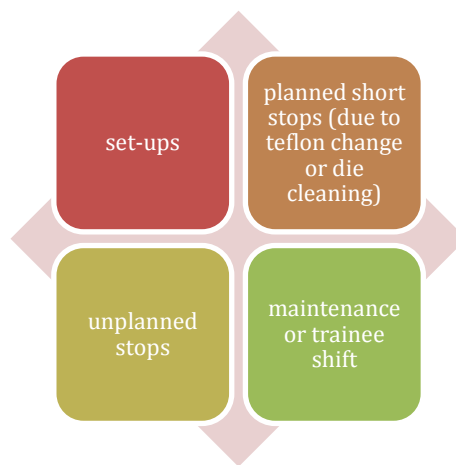
Figure 27: Reasons why the machines stop or are forced to slow down the speed

4.7.1. Laminators set-ups

The lamination machine does a set-up almost every time there is a block switch (and some of them require stopping the machines, while others can be done flying).

The following set-ups are the ones that entail stopping the machine:

- Change of nip rollers in the lam. station or/and the inside station

---

[6] Excel file named "Coating-Set up-SS-Ideal Plan" provided by the laminator leader in Arganda.

- Add or remove teflon tapes in the lam. station or/and the inside station
- Change of the roll width from narrow to wide for big gaps (more than 4mm) → Adjustment of side tools + drooling is performed + set-up paper is used
- Change the content of D1 of extruder 2 in the inside station → drooling of D1[7]

Set-ups that can be done flying or by lowering the speed:

- Empty extruder 1 in the inside station (only PLH packages)[8] → waste of paper[9]
- Change of the roll width from wide to narrow → For small gaps (4mm or less) there won't be set-up waste. For big gaps (>4mm) set-up paper is used, drooling is performed, and side tools are adjusted.
- Change of the roll width from narrow to wide, but only for small gaps (4mm) → no set-up paper is used
- Change paper width from wide to narrow

There is a document[10] where it is stated how much time, paper waste, and PE waste is generated when changing production from blocks of a certain *Size* QSV to another *Size* QSV. Obviously, this information has been used to define the ideal block sequence the planner uses in the draft plan, so that the sequence defined entails the minimum impact. In the DB, there is a table named *lamSetupWasteCombos*, where each set-up code is given a *SetupPaperWaste* and a *DroolingWaste* value.

Besides the set-up waste material, some more waste is generated in the laminators. For instance:

---

[7] About 100-200kg of PE are wasted.
[8] If the machine has to stop due to other reason, i.e. teflon change, this set-up won´t be done flying and instead a drooling of extruder 1 will be performed (what generates approx. 100kg of PE) during the same time the teflon change set-up is happening.
[9] For Lam22, 2500m; and for Lam21, 500m.
[10] Excel file named "Coating-Set up-SS-Ideal Plan" provided by the laminator leader in Arganda.

- Trim[11]
- Top/core wrapping of each roll
- Top/core wrapping of the aluminium roll
- Sample of processed paper roll cut to perform an adhesion and tension quality control (which is done every 20 minutes)

4.7.2. Printers set-ups

Printing machines need to stop more frequently than laminating machines. Printers have to stop every time there is an order switch (considering that a new order implies a new design or at least a new colouring) since the sleeves (design pattern) need to be replaced. This activity takes up to 10-15 minutes. Besides, printers require a set-up every time there is a block switch, since the printing specifications change. It must be said though, that in general, the impact of stopping a printer is much lower than the impact of stopping a laminator.

Set-ups performed in printing:

- Creasing Tool change (new shape and/or opening)
- Anilox change (new printing technique)
- Doctor chamber change (new colours in at least one of the 7 stations)
- Size change (adjustments due to a new roll width)
- Combination of the previous

There are many printing set-up codes defining all the specification changes that may occur when switching from one block to another. Each set-up code has a time for setting-up the machine related, and also a quantity of paper waste related. Each set-up code has different time and waste values depending on the printer (since each machine –printer12, printer 14 or printer16- is physically different, ones are longer than others).

Besides the set-up waste, more waste-material is generated in the printers. For instance:

---

[11] Film strip on the sides.

- Technical waste: top/core wrapping of each roll → it can be from 4 to 10 meters overall depending on the paper supplier.
- Technical waste: Sample of processed paper roll cut from each roll to perform a quality control →about 2 meters
- Defect waste: printed rolls that are removed from the production line because the printing was faulty → 3-5% of the printed rolls
- Used sleeves

4.7.3. Slitters set-ups

The slitter machine in Arganda (model RCX-J) has to stop every time a set of rolls is ejected, and mechanical arms are used to pick them up. It takes around 20 minutes to cut one roll. Rolls belonging to a same block will have the same number of lanes, and the same package width. Therefore, the set-ups in the slitters basically consist of adjusting the knives to the proper positions, which doesn´t take much time (around 20 minutes). When changing from one order to another within a block, sometimes an adjustment needs to be done to the machine which takes around 4-5 minutes. For instance, an adjustment is required between the productions of orders that have different grammage properties.

Only technical waste is generated in the slitters. The top and core wrapping of each roll is removed (10m+5m). The defect waste is treated in the following machine, the doctoring machine, and lasts around 15 minutes per roll.

4.8. The Arganda Factory Simulation Model

Prior to this project, a simulation model for Arganda factory was built. Its first purpose was to evaluate the factory performance. In this project, the model will be used to evaluate the factory performance when rush orders are accepted.

4.8.1. Input data

The factory model has broadly two kinds of data: *Order Data* (which includes Historical data, Synthetic Data and Live Data) and *Configuration Data*. The

first kind of data, *Order Data,* is data regarding the planning (Historical Data are production plans from the past, Synthetic Data is fake planning information added by the user, and Live Data is the current production plan). The second kind of data, *Configuration Data,* refers to data defining parameters of items in the model. All this data needs to be imported to *Flexsim* in order to be able to run the model. The data is imported to *Flexsim* from an Access DB through an ODBC connection. The data regarding planning and some other kind of data, is downloaded from *MES*, while *Configuration Data* was directly introduced to the DB by the user.

The following figure (figure 28) describes the interaction between the informatics systems in the factory (reality), and the softwares used in the model. Excel can be used as an interface between Access and Flexsim, but is currently quite unused.
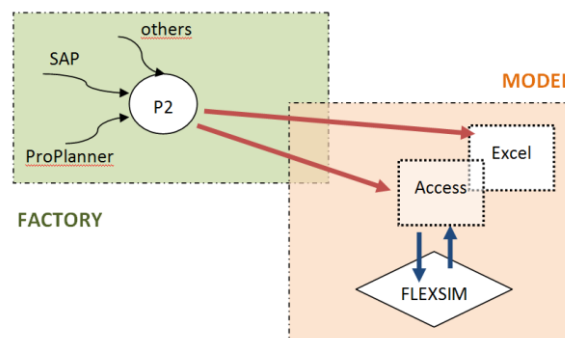
Figure 28: Interaction between systems in the factory and in the model

It is good to know that the DB file has also been used for running other models besides the "Arganda factory model". For this reason there are some tabs that won´t be used for running the "Arganda factory model" anymore. The tables in the Access DB which will be handled in the process defined in this project are the ones regarding planning. Those are: *MainOrders, Plan,* and *ProductionOrders.* Also the querie *RollPlan* (combination of tables) can be useful to check what exactly will be imported to *Flexsim*.

However, some other tabs in the DB will be useful in this project to get to know about *Configuration Data* such as: set-up times, waste quantities, etc. If a RO is to be introduced in the plan in a way that causes the fewest impact, it is necessary for the planner (or in this case, for the person who is following

the process), to have access to this kind of *Configuration Data*. Some of the most useful tables in the DB are: *ProductionOrders, MainOrders, QualSizeAttribs, QualSizeVarAttribs,* and *LamSetupWasteCombos* (see figure 29).

Figure 29: DB displaying some of the tables

4.8.2. The model´s layout and functionalities
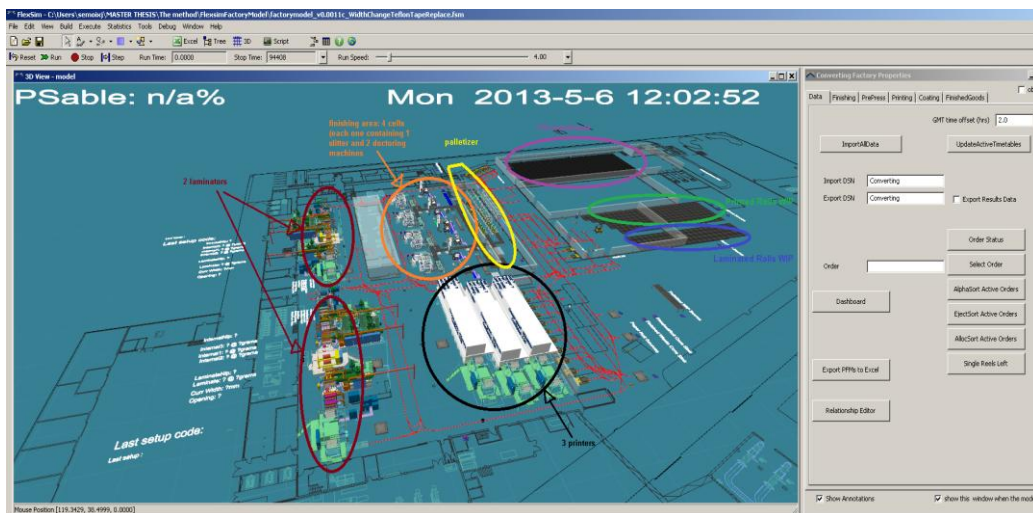
Figure 30: Factory Model layout

Since this process embraces the usage of Flexsim, it´s been considered relevant to explain a few features of Flexsim´s functionality. The layout above (figure 30) shows the distribution around the factory. Some display figures have been placed on the layout such as the date and time, or specific KPIs for each machine. In the right side of the screenshot there is the *Graphical User*

Interface (GUI) window. In the *Data* tab, the *ImportAllData* button allows importing to the model the desired DB (which will be different for each scenario due to different RO in the planning). Previous to it, the OBDC connection should be fixed and its name must be introduced in the *Import DSN* field. The *UpdateActiveTimetables* button lets the user introduce the periods of time during the week when the machine´s production will be interrupted to do maintenance and trainings (those periods are specific ones every week and for machines as well). The *Dashboard* button opens a window where graphical tools describe the states of each machine while the model runs. In the *Order* gap, an orderID can be introduced and tracked (the rolls belonging to the order will be highlighted) while the model runs by pressing *Select Order*. To follow the order sequence of each printer while the model runs, a list of the orders being sent to each machine can be seen by doing double click on the *PaperSourceXX* object. As well, to follow the order sequence of each laminator while the model runs, a list of the orders being sent to each machine can be seen by doing double click on the *WIP2LamXX* object. In the *Finishing* tab there is the possibility to check on *Bypass Finishing Area* what will deactivate the functioning of the finishing area when the model runs (what is actually what will happen in the process defined in this thesis). In the *Printing* and *Coating* tabs, it is possible to alter some particular features of each machine.

4.8.3. The model behaviour

The model doesn´t follow rigorously the timings stated in the planning (block start time); it simply follows the sequence and then performs according to configuration data (statistical distributions for the machines processes, machine mechanical/technical speed, set-up times, set-up requirements i.e. nip rollers per QSV...). The purpose of the model is to approach reality as much as possible, and since in the factory machines are never stopped, and keep producing one order after the other according to the plan order sequence, the model has been coded to do the same. Therefore it may be that in the model, the printing and lamination activities of an order don´t happen exactly when expected (time given in the planning input data).

Since breakdowns and shortstops of the printers, among others, still haven´t been modelled in the Arganda factory model, the efficiency KPI provided by the model is not close to reality. Therefore, a correction factor has been added to the results obtained with the model. This correction factor has been

defined upon week19's real data downloaded from *MES*. See Appendix III for further information.

5. Rush orders in Arganda

In this chapter rush orders in Arganda will be defined and afterwards, ROs with a greater impact will be identified. Next a RO's scenarios categorization will be provided. Then it will be explained the methodology the planer follows when scheduling a RO. Finally the KPIs used to measure the RO's impact will be exposed and as well the specific costs.

5.1. Definition of what is a rush order in Arganda

At Arganda factory of Tetra Pak, they consider an order to be a RO when it offers less than 14 days between its *Order Date Time* and its *Due Date*. This means that the planner receives the order less than 14 days before the order has to be dispatched (an order is ready to be dispatched once it has been palletized and wrapped, and is about to be sent to the FGI warehouse). They believe that orders must be placed with a margin of at least 14 days in order to make sure that they can be scheduled properly in the optimal plan. As stated in section 3.4., in the *frame of reference* chapter, a rush order needs to be handled within a short time because it has been placed very close to its due date. This will have an impact on STOs' lead time, on WIP levels, on production efficiency, and on factory costs.

5.2. Rush orders with a greater impact

In order to know which the most relevant kinds of ROs in Arganda factory are, an analysis has been conducted. The planner in Arganda took note of all the rush orders from 2012-12-18 to 2013-04-08. Its urgency was recorded and now has been plotted in the graphic below (see figure 31). From it we can learn that the majority of the rush orders (65%) have a lead time greater than 7 days.
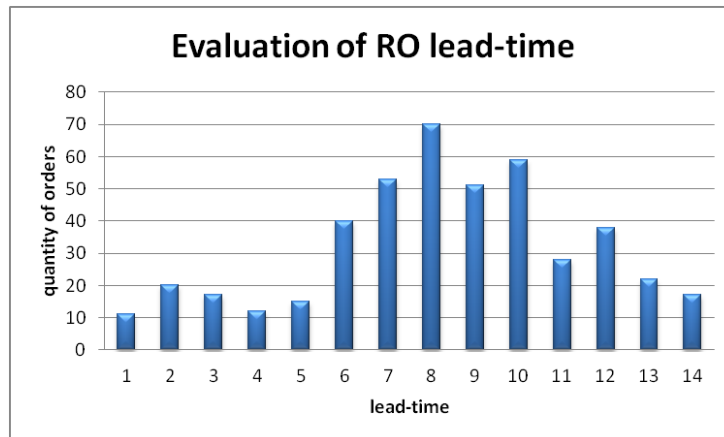
Figure 31: Evaluation of the lead time of Arganda´s ROs (days)

In addition to the analysis, the planner described rush orders in general, and gave his opinions about which are the ROs that worth to be studied the most. He explained that the majority of the rush orders have a small size and have a lead time greater than 7 days. He said that they usually can be introduced to the plan easily and therefore don´t have an impact on the production performance and cost. Also, he added that big or small orders with a lead time of less than 7 days, although being less frequent (as can be seen in Figure 31), are those with the most significant impact on production performance because they usually require creating or breaking new blocks.

Therefore, this master thesis will only study small and big orders with a lead time shorter than 7 days. Although not being the most numerous, they are the ones with greater impact and thus worth to be analysed the most.

5.3. RO's scenarios categorization

The impact on cost, on efficiency, and on lead time for other orders, will depend on the order´s size and urgency, and also on the lamination and printing blocks availability (at the moment when the RO is to be scheduled into the production plan). So, somehow, the impact of a RO not only depends on its own characteristics (size and urgency), but also on the particular plan sequence the RO meets when is about to be inserted in the production plan. Therefore, the scenarios caused by ROs can be categorized as shown in figure 32:
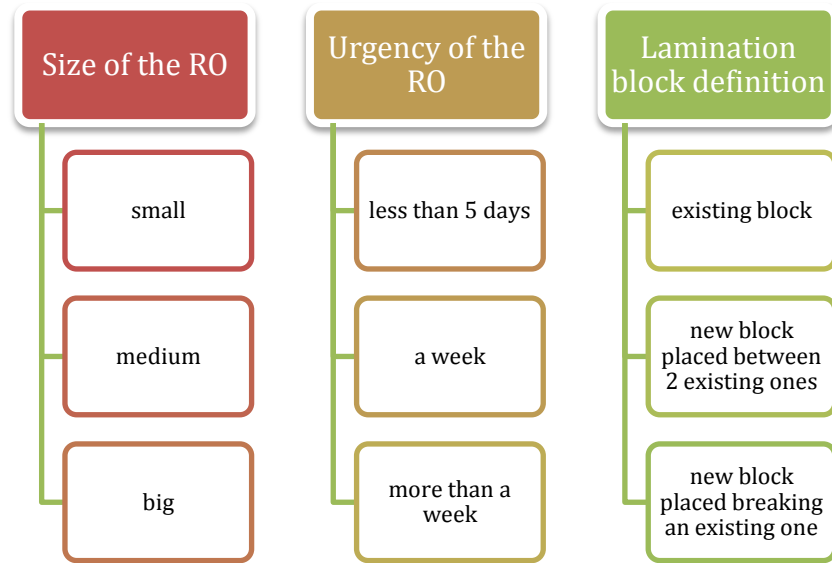
Figure 32: RO's scenarios categorization

- "Size of the RO" refers to how big the order is. The size can either be measured in number of packages or in number of rolls. In this project, the RO size has been defined according to Arganda's particular ratios, and the unit chosen has been number of rolls. Roughly, small orders usually have 1-5 rolls, medium orders have 5-10 rolls, and big orders have more than 10 rolls.

- "Urgency of the RO" refers to how rush is the order. It embraces the time between the "*OrderDateTime*" and the "*DueDate*". It defines in how many days the order must be planned, manufactured and handed in. This category has been classified in "*less than 5 days*", "*a week*", and "*more than a week*". In the analysis of this master thesis only the two first options will be studied.

- "Lamination block definition" refers to the blocks availability. The lamination block where the RO is inserted can be an existing one, a new block placed between 2 existing ones, or a new block placed breaking an existing one. A new block needs to be created when in the plan there is none of its kind on time.

5.4. Planning a RO in the Advanced Planning System

When a RO has been accepted and is to be inserted in the planning, the planner will follow the procedure defined in the flowchart below (see figure 33). The procedure is quite similar to the STO planning process, since it first schedules the lamination activity, and afterwards the printing and slitting activities.

5.4.1. The planner inserts a RO in the block sequence

However, what is particular of the RO planning process is the need of making sure that there is enough time for the *PrePress* work, and also enough raw materials (paperboard and inks) available. Also, it is important to have in mind that before widening an existing full block, is always convenient to check if a switch of orders is possible (this means to move a STO to another block of its kind placed later in time, so that the RO can fit on the free spot). And finally, when scheduling a RO there might be the need of altering the block sequence of the draft plan. In that case, be aware of the set-up impact of changing from one block kind to another, and chose the block sequence with lower impact[12].

---

[12] To get to know about the impact of switching from one block kind to another, having a look to the file **"120914_ Production Block DefinitionPP - Planning and FI"** can be useful.

A RUSH ORDER wants to be inserted in the block planning of ProPlanner...

Is there any lamination block on time (before its DueDate)?

YES — NO

Does the lamination block found has free capacity ?

Creation of a new lamination block either between 2 existing ones, or in the middle of one block (depending on the urgency of the RO and also on the blocks that are currently being processed). Try to insert the new block where it has less impact.

YES — NO

Program the order in the lamination block chosen

Wide the existing block and program the RO in it. Be aware that the orders in the posterior blocks will be delayed
OR
If the client has other non-urgent orders in this block, try to switch the orders. This way, subsequent standard orders won´t be delayed
OR
If ithe block contains orders that have been planned well in advanced, reschedule them for next week (ensuring that they will still reach its DueDate). Now the RO fits in the block.
OR
If ithe block contains orders that accept to be delivered with a short delay (clients that are not strict), reschedule them for next week . Now the RO fits in the block.

Is there any printing block on time (before the lamination)?

YES — NO

Does the printing block found has free capacity ?

Creation of a new printing block either between 2 existing ones, or in the middle of one block (depending on the urgency of the RO and also on the blocks that are currently being processed). Try to insert the new block where it has less impact

NO

YES

Program the order in the printing block chosen

Wide the existing printing block and program the RO in it. Be aware that the orders in the posterior blocks will be delayed

Make sure that there will be enough time to prepare PrePress work, and that there is raw material available (inks and paperboard)

57

Figure 33: RO Planning process flowchart

Check that there is enough capacity in the slitters so that the RO can meet its DueDate

The RO is now inserted in the planning

5.4.2. Communication of the RO arrival to the factory

Once the planner has scheduled the RO and it starts being manufactured, he needs to communicate about the RO to the slitter operators in the factory. In this way they can ensure that the slitter machines, the doctoring, and the palletizing station will be ready to receive the RO. For instance, they will avoid processing many co-production orders since they take a lot of places in the palletizing station. Also, if the RO rolls need to be individually wrapped, operators will try not to process many standard orders that require single wrapping as well, at that time.

In the flowchart above, the action box "Check that there is enough capacity in the slitters so that the RO can meet its DueDate" is imprecise, since the amount of time before its DueDate that the RO rolls need to arrive to the *LamWIP* (laminated rolls WIP) depends on:
- number of rolls
- if a change of block is required in the slitters
- number of slitters dedicated to the RO (number of machines working in parallel)
- % of rolls that need to be doctored
- free spaces in the palletizing station

To check if there will be enough time for dispatching the RO on time, the planner has to do a rough approximation of the time needed between the *LamWIP* and the *DueDate.* Considering all the variables of the list, and knowing that it takes 20 min to cut each roll; 20 min to do a set-up in the machine; and that, according to statistics, 16-17% of the reels will have to be doctored (as an average, it takes 15 min to doctor a reel), an estimation of the time needed for slitting, doctoring and palletizing can be done.

5.5. KPIs to measure the RO's impacts

When ROs are introduced in the system, they have an impact on cost and on efficiency, and on STOs lead time. After discussion, it has been concluded that the outputs needed to study the impact of a rush order are the ones shown in figure 34.

| machine´s EE | machine´s % of set-up state | machine´s waste | WIP warehouse level | % of "Perfect Deliveries" |

Once the outputs are clear, then it is time to state which the KPIs that will be recorded in *Flexsim* are. Table 1 shows their names in *Flexsim* and also provides a definition and the unit measure.

KPI	Definition	Units
Printer XX EE Laminator XX EE	The EE is defined as *effective time* divided by *used time*. The *effective time* is the time during which the machine has been producing output. The *used time* also includes set-ups, short stops and breakdowns. However, in the model the EE is defined as produced meters divided by potential produced meters during the *used time*.	%
Printer XX Setup % Laminator XX Setup %	Percentage state time that the machine is performing a set-up	%
Printer XX Waste meters Laminator XX Paper Waste	Number of meters wasted due to set-ups. In the case of the laminators, those meters refer to both paperboard and aluminium foil.	m
Laminator XX Drooling	Quantity of PE wasted due to set-ups	kg
AverageContent_PrintedRoll	Average number of rolls in the	qty

WIP	printed rolls' WIP	
PerfectlySlitable[13]	Percentage of full orders that have arrived to the printed rolls' WIP with an enough security buffer time before its DueDate	%

Table 1: Flexsim KPIs

5.6. Specific costs

In order to achieve a sensitive analysis, the KPIs will be translated into costs by using the following sensitive figures:

Regarding factory equipment utilization:

- Printing machine hour cost (€/hour)
- Coating machine hour cost (€/hour)
- Inventory storage cost for PrintedRollsWIP (€/roll&day)

Regarding material waste:

- Paperboard cost (€/m)
- Aluminium foil cost (€/m)
- PE cost (€/kg)

The real values for these figures are believed to be highly confidential for Tetra Pak. In addition, these values are not unique. Since they strongly depend on where the factory is placed in the world, each factory of Tetra Pak has its own values. The values used in this thesis are only approximate values (see them in table 2). Some of them have been provided by the company, but

---

[13] This KPI has been defined to substitute the "PerfectDelivery". Since at the time this project is being developed, the slitting area of the converting line is not yet properly modelled, the KPIs used only cover the printing, WIP and coating processes.

others have had to be assumed after gathering information on the internet. Because the aim of this thesis is only to provide a sensitive analysis, it has been considered that the values gathered can provide a fair impression of the cost ROs entail.

The underline machine hour cost is a specific cost rate that divides the estimated overhead of a machine by the number of active hours. The *overhead of a machine* accounts for all those expenses related to using the machine; such as labour, power, depreciation, repairs, maintenance, insurance… *Active hours* refers to the quantity of hours when the factory is supposed to be active (factory time capacity).

The inventory storage cost refers to the cost of the space used to store the WIP rolls, which mainly includes heat, maintenance and insurance.

Sensitive Figure	Cost
Printing machine hour cost (€/hour)	580
Coating machine hour cost (€/hour)	715
Inventory storage cost for PrintedRollsWIP (€/roll&day)	0,1
Paperboard cost (€/m)	0,3
Aluminium foil cost (€/m)	0,6
PE cost (€/kg)	1,3

Table 2: Sensitive figures' value

6. Process for evaluating the cost impact of a rush order

In this chapter the process to evaluate the cost impact of a RO is described step by step.

At a first stage, in order to fulfil the requirements stated in the purpose (chapter 1.3), it was believed that the main steps of the process would be the ones shown in figure 35:
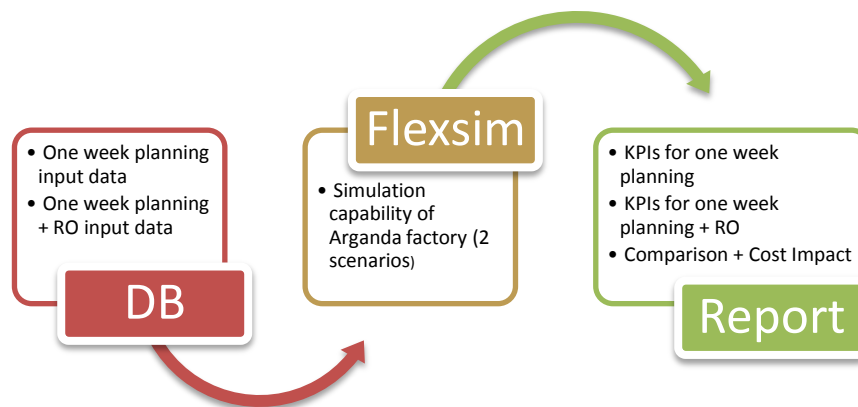
Figure 35: Process's potential main steps

Based on this first idea, the process has now been defined in detail.

6.1. Steps in the process

The process has three main steps (see figure 36). The first one is the insertion of the RO in the planning. The second step is to do simulation runs (using the modified planning as input data) and to gather the desired KPIs. The third step is to evaluate the KPIs obtained and to deliver a cost assessment report to inform about the RO's impact. Logically, to gather the KPIs for the scenario without a RO (base line), only steps 2 and 3 need to be followed.

63

Figure 36: Steps in the process

6.2. First step: Insertion of the RO in the planning

6.2.1. Tools used

As explained in section 4.5.1., *MES* stores the current planning data. So whenever the evaluation process wants to be followed, the first thing to do is to import the current planning data from *MES* to the DB file. In this project, a representative one week planning[14] was exported to the Access DB file in order to perform all the analysis.
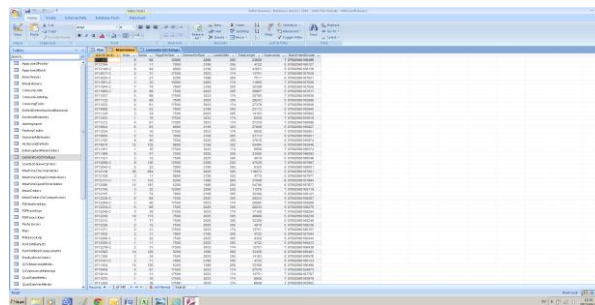
Figure 37: DB displaying the tables where RO data has to be inserted

---

[14] Data extracted at the beginning of week 19, year 2013. The extraction only provided data for a little bit more than a week. Thus, simulation runs are limited to a simulation time of less than a week.

Once the data is loaded in the DB Access file (see figure 37), it is time to add the data corresponding to the RO. For that, only three tables will need to be edited (*MainOrders, Plan*, and *ProductionOrders*).

Another "tool" used for facilitating the RO insertion is a *Proplanner* screenshot (see figure 38) that has to be taken at the same moment the extraction of data is done. It is a block sequence mapping of the plan for each machine, which can be helpful to know where the different block kinds are placed along the week[15].
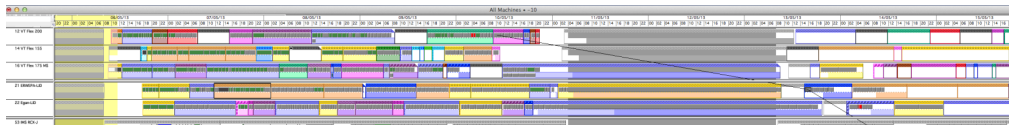
Figure 38: Screenshot of *Proplanner*

6.2.2. Definition and insertion of the RO

To perform the analysis in this project, some RO will have to be defined. In order to make it easier, RO won´t be defined from scratch, but instead a random STO of the planning, meeting the RO requirements (size and QSV), will be used as a template to define the desired RO. The data (such as number of meters, time it takes to be printed, time it takes to be laminated, content of Internal1, content of Internal2, width, among others) of the existing STO chosen, which is all dependent on the QSV and the number of rolls, will be extremely helpful to define the RO data. Therefore, once the STO is chosen, all its data is copied again and then some of its fields should be modified in order to characterize the RO and make it unique. As said, most of the fields will remain the same (for instance, the *Rolls*, the *PkgsPerReel*, the *LaneWidth*, the T*otalLength*, etc). The fields that need to be changed in each of the three tables of the DB are:

---

[15] To match the block colours with its name or code, legends are also provided. See Appendix V

65

- *MainOrders* tab (1 row):

MainOrderID   Invented value that cannot be equal to any existing one

MainOrderIDcode   Invented value that cannot be equal to any existing one

- *Plan* tab (3 rows[16]):

MainOrderIDcode   Invented value that cannot be equal to any existing one

Block_start_qty   This value refers to the block start time. First of all, in order to fill in this value, we have to decide where in the planning we want to program the activity. It has to be in a block of the RO´s kind, if possible. To get to know to which block kind (name in *Proplanner*) the RO belongs to, we can check so in the following DB tables: SizeAttributes, QualSizeVarAttribs, QualSizeAttribs.

Block_qty   This value refers to the position of the order inside its block. *Flexsim* processes all orders belonging to a same block following the cardinal order sequence stated by this field (see 4.8.3). Thus the criterion to sort them is from small to big numbers. So, for example, if we want the RO to be the last one of the block, we will give the RO a value which only needs to be a unit bigger than the one that the last standard order of the block has.

MachineID   Once decided to which block kind the RO belongs to, then we will also know the machine where the RO will be processed, and thus this field can be easily filled in.

---

[16] Notice that in the "Plan" tab there is no need to program the slitting action since Flexsim won´t use that data. Thus, we can avoid this, and simply define 3 rows (2 for printing and 1 for lamination) instead of 4.

- *ProductionOrders* tab (1 row):

ProductionOrderID   Invented value that cannot be equal to any existing one

MainOrderID   Invented value that cannot be equal to any existing one

OrderDateTime   Invented value

DueDate   Invented value

Finally, once the RO has been properly inserted in the three tables of the DB, the information has to be saved. Then, in order to verify that the printing and laminating activity have been placed exactly where wanted in the order sequence, a quick validation of step 1 can be performed. First of all, the *RollPlan* querie of the DB can be used to check the order sequence of each machine, followed by *Flexsim*, and make sure the RO is appearing when expected. Also, the model can be run (loaded with the planning which contains the extra order) so that the RO can be tracked along simulation time. When doing this, it is possible to check if the extra order has the expected size, the expected QSV, and also if it is arriving at the working stations when expected, among others.

6.3. Second step: Simulation runs

6.3.1. Set ODBC Data Source & Import data to *Flexsim*

An ODBC[17] is a system that defines a source to be a data provider. *Flexsim* imports data through this source. Therefore, when a specific certain data wants to be used in Flexsim, the first thing to do is to connect the data file to the source defined in the ODBC. To connect the data file to the source, and to later import it to Flexsim, go through the following steps (VE_TetraPak, 2013):

---

[17] Open Database Connectivity

1. Open odbcad32.exe via the path…
2. For <u>Windows XP</u>: Start => Settings => Control Panel => Administrative tools => Data Sources (ODBC)
3. For <u>Windows 7</u>: C:\Windows\SysWOW64
4. In the *OBSC Data Source Administrator* Dialog choose the System DSN tab
5. Click *Add*
6. Choose *Driver do Microsoft Access (*.mdb)* Press *Finish*
7. In the *Data Source Name* field write "Converting". Press *Select*
8. In *Select Database* Dialog Box find the folder where the MS Access file is located (*.mdb)
9. Choose MS Access file
10. Press *OK*
11. In the *OBSC Data Source Administrator,* press *OK*
12. Open Flexsim model
13. In the *Converting GUI* window, write "Converting" in the *Import DSN* field
14. Press on the Button *ImportAllData* in the *Converting GUI*

6.3.2. Customize *Flexsim* according to the data extraction

Once Flexsim is opened, and the data has been imported, check *Bypass Finishing Area* in the *Finishing* tab of the GUI window. In the *Data tab* of the GUI, click on *UpdateActiveTimetables* button (previous to this, the *EditTimetableReference* must be edited according to the training and maintenance shift planned for the week of the data extraction. See *Appendix IV*). At this point, it is only left to press the *Reset* button, and after that the model can be run.

6.3.3. Define and run the experiments

To define the experiment parameters and chose the results that need to be recorded, open the window *SimulationExperimentControl* through the path: Statistics → Experimenter. In each tab of the window do the following actions:

- *Scenario* → give a name to the scenario, i.e., "ScenarioA"
- *Performance Measures* → choose the desired KPIs
- *Experiment Run* → fill in the fields *Run to…* and *Replications per*.

➢ *Run to:* This project will run the model only during the week due to the lack of more data.
➢ *Replications per*: This project will be running the experiments with only one replication since all the configuration data introduced to the model so far is constant.

Once the experiment is defined, in the *Experiment Run* tab, press the *Run Experiment* button. Wait for the model to run. Click on the *Export/merge Results* button to export the results in a *.t file. Or instead, click the *ExportPFMs to Excel* button in the GUI window to export the results to an Excel file.

6.4. Third step: Analysis of the results and evaluation the RO impact

If the results of a certain scenario want to be analysed from a relative perspective, that is, comparing them to a "Base Line" scenario, results from both experiments can be merged. In order to do so, a new Flexsim file must be opened, and in the *Experiment Run* tab of the *SimulationExperimentControl* window, the *Export/Merge Results* button must be pressed, to first "Load" one *.t file of results, and afterwards "Merge" another *.t file of results. A comparison report will appear.

In order to know which the impact of a RO is when it comes to costs, the KPIs obtained can be translated into money with the sensitive figures presented in chapter 5.6. By doing this, absolute values will be obtained.

- The delta of the *efficiency* can be translated into cost with the *machine hour cost* figure. This way it can be calculated how much money is costing to the factory to run a machine without producing.
- The delta of the *AverageContent_PrintedRollWIP* can be translated into cost with the *inventory storage cost* figure.
- The delta of the *LaminatorXX Drooling* can be translated into cost with the *PE cost*, and the delta of the *LaminatorXX PaperWaste (m)* has to be translated into cost with both the *Aluminium foil cost* and the *paper board cost*.

Besides calculating an absolute cost, it can also be calculated a cost index for each scenario. This indicator will compare the situation where the extra order

is produced in normal conditions (what means that the order is placed inside existing blocks without extending them) to the situation where the extra order is produced in "rush" conditions (what means that it will probably imply set-ups and extra waste). The cost index shows the difference between how much it costs producing the order under normal conditions and how much it costs producing the order under "rush" conditions. See Appendix VI.

7. Analyzing rush order scenarios

This chapter presents the results of the three analyses conducted and discusses them. Each analysis contains more than one scenario and aims to evaluate which is the impact of a RO when one category is varied. The results (KPIs) have been obtained through simulation runs. For the most relevant scenarios a cost impact analysis is also provided. The technical information related to each scenario can be found in Appendix V.

The results obtained in each scenario will be compared to a base line scenario with a delta (see last columns of tables 3, 5 and 7). As expected, this base line scenario doesn´t contain the extra order. For the most relevant scenarios, the increase/decrease of EE, of the waste materials, and of the av. content of printed rolls in the WIP, will be presented in a table. To conclude, a cost index will also be provided for each relevant scenario.

7.1. ANALYSIS 1: Impact of the rush order AOS

This first analysis will show which the impact is on STOs lead time when the number of rolls of the RO varies. Therefore, the aim of this analysis is to compare the results of the three following scenarios: scenario1 will have a RO of 4 rolls, scenario 2, a RO of 11 rolls, and scenario 3, a RO of 16 rolls.

This analysis has been conducted with a RO of 1L Square packages, and with a QSV 7134-811-56. In the 3 scenarios both the printing (*printer16*) and the lamination (*laminator21*) activities of the RO have been placed inside an existing block.

7.1.1. KPIs' results of analysis 1

The KPIs obtained from the simulation runs are shown in table 3.

Performance Measures	Base Line	S1. 4rolls	S2. 11 rolls	S3. 16 rolls	Delta s1 (%)	Delta s2 (%)	Delta s3 (%)
Perfectly Slitable (%)	70,29	70,35	70,29	69,36	0,1%	0,0%	-1,3%
Printer16 EE	49,74	49,67	49,82	49,85	-0,14%	0,16%	0,22%

Printer16Setup%	21,30	21,49	21,49	21,49	**0,9%**	**0,9%**	**0,9%**
Printer16 Waste Metres	18902	19086	19086	19086	**1,0%**	**1,0%**	**1,0%**
Laminator22 EE	69,01	69,22	69,46	68,64	**0,30%**	**0,65%**	**-0,54%**
Laminator22Setup%	5,22	5,22	5,22	6,41	**0,0%**	**0,0%**	**22,9%**
Laminator22 Drooling (kg)	990	990	990	1030	**0,0%**	**0,0%**	**4,0%**
Laminator22 PaperWaste (m)	23800	23800	23800	24100	**0,0%**	**0,0%**	**1,3%**
AverageContent_PrintedRollWIP	233,87	234,31	235,93	242,26	**0,2%**	**0,9%**	**3,6%**

Table 3: KPIs Analysis 1

7.1.2. Discussion of the results – Analysis 1

- **Perfectly Slitable (%) & AverageContent_PrintedRollWIP**

The quantity of rolls a RO has, doesn´t have much impact on the *Perfect Slitable* performance measure. This leads us to think that the planning which we are working with is quite relaxed, what means that orders are planned to be produced with a security margin of time. Thus, even though STOs lead time will increase, they will still meet their due date

If we look at this KPI results we can see that the value increases as the number of rolls does (up to 3,6% in scenario 3). This is due to two factors. The first one, valid for s3, is because a RO forces some of the STOs (the ones that have to be laminated in the same machine and later than the RO) to be laminated later than expected (because the RO insertion has implied an extra set-up in the laminator). Thus, they have to spend longer time in the WIP. The second one, is because the momentary efficiency of the printer, while it is producing a very long order, will increase. Therefore, the WIP will be receiving orders more frequently, while it will remain releasing orders to the laminator with the same frequency as in the base line. The reason why the

value suddenly raises a lot, from s2 to s3, is because an extra set-up in the laminator is required as it will be explained below.

- **Printer's KPIs**

Although the same set-up has been required in the three scenarios, ROs with more number of rolls than the AOS[18] (like ROs in s2 and s3), will increase the printer´s efficiency in comparison to the base line one. In s1, the small size of the RO cannot balance the impact of the set-up and thus the printer's efficiency decreases. The printer's % of set-up state increases equally in the three scenarios since in all of them one RO has been introduced in the same place (a set-up is required every time a new order comes, no matter how many rolls the order has). The number of meters wasted in the printers increases since there is one more order in the planning, and every order involves doing a set-up when it starts (at least a change of sleeves is required).

- **Laminator's KPIs**

In s1 and s2, the laminator's efficiency increases as the RO's number of rolls does, because more meters are produced during the simulation time. Also in s1 and s2, the laminator's % of set-up state remains equal to the base line one, since the RO has been introduced in an existing block. The reason why the % of set-up state has increased in s3 is because the insertion of the RO (16 rolls) has made the blocks too long and short stops have been required. (Short stops are due to either die cleaning, or to teflon changes. These actions are required when producing a long block and occur every certain fixed amount of times -these intervals of time depend on the QSV that is being produced-). Because some extra set-ups have been performed, fewer meters have been produced during the simulation time and thus the efficiency in s3 decreases. In s1 and s2, the waste in the laminator remains the same since the RO has been inserted in an existing block. However, in s3, although the RO has also been placed in an existing block, the waste values have risen in comparison to the base line ones because of the short stops, which entail waste of PE and roll meters.

---

[18] In this DB the AOS is 4,59 rolls.

7.1.3. Cost impact – Analysis 1

The increase/decrease of EE, of the waste materials and of the av. content of printed rolls in the WIP, is specified in table 4. These figures can be used to calculate the absolute cost entailed by scenario 3 (16 rolls order placed in existing blocks).

Performance Measures	Delta s3
Printer16 EE	+0,12h (0,11% out of 111,5h)
Printer16 Waste Metres	+184m
Laminator22 EE	-0,41h (0,37% out of 111,5h)
Laminator22 Drooling (kg)	+40 kg
Laminator22 PaperWaste (m)	+300m
AverageContent_PrintedRollWIP	8,39 rolls/dia

Table 4: Absolute values to calculate the cost impact of s3 - Analysis 1

The cost index of scenario 3 is **103,63**.

7.2. ANALYSIS 2: Impact of a RO depending on whether a new lamination block needs to be created or not

Sometimes, when the planner has to schedule a RO with a low margin of days, he cannot find in the ideal block plan a block of the RO´s kind. This will force him to create a new block. This fact causes an impact on STOs' lead time and on factory's costs since new set-ups will be required when introducing the new blocks. Introducing a new block entails time and waste.

The purpose of this analysis is to compare the RO impact between three possible scenarios: RO inserted in an existing block, RO inserted in a new block which will be placed between 2 existing blocks, and RO inserted in a new block which will be placed breaking an existing block. All the blocks mentioned are coating blocks. Since lamination blocks entail much more time and waste than printing blocks, this analysis will focus on the impact a RO has depending on how is the lamination activity scheduled, while the printing activity will always be placed in an existing block (in the *printer 14*). Therefore, the printer's KPIs will be presented but won´t be analysed in depth. They are expected to behave the same for all three scenarios.

This analysis has been conducted with a RO of 5 rolls and 1L Slim packages. More specifically it has the following QSV 7626-813-49. This means that this order has specific requirements (it is a Helicap) and therefore setting a new block of this kind has greater impact. The lamination activity has always been scheduled in the *laminator 22*. In scenario 1 the RO is placed in an existing block, in scenario 2 the RO is placed in a new block between existing ones, and in scenario 3 the RO is placed in a new block breaking an existing one.

7.2.1. KPIs' results of analysis 2

The KPIs obtained from the simulation runs are shown in table 5.

Performance Measures	Base Line	S0. Existing block	S1. New block between existings	S2. New block breaking	Delta s0 (%)	Delta s1 (%)	Delta s2 (%)
Perfectly Slitable (%)	70,29	70,02	69,92	69,25	-0,4%	-0,5%	-1,5%
Printer14 EE	77,17	77,10	77,10	77,10	-0,09%	-0,09%	-0,09%
Printer14Setup%	10,49	10,69	10,69	10,69	1,9%	1,9%	1,9%
Printer14 Waste Metres	7552	7706	7706	7706	2,0%	2,0%	2,0%
Laminator21 EE	84,24	84,24	82,35	81,98	0,00%	-2,25%	-2,68%

Laminator21Setup%	4,93	4,93	7,25	7,62	0,0%	47,0%	54,6%
Laminator21 Drooling (kg)	1540	1540	1930	1900	0,0%	25,3%	23,4%
Laminator21 PaperWaste (m)	26900	26900	28800	29100	0,0%	7,1%	8,2%
AverageContent_PrintedRollWIP	233,87	236,54	238,42	242,65	1,1%	1,9%	3,8%

<p align="center">**Table 5: KPIs Analysis 2**</p>

7.2.2. Discussion of the results – Analysis 2

- **Perfectly Slitable (%) & AverageContent_PrintedRollWIP**

The results show that inserting a new block in the ideal plan has a slight impact on the STOs' perfect delivery. The quantity of orders that cannot reach their due date due to the RO new block insertion only increases a 1,5% (for s2, the most critical). However, if we look at the average content of rolls in the *PrintedRollWIP* we can see a greater impact (3,8%). The fact that STOs can still reach their due date even when a new block has been inserted, lead us to the same conclusion extracted in *Analysis 1* (i.e., the planning which we are working with is a relaxed one, what means that the planner programs the order with a margin of time, in order to ensure that it is not produced too close to its due date). Another reason that explains not much deviation for the *Perfect Slitable* is the fact that is only a 5 rolls order (small one).

- **Printer's KPIs**

The printer's efficiency decreases equally in all three scenarios since the RO inserted has a low order size (5rolls), almost equal to the AOS. The printer's % of set-up state increases equally for the three scenarios, since a printer has to do a set-up every time a new order comes. The number of meters wasted in the printers also increases equally since there is one more order in the planning, and every order involves doing a set-up when it starts (at least a change of sleeves is required).

- **Laminator's KPIs**

<p align="center">76</p>

The laminator's efficiency decreases in s1 and s2 since fewer meters were produced during the running time. The laminator % of set-up state increases (47,0% for s1, and 54,6% for s2) due to the set-ups required when inserting a new block (the set-up of this case involves a lot of time). Since when breaking a new block (s2) entails 2 extra set-ups, while placing a new block between two existing ones (s1) only implies 1 extra set-up, the delta is greater for s2 than for s1. However, the lost of efficiency and the raise of set-up state %, strongly depend on the specification semblances of the blocks. Contrary, in s0, since there have been no extra set-ups, the efficiency of the laminator and the % of set-up state, have remained the same. When it comes to waste generated in the laminator is when we can better see the difference between the 3 scenarios: inserting a new block implies a big rise of the PE waste (25,3% in s1, and 23,4% in s2) and an increase of the paper and aluminium foil waste (7,1% in s1, and 8,2% in s2). Again, the generation of waste strongly depends on the kind of set-up required.

7.2.3. Cost impact – Analysis 2

The increase/decrease of EE, of the waste materials and of the av. content of printed rolls in the WIP, is specified in table 6. These figures can be used to calculate the absolute cost entailed by scenario 1 (5 rolls order placed in a new lamination block in-between two existing ones).

Performance Measures	Delta s1
Printer14 EE	-0,08h (0,07% out of 111,5h)
Printer14 Waste Metres	+154m
Laminator21EE	+2,11h (1,89% out of 111,5h)
Laminator21 Drooling (kg)	+390 kg
Laminator21 PaperWaste (m)	+1900m
AverageContent_PrintedRollWIP	+4,55rolls/dia

Table 6: Absolute values to calculate the cost impact of scenario 1 - Analysis 2

The cost index of scenario 1 is **115,37**.

The increase/decrease of EE, of the waste materials and of the av. content of printed rolls in the WIP, is specified in table 7. These figures can be used to calculate the absolute cost entailed by scenario 2 (5 rolls order placed in a new lamination block breaking an existing one).

Performance Measures	Delta s2
Printer14 EE	-0,08h (0,07% out of 111,5h)
Printer14 Waste Metres	+154m
Laminator21EE	+2,52h (2,26% out of 111,5h)
Laminator21 Drooling (kg)	+360 kg
Laminator21 PaperWaste (m)	+2200m
AverageContent_PrintedRollWIP	+8,78rolls/dia

Table 7: Absolute values to calculate the cost impact of scenario 2 - Analysis 2

The cost index of scenario 2 is **117,34**.

7.3. ANALYSIS 3: Impact of a RO depending on its urgency

When the urgency of a RO is high, then it is more likely that new production blocks have to be created and inserted in the ideal block plan. This fact causes an impact on STOs' lead time and on factory's costs since new set-ups will be required when introducing the new block. Introducing a new block entails time and waste.

The aim of this analysis is to evaluate the RO impact depending on how much rush the RO is. Two scenarios will be defined: in scenario 1, a RO with a lead time of only 2 days will be introduced in the planning, and in scenario 2, the RO added to the plan will have a lead time of a week. The consequence of having so few days to produce the RO, as happens in scenario 1, is that a new block will have to be created for the printing activity, and a new block will have to be created for the lamination activity as well. Both new blocks will

have to be placed breaking an existing one. Contrary, in scenario 2 no blocks will have to be added to the ideal plan. This is due to the fact of having a margin of a week, what means that all kind of blocks are available (the ideal plan lasts a week). In scenario 1 the RO has been printed in *printer12*, while in scenario 2 the RO has been printed in *printer14.*

This analysis has been conducted with a RO of 5 rolls and 1L Slim packages. More specifically it has the following QSV 7626-813-49.

7.3.1. KPIs' results of analysis 3

The KPIs obtained from the simulation runs are shown in table 8.

Performance Measures	Base Line	S1. 2 days lead time	S2. 1 week lead time	Delta s1 (%)	Delta s2 (%)
PerfectlySlitable (%)	70,29	67,67	70,23	-3,7%	-0,1%
Printer12 EE	51,87	51,65		-0,42%	
Printer14 EE	77,17		77,10		-0,09%
Printer12Setup%	18,54	19,09		3,0%	
Printer14Setup%	10,49		10,69		1,9%
Printer12 Waste Metres	15162	15344			
Printer14 Waste Metres	7552		7706		
Laminator21 EE	84,24	81,98	84,24	-2,68%	0,0%
Laminator21Setup%	4,93	7,62	4,93	54,6%	0,0%
Laminator21 Drooling (kg)	1540	2000	1540	29,9%	0,0%

Laminator21 PaperWaste (m)	26900	29100	26900	**8,2%**	**0,0%**
AvergaeContent_PrintedRollWIP	233,87	252,64	236,64	**8,0%**	**1,2%**

Table 8: KPIs Analysis 3

7.3.2. Discussion of the results – Analysis 3

- **Perfectly Slitable (%) & AverageContent_PrintedRollWIP**

The insertion of a RO at the very beginning of the plan, as happens in scenario 1 -due to the low margin of time that is given to produce the order-, affects and delays almost all the orders in the plan. All the orders placed after the RO, both in the activity of printing and in the activity of lamination, will suffer a delay. This delay can imply that a STO doesn´t reach it´s lamination time (because its printing activity was postponed), or worst, that the STO cannot reach its due date (because its lamination activity was rescheduled in a block too late in time). In scenario 1, the number of orders that aren´t on time to be slitted increases a 3,7%. The number of rolls in the *PrintedRollsWIP* increases considerably when the RO is very urgent, a 8,0%, while only increases a 1,2% when the RO has a bigger margin of time.

- **Printer's KPIs**

The printer's efficiency decreases in both scenarios since the RO's number of rolls is low, almost equal to the AOS of week19. In s1, where the RO has implied to insert a new printing block, the efficiency has decreased more notably since the new block has entailed a more complex set-up. The printer's % of set-up state increases more in s1 (3%) than in s2 (1,9%). In s1, the RO is breaking an existing block, and therefore the set-up required will have greater impact. In s2 the set-up required will be the standard one (*Sleeves Change*). The reason why *printer12* has a higher percentage of set-up state than *printer14*, is because it produces almost the double of orders (which by the way are smaller). Considering that every new order involves a set-up, it makes sense that the printer that has processed more orders has a higher % of set-up state. The number of meters wasted in the printer increases in both scenarios since there is one more order in the planning. However, while in s2 the set-up required has been the standard one (change

of sleeves), in s1 the set-up required has been a more complex one, and thus the quantity of meters wasted has been higher.

- **Laminator's KPIs**

The laminator's efficiency decreases in s1 since less output has been produced during the running time (because more time has been dedicated to set up). The laminator's % of set-up state increases (+54,6% for s1) due to the set-ups required when inserting a new block. Contrary, in s2, since there have been no extra set-ups, the efficiency of the laminator and the % of set-up state, have remained the same. In s1, where a new lamination block has been inserted, the paper waste has increased 8,2% and the drooling waste 29,9%.

7.3.3. Cost impact – Analysis 3

The increase/decrease of EE, of the waste materials and of the av. content of printed rolls in the WIP, is specified in table 9. These figures can be used to calculate the absolute cost entailed by scenario 1 (5 rolls order placed in new printing and lamination blocks breaking existing ones).

Performance Measures	Delta s1
Printer12 EE	**+0,25h (0,22% out of 111,5h)**
Printer12 Waste Metres	**+182m**
Laminator21EE	**+2,52h (2,26% out of 111,5h)**
Laminator21 Drooling (kg)	**+460 kg**
Laminator21 PaperWaste (m)	**+2200m**
AverageContent_PrintedRollWIP	**+18,77rolls/dia**

Table 9: Absolute values to calculate the cost impact of scenario 1 - Analysis 3

The cost index of scenario 1 is **117,84**.

8. Conclusions

In this chapter, the author will discuss about the achievement of the two purposes. For the second purpose, which was to obtain some general conclusions about the ROs' impacts, the main findings of the previous chapter will be pointed out.

8.1. Conclusions for the first purpose

This thesis's first purpose was to propose, define and validate a process for Tetra Pak to evaluate the cost impact of a rush order. In order to achieve this purpose, the author has done a wide literature review, has pictured a detailed description of the converting line, has gained a good understanding of the blocks planning strategy, has become familiar with the machines set-ups, and has achieved a good handling of *Flexsim*, among others. Besides collecting all this information, the author has gained a good understanding of rush orders in Arganda, and has figured out which are the main factors the rush orders have impact on. It is the author beliefs that the process defined fulfils all the requirements (stated in the purpose definition) and succeeds on evaluating the cost impact of a rush order.

8.2. Conclusions and findings for the second purpose

The second purpose of this thesis was to conduct analysis to extract general conclusions on the impact different kinds of ROs' scenarios have, and to analyse the costs that rush orders are currently entailing in Arganda. From the analysis conducted in the previous chapter, the following conclusions have been extracted:

1. **ROs bigger than the AOS have a positive impact on the printer efficiency**

   A RO with a greater number of rolls than the AOS, and which is inserted in an existing printing block, will entail the printer´s efficiency to increase. The impact of the standard set-up that every new order requires will be mitigated by the fact that the RO has a bigger size than the mean of the STOs in the plan. The momentary efficiency of the printer increases while

it is producing a very long order. However, if the RO involves creating a new block, then its size will have to be considerably bigger than the AOS in order to mitigate the impact of the non-standard set-up that the insertion of the RO will entail.

2. The planning which we are working with is relaxed

Orders are planned to be produced with a security margin of time. Thus, even though STOs' lead time will increase when a RO is inserted in the planning, they will still meet their due date.

3. When it comes to STOs' perfect delivery, the insertion of a new lamination block generally has more impact than the rush order size

The number of rolls a RO has doesn´t have much impact on STOs' perfect delivery. It has more impact whether a new lamination block is introduced or not in the plan since that involves at least one extra set-up. One extra set-up can take up to 90 minutes of time, while laminating one more roll only takes 8-9 minutes. Thereby the raise in the number of rolls a RO has, won´t affect much at STOs' perfect delivery unless it is a really big RO, which could imply a short stop set-up.

4. The impact of a RO strongly depends on its QSV, especially when inserting lamination blocks

There are QSVs (such as Helicap, DreamCap or 330PLH) that have specific requirements and therefore an insertion of a block of its kind has a big set-up impact (time & waste). For instance, blocks with these characteristics are those that only allow one kind of *InteriorNipRoller* and *LaminatorNipRoller*. Therefore it is highly probable that, whenever there is a block-switch towards a block with specific requirements, a set-up will be required to change the *NipRollers*. PLH packages (which have specific requirements) require a set-up in *internal 1* of the *lamination station* when switching production from milk to juice and vice versa. Also, all of these QSVs' blocks require both *InteriorTeflonTape* and *LaminateTeflonTape*. All these features make these kind of blocks have higher set-up times and set-up waste. In the ideal plan, blocks with specific requirements (which actually are only a few) are kept in laminator21 and they occur quite often to ensure that new insertions are

barely needed. Since depending on the kind of block, the laminator runs at a certain speed[19], a RO which belongs to a block that requires the laminator to run at low speed, will have an impact on the average content of the *PrintedRollsWIP*. Since the flow of orders from the WIP to the laminator will be slower, the insertion of the RO will have an impact on the WIP's average content of rolls, which will increase.

5. **Widening a lamination block too much might imply a short stop**

   Widening a lamination block more than what is defined in the ideal block plan can require extra set-ups (what implies time and waste) due to short stops. It is believed that the length of the blocks defined in the ideal plan is a consequence of the demand forecasted (of course), but as well is such that the fewer number of short stops (die cleaning or teflon changes) are needed.

6. **RO with an urgency of a week, have many chances of finding a block of its kind**

   An urgent RO can only be inserted during the very first days of the plan, and therefore has less chances of finding a block of its kind where it can be inserted. Also, even if a block of its kind is programmed for the very first days, it is highly likely that it will be fully booked, and widening it can have impacts on STOs' lead times and on set-ups. In summary, a RO with a very short lead time will probably require inserting a new block at least in one of the two activities. Contrary, a RO with a lead time of at least 7 days will for sure find a block of its kind in the planning (since the draft week plan lasts a week). The only problem that there might be is that the block is already full, and in that case, widening it can have consequences which have to be compared to the impact of inserting a new block. Also, a non-so-urgent RO can be produced later on the week, and this will have a lower repercussion on STOs' lead time.

7. **Cost concentrated in the laminator rather than the printer**

---

[19] For instance: 1000Sq- 340m/min, Helicap- 500m/min, All PoB– 500m/min, Dreamcap-300m/min

Since there exist a great variety of printing blocks (bigger than the variety of lamination blocks), in general they have a shorter length than lamination ones, so that there can fit many of them in a week plan. Because of that, for urgent orders, it is more likely to have to insert new blocks in the lamination activity than in the printing activity. Since set-ups in the laminators involve more time and waste than set-ups in the printers do, the cost impact of ROs are basically concentrated on the laminators.

8. **The more costly RO scenarios are those requiring the insertion of a new block**

SCENARIOS	A1.s3	A2.s1	A2.s2	A3.s1
COST INDEX	103,63	115,37	117,34	117,84

Table 10: Cost index for the most relevant scenarios

The table above compares the cost index of the four most impactful scenarios defined in the analyses. A1.s3 (analysis 1, scenario 3) corresponds to the scenario that has a rush order of 16 rolls (big size) and which has been inserted inside existing blocks. A2.s1 (analysis 2, scenario1) belongs to the scenario that has a rush order of five rolls inserted in a new lamination block between existing ones. A2.s2 (analysis 2, scenario2) corresponds to the scenario were a rush order of five rolls has been inserted in a new lamination block breaking an existing one. A3.s1 (analysis 3, scenario1) belongs to the scenario that has a rush order of five rolls and a very short lead time and which has required to insert new blocks breaking existing ones. It can be concluded that the most costly scenarios are those where the rush orders requires inserting new blocks, especially if the new blocks are breaking existing ones.

Most of the extra cost entailed by the RO is due to the waste (specially the paper waste) and to the laminator's efficiency loss. This can be concluded from tables in chapter 7.

To get an idea of how costly the ROs are for Tetra Pak it might help knowing that there is an average of 45 RO per month. This figure only includes ROs with lead times between 1 and 7 days, and it must be taking into consideration that most of them have lead times of 6 or 7 days. Therefore, not all the 45 RO per month will have the same impact. Only some of them will have notably impact when it comes to costs.

9. Concluding remarks

Based on the conclusions extracted from the previous chapter, some recommendations will be given for a proper handling of the rush orders. Then, some potential future studies will be suggested, and the contribution to ROs theory will be explained. Finally, a reflection on what this thesis has entailed for its author will be made.

9.1. Recommendations

The first recommendation is to use simulation capabilities to better understand rush orders impact. Using simulation, certain events which are not obvious can be detected and be taken into consideration. Besides, when inserting a RO in the block planning, always try to seek existing blocks where the RO can be placed. If the block we are looking for is already full, before extending it, is always convenient to check if a switch of orders is possible (this means to move a STO to another block of its kind placed later in time, so that the RO can fit on the free spot). In the case where no block is found, then there is no option but to create a new block. It is usually more convenient to place the new block between existing ones, than breaking an existing one. However, this highly depends on the RO's QSV and on the blocks' QSVs that the RO's insertion might affect. Two set-ups don´t always imply more waste and time than one unique set-up. It everything depends on which QSV we are handling and on which set-ups they entail. For really long orders, the recommendations just presented might not be correct. The point is that inserting a considerable long order in an already long existing block will probably entail short stops and therefore set-ups. Thus, the impact of placing the RO in an existing block or in a new one will be similar. Then, the purpose is to insert the RO the most lately in the planning as possible, so that the fewer STOs' lead time are affected, and so that the printed rolls' WIP doesn´t raise much (and so doesn´t the cost it entails).

9.2. Potential future studies

- Conduct the analysis again but with another DB extraction which has more orders content. This way, the simulation runs can last longer and the impact of RO scheduled a week ahead can be tested. Despite, after the analysis

conducted, it seems that one week ahead the plan is pretty empty and therefore no problems are expected if a RO wants to be inserted.

- Put a price on the acceptance of a RO. Investigate how much should be charged to the customer to cover the cost that the RO entails, and to maybe make some profit out of it. The idea is to let customers know how much money a RO costs and make them understand there has to be a limit. However, considering that Tetra Pak´s policy is to always satisfy its customer´s desires, and that some customers deserve better deals than others, a categorization of customers could help to put a fair limit on the acceptance of the rush order. This categorization would define specific rules for each customer depending on the quantity of orders he places annually. For instance, it could be that very important customers were allowed to place one "free" RO per year, and were forced to pay the extra cost for the other ROs, while standard customers weren´t allowed to place any RO for "free" and were always forced to pay the extra cost for their ROs.

- Since validating a process entails a lot of time and resources, the process defined in this thesis hasn´t been completely validated. Of course it has been tested and discussed, but still more could be done. Therefore, as a potential study, it is suggested to verify properly the reliability of the process. It is the author belief that managers in Arganda could help with the task since their knowledge about the issue would provide a reasoned opinion on whether the process properly succeeds on achieving its purpose or not. Besides, the factory simulation model needs to be validated completely by the VE Dept. in order to make the process defined in this thesis accurate (all areas in the factory should be included in the model) and reliable.

9.3. Contribution to the rush orders' theory

After conducting an empirical study, some contributions can be made to the rush orders' theory presented in chapter 3.4. The study conducted in this thesis hasn´t dealt with more than one RO at a time. Therefore, it cannot contribute on whether there is a clear relationship between the share of RO and the delay of standard orders or not. However, the common sense and the knowledge gained about the topic, makes this thesis' author to agree with the statement presented in the frame of reference in chapter 3.4. (The share of RO has an impact on STOs' lead time). Through the empirical study

of this thesis it has been found out that the perfect delivery of STOs strongly depends on the way the planner schedules the production activities. It has been discovered that if the orders are planned to be produced with a security margin of time, a RO will not affect the perfect delivery of the STOs. The RO insertion will only increase STOs' lead time. Another finding of this empirical study is that because STOs spend longer times in the production line (due to longer interoperation times), the WIP buffer levels will increase. Therefore, it can be said that a RO has an impact on WIP levels, which leads to higher inventory storage costs. Finally, another finding is that the RO impact strongly depends on the complexity handled in the factory. RO will have greater impact in factories which produce lots of different products rather than in factories which produce one single kind of product. RO in factories with high complexity will also have a relevant impact on set-up waste material.

9.4. Reflections

Now that the thesis is done, the author of the thesis realises how much she has learned since she started four months ago. Not only about the company, about which she believes to have become quite familiar with, but also about how to develop a project. The writing of a master thesis requires a good organization and a lot of motivation. The author has learned to plan her time and to schedule along twenty weeks all the activities to be conducted. Besides this, she has had fun working on it, and she has met very interesting and supporting people. The fact that the project has taken place at a company has meant a great opportunity for her to get to know about the work environment. In addition, the author went on a trip to visit the factory in Arganda which made the whole project even more attractive. Finally, she believes to have gained a deep understanding about rush orders, about planning, and about the Arganda simulation model. She wishes and hopes to be able to use all this knowledge in potential future projects at the company, and later on, in challenges she might face during her professional career.

References

Bjärnemo, R., Jönson, G. & Johnson, M. (2000). Packaging in Product Development.

Brooks Automation, I. (2003). *AutoMod User's Guide Volumes 1&2.*

Chun-Lung Chen. (2010). A heuristic model for justifying the acceptance of rush orders in multi-plants manufacturing supply chain with outsourcing. *8th International Conference on Industrial Informatics* (pp. 607-611). Osaka: INDIN, 2010.

Dominic, C. et al. (2000). *Packforsk.*

GoldSim Technology Group, L. (2011, August). Retrieved March 2013, from www.GoldSim.com.

Gruber, R. (2012). *Flexsim Training Course 1 Manual.* Flexsim Software Products.

Hvolby, Hans-Henrik; Steger-Jensen, Kenn. (2010). Technical and industrial issues of Advanced Planning and Scheduling (APS) systems. *Computers in industry vol. 61, no. 9* , 845-851.

Lee, H. & Billington, C. (1993). Material management in decentralized supply chains. *Operational Research, 41(5)* , 835-847.

LundUniversity, P. . (2013, 02). *www.plog.lth.se*. Retrieved 03 2013, from www.lunduniversity.lu.se.

Nurcin Celik, Sai Srinivas Nageshwaraniyer, Young-Jun Son. (2012). Impact of information sharing in hierarchical decision-making framework in manufacturing supply chains. *Journal of Intelligent Manufacturing, Vol. 23, Iss 4* , 1083-1101.

PEREZ. (1990). *AKÑNA.* BCN: Ama.

Plossl, G. W. (1973). *Manufacturing control: the last frontier for profits.* Reston, Va., Reston Pub. Co.

Proplanner. (2002). Retrieved March 2013, from www.proplanner.com.

Pålsson, H. (2012). Packaging Scorecard. *Packaging logistics course at LTH*, (p. 6).

Richard A. Lancioni, Rajan Chandran. (1990). The Role of Packaging in International Logistics. *International Journal of Physical Distribution & Logistics Management, Vol. 20 Iss: 8* , 41-43.

Saghir, M. (2002). Packaging information needed for evaluation in the supply chain: teh case of the Swedish grocery retail industry. *Packag. technol. Sci., 15* , 37-46.

Santa-Eulalia, Luis Antonio; Halladjian, Georgina; D'Amours, Sophie; Frayret, Jean-Marc. (2011). Integrated methodological frameworks for modelling agent-based advanced supply chain planning systems: A systematic literature review. *Jounal of Industrial Engineering and Management, Vol 4, No 4* , 624-668.

Schneeweiss, C. (2003). Distributed decision making—a unified approach. *European Journal of Operational Research, Volume 150, Issue 2* , 237-252.

Sonneveld, K. (2000). What drives (food) packaging innovation? *Packaging Technology and Science, Vol 12 No. 1* , 29-35.

Trzyna, D.; Kuyumcu, A.; Lödding, H. (2012). Throughput Time Characteristics of Rush Orders and their Impact on Standard Orders. *Procedia CIRP, Vol. 3* , 311-316.

VE_TetraPak. (2013). *Introduction to factory simulation. Packaging Material.* Lund: TetraPak.

Wiendahl, H.P. (1995). *Load-oriented manufacturing control.* Berlin: Springer.

Wu M. C.; Chen S. Y. (1997). A multiple criteria decision-making model for justifying the acceptance of rush orders. *Production Planning and Control, Vol. 8, No 8* , 753-761.

Zoryk-Schalla, A. J., Fransoo, J. C., & de Kok, T. G. (2004). Modeling the planning process in advanced planning systems. *Science Direct* .

Zoryk-Schalla, Anastasia J.; Fransoo, Jan C.; de Kok, Ton G. (2004). Modeling the planning process in advanced planning systems. *Science Direct* .

Appendixes

Appendix I – Steps 1 to 6 in the simulation process

The six first steps in the flowchart of figure 1, are explained below. The purpose is to briefly explain what the engineers at the VE Dept. did at each step when they built the factory model.

1. Formulate the problem

The Arganda factory model was created out of existing subsystems models. Those ones were: Prepress Model, Finishing Model and FGI Model. The remaining parts of the factory that had to be developed were: printing area, coating/laminating area, and work in progress (WIP) area. The main purpose of this synthesis was to build a single big system, in order to have a holistic approach and be able to evaluate the performance of the whole factory. There were several factors that promoted the creation of the factory model capability, as different stakeholders were interested in it. For engineers at the VE SE PM (or DSO PM), who are currently responsible for the execution of the PM VE Strategy, this project meant to be one corner stone of their strategy. The development of a whole factory simulation capability was seen as a great opportunity to obtain a master model and also a standard objects library. In addition, they saw the chance of gathering more knowledge on discrete events simulation's methodology. For Arganda Factory, who had shown and identified the need of using factory simulation, the development of the factory model was also highly valuable. Finally, SCO PM CL SE, who had identified the need of using simulation for the evaluation of order allocation across the cluster, were also supporting the creation of the model.

2. Set an objective and overall design

The purposes of building a factory model for Arganda factory were several, and coming from the 3 different stakeholders.

- For DSO PM:

- Develop a capability that shall serve as a master model that can be reused to simulate other factories
- Support development projects with factory simulation
- Learn more about the converting line (CL) system (consisting of the converting equipment sub-system, the workforce sub-system and the packaging material sub-system)

- For SCO PM - Factory Level:

- Get a good understanding on how the several complexities in the factory impact the CL. Understand the impact of planning orders, coproduction, average order size, production mix, etc.
- Simulate machines behaviour: set-up times, short stops, etc.
- Evaluate the impact of WIP

- For SCO PM – Cluster Level:

- Get to know how to allocate production blocks of different complexity between factories within a cluster (in this case, the Cluster South Europe)
- Look into the impact of various parameters on waste and throughput
- Try to anticipate capacity problems due to forecast demand and solve them through individual reallocations.

3. Collect Data

The data to be collected to build the model was divided into two different data types: configuration data (which had to be filled manually in the data base (DB)) and order data (which was automatically dropped into the DB from other systems). The two kinds of data were provided by production engineers at Arganda factory. In parallel to the data collection, the conceptual model was being built. Several flow charts were drawn to map the different logic processes; for instance, a flow chart was drawn to map the machines set-ups that need to be fixed every time there was a new order going through. Also, in order to collect all the appropriate data, the collection of the requirements was another important task to handle in this step. The engineers were constantly coming up with questions and doubts, which they used to write down in order to seek for an answer. With the feedback from

the workers, the requirements were finally settled down, after being verified and validated.

4. Define model boundaries

To define the boundaries of the model, it is important to clearly state which are the outputs that want to be achieved. To define the scope of the model, the things to bear in mind were: what KPI's were of interest, what level of detail was desired, and what the use cases of the model were going to be. For example, it was discussed which level of detail was needed to define set-up material, set-up and operators task, planning RO, carriers, factory integration, warehousing, etc.

5. Develop the model

Coding. Meanwhile coding, several loop backs towards previous steps were performed to see if they were missing something such as requirements or data.

6. Verify the model

Once the model was built, it was verified by running it and analysing what was happening, whether all the requirements (gathered to build the conceptual model) were fulfilled and satisfied, or not.

Appendix II – Interviews

The table below shows the persons who the author of this thesis has talked to in order to get to know about several topics, such as the performance of each machine in the factory, the planning rules and procedures, the KPIs, the Flexsim software or the database contents.

Name	Responsable for…
Jose Maria Asenjo	WCM (Arganda)
Marta Rapun	Slitters (Arganda)
Alfonso Navarro	Laminators (Arganda)
Mario Ruiz	Printers (Arganda)
Raul Alonso	Production plan (Arganda)
Javier Zamorano	*MES* (Arganda)
Mikael Larsson	Production plan (Lund)
Hansen Jeanette	KPI´s & costs
Jason Lightfoot	Flexsim
Haris Omeragic	Flexsim
Sebastian Ferrada	Overall CL process & Flexsim

Appendix III – EE performance measure
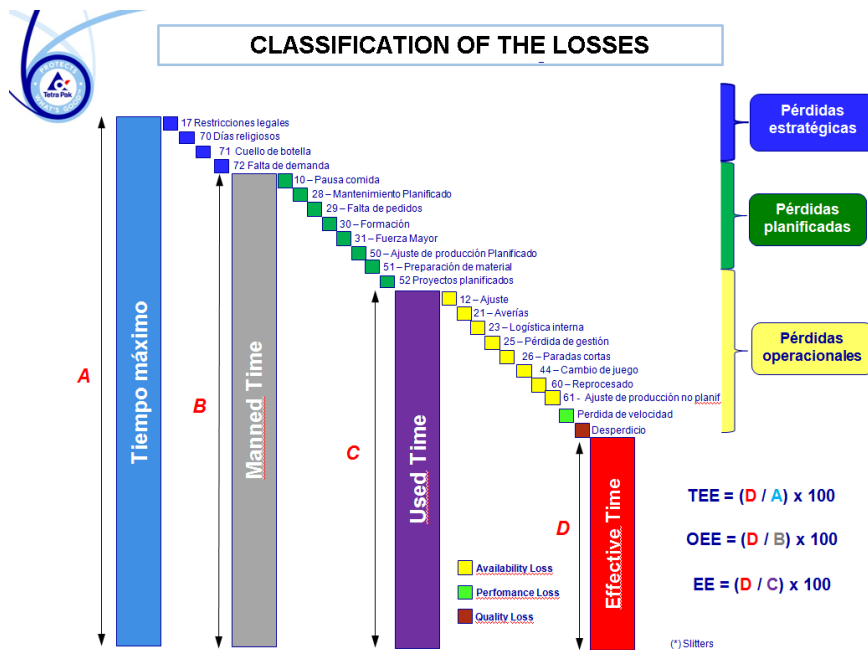
The efficiency has been calculated as:

$$E(\%) = \frac{m_{produced}}{mechanical\ speed * (processing\ time\ +\ setup\ time)} * 100 * \omega$$

All these variables' values have been extracted from the simulation runs. However, the corrective factor (ω) has been calculated with real data from week19.

How the corrective factor has been implemented:

$$\omega = \left[1 - \frac{(U040 + U251 + U060 + U260 + U270)}{U030} \right]$$

U040 $\rightarrow$ Breakdowns and Repairs
U251 $\rightarrow$ Management Loss
U060 $\rightarrow$ Short Stops

U260 →Performance Loss
U270 →Quality Loss
U030 →Used Time

For the laminators, only U040, half of U060 (the part corresponding to unexpected short stops), and U270 will be used in the formula. The other variables are believed to be modelled in the model.

Appendix IV – Edit Timetables Reference

For the analysis performed in this thesis with the extraction of data of week 19, the training and maintenance shifts of the machines are the followings (they correspond to the black blocks of *Proplanner*'s screenshot):

Printer12: Tuesday 7th, 7–15.15 & Thursday 9th, 9–16.45
Printer14: Monday 6th, 9–17.15 & Wednesday 8th, 6.15–14
Printer 16: Friday 10th, 3–11
Laminator 21: Monday 6th, 7–15.30
Laminator 22: Monday 6th, 7–15.45

The default machine's week working hours are:

Printers: Monday 7am – Saturday 3am
Laminators: Monday 7am – Saturday 3.30am

Considering that code 30 (state_off_shift) corresponds to periods of time when the machine is down due to the weekend, and that code 12 (state_scheduled_down) corresponds to periods of time when the machine is doing maintenance or trainings, the *EditTimetableReference* in this thesis looked like this:
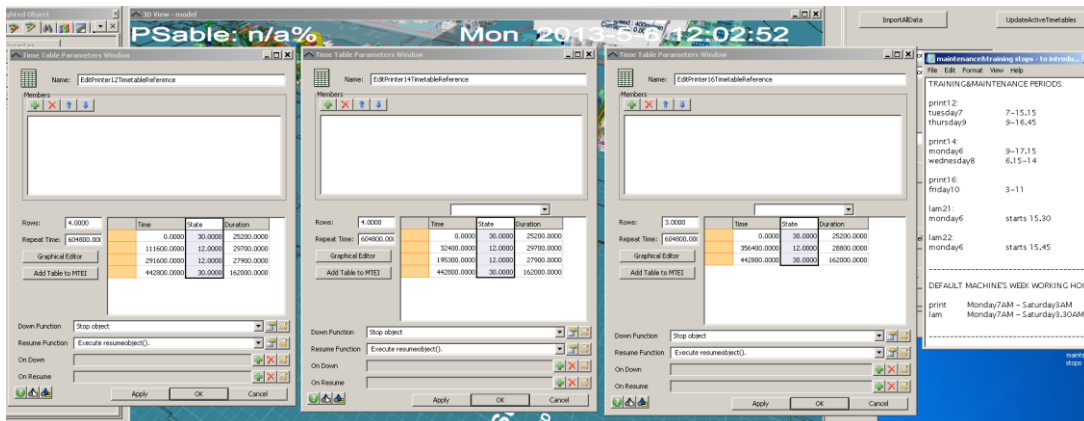
Time Table Parameters Window (EditLaminator21TimetableReference)

Name: EditLaminator21TimetableReference

Members

Rows: 3.0000
Repeat Time: 604800.00

Time	State	Duration
0.0000	30.0000	25200.0000
25200.0000	12.0000	30600.0000
444600.0000	30.0000	160200.0000

Graphical Editor
Add Table to MTEI

Down Function: Stop object
Resume Function: Execute resumeobject().
On Down:
On Resume:

Apply   OK   Cancel

Time Table Parameters Window (EditLaminator22TimetableReference)

Name: EditLaminator22TimetableReference

Members

Rows: 3.0000
Repeat Time: 604800.00

	Time	State	Duration
	0.0000	30.0000	25200.0000
	25200.0000	12.0000	31500.0000
Row3	444600.0000	30.0000	160200.0000

Graphical Editor
Add Table to MTEI

Down Function: Stop object
Resume Function: Execute resumeobject().
On Down:
On Resume:

Apply   OK   Cancel

maintenance&training stops - to introdu...

File Edit Format View Help

TRAINING&MAINTENANCE PERIODS:

print12:
tuesday7   7–15.15
thursday9   9–16.45

print14:
monday6   9–17.15
wednesday8   6.15–14

print16:
friday10   3–11

lam21:
monday6   starts 15.30

lam22:
monday6   starts 15.45

DEFAULT MACHINE'S WEEK WORKING HOURS:

print   Monday7AM – Saturday3AM
lam   Monday7AM – Saturday3.30AM

Relationship Editor

☑ Show Annotations   ☑ show

Appendix V – Analysis' technical information

ANALYSIS 1

- Blocks to which the RO (QSV: 7134-811-56) belongs to:

    Printing block name: 1L Prisma Zumo FP PLH Pob 6 Bandas
    Lamination block name: 1L Prisma Zumo PLH PoB 6 Bandas

ANALYSIS 2

- Blocks to which the RO (QSV: 7626-813-49) belongs to:

    Printing block name: 1L Slim Leche F D HeliCap
    Lamination block name: 1L Slim Leche HeliCap

- Sequence of lamination blocks in Scenario 1

	LAMINATION BLOCK		
	810 (1000B)	813 Helicap	813 (1000S)
Opening	No Open	Helicap	Wave
Interior Nip Roller	DD, DD2	DD2	DD, DD2
Lam Nip Roller	DD1, DD2, Teflon	DD1	DD1, DD2, Teflon
Interior Teflon	0	1	0
Lam Teflon	0	1	0
Internal2	Dryblend	LDPE	Dryblend
Internal 1	Primacor 3540	Medium Acid Adhesive	Primacor 3540
Width	1618	1533	1533

Blocks' specifications in the lamination block sequence of A2–s1

From table 5, it can be said that when switching from block 810 to block 813Helicap, a set-up will be required since the opening type is different and therefore Interior Teflon and Lam Teflon need to be added for producing 813Helicap. Nip Rollers will only have to be changed if the first block is already using DD2 and DD1 in the interior and laminator stations, respectively.

A drooling is required in D1 of Internal 2 since the content changes from Metalocen to LDPE. Also a set-up is required when changing the content poured through Internal1, but only when going to high specification block, since PLH packages are very sensitive to the mixture of them. Finally, because of changing the roll width from wide to narrow another set-up is performed, and side tools are adjusted.

- Sequence of lamination blocks in Scenario 2

	LAMINATION BLOCK		
	810 (1000B)	**813 Helicap**	**810 (1000B)**
Opening	Wave 3	Helicap	NoOpen
Interior Nip Roller	DD, DD2	DD2	DD, DD2
Lam Nip Roller	DD1, DD2, Teflon	DD1	DD1, DD2, Teflon
Interior Teflon	0	1	0
Lam Teflon	0	1	0
Internal2	Dryblend	LDPE	Dryblend
Internal 1	Medium Acid Adhesive	Medium Acid Adhesive	Medium Acid Adhesive
Width	1618	1533	1618

Blocks' specifications in the lamination block sequence of A2–s2

From table 6, we can extract pretty much the same conclusions than from table 5 since the set-ups performed are quite similar. However, in this case the content of Internal 1 doesn´t change.

ANALYSIS 3

- Blocks to which the RO (QSV: 7626-813-49) belongs to:

    Printing block name: 1L Slim Leche F D HeliCap
    Lamination block name: 1L Slim Leche HeliCap

- Sequence of printing blocks in Scenario 1

    1L Slim Zumo FP CLC KLABIN

1L Slim Leche F D HeliCap
1L Slim Zumo FP CLC KLABIN

The RO (*flexo line*) has different printing technique than the block it is breaking (*flexo process*). Because of that, an *Anilox Change* is required. Both the RO and the orders of the block is breaking, have the same packages size, so a *Creasing Tool Change* is not needed. The set-ups happening will be both "*Anilox Change - 3 or more inks*" (12-02-05).

- Sequence of lamination blocks in Scenario 1

	LAMINATION BLOCK		
	813 (1000S)	**813 Helicap**	**813 (1000S)**
Opening	ReCap3	Helicap	ReCap3
Interior Nip Roller	DD, DD2	DD2	DD, DD2
Lam Nip Roller	DD1, DD2, Teflon	DD1	DD1, DD2, Teflon
Interior Teflon	0	1	0
Lam Teflon	0	1	0
Internal2	Dryblend	LDPE	Dryblend
Internal 1	Primacor 3540	Medium Acid Adhesive	Primacor 3540
Width	1533	1533	1533

Blocks' specifications in the lamination block sequence of A3–s1

From table 7, it can be said that when switching from block 813(1000S) to block 813Helicap, a set-up will be required since the opening type is different and therefore Interior Teflon and Lam Teflon need to be added for producing 813Helicap. Nip Rollers will only have to be changed if the first block is already using DD2 and DD1 in the interior and laminator stations, respectively. A drooling is required in D1 of Internal 2 since the content changes from Metalocen to LDPE. Also a set-up is required when changing the content poured through Internal1, but only when going to high specification block, since PLH packages are very sensitive to the mixture of them.

Appendix VI – *Production costs*

In this appendix, it is explained what is included in the total cost of producing an order in normal conditions, and also what is included in the overall cost of producing an order in "rush" conditions.

Cost of producing an order in normal conditions:

- Printing time
- Printer set-up time (*Change of sleeves* set-up)
- Printer set-up waste (*Change of sleeves* set-up)
- Laminating time
- Paper Board
- Aluminium Foil
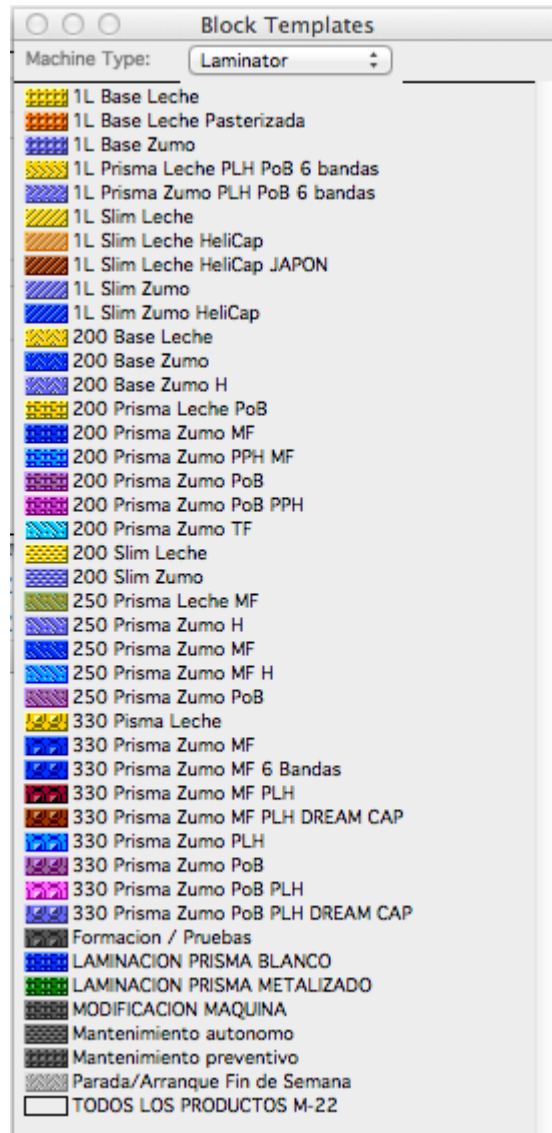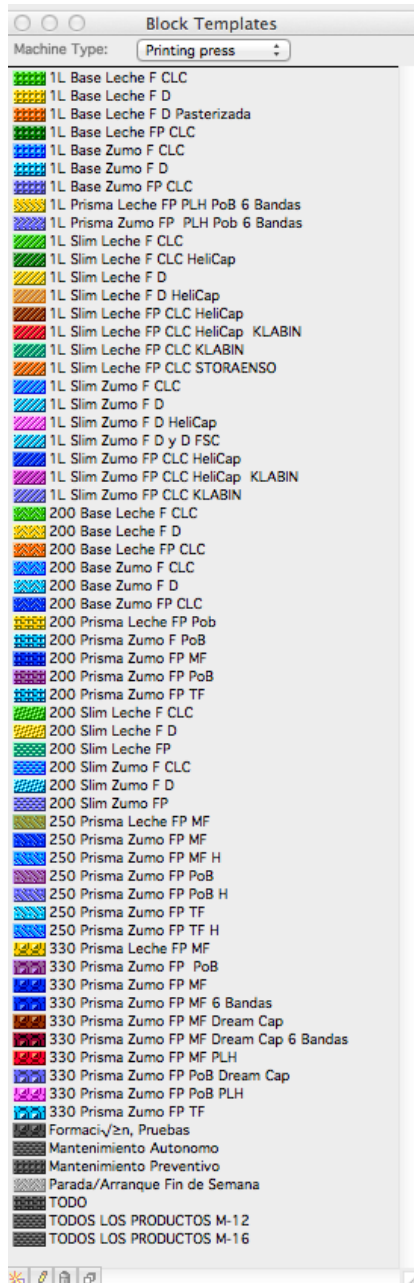- Materials required in the lamination station, inside station and decor station of the laminator
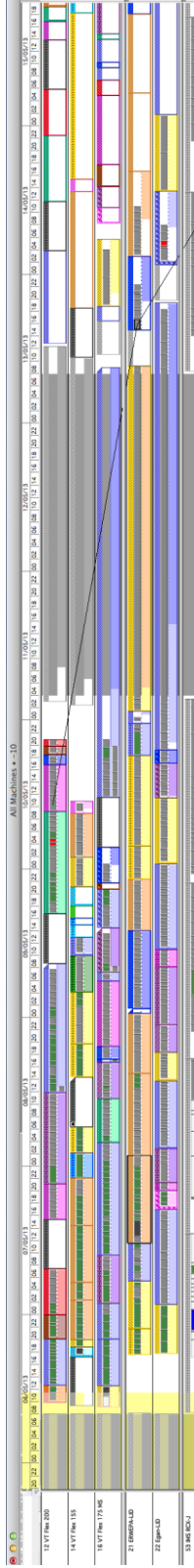
Cost of producing an order in "rush" conditions:

- Cost of producing an order in normal conditions
- Additional printer set-up time*
- Additional printer set-up waste*
- Laminator set-up time*
- Drooling waste in the laminator*
- Paper waste in the laminator*

* if aplicable

Appendix VII –*Proplanner*'s legends and week29's planning

Block Templates — Machine Type: Printing press

- 1L Base Leche F CLC
- 1L Base Leche F D
- 1L Base Leche F D Pasterizada
- 1L Base Leche FP CLC
- 1L Base Zumo F CLC
- 1L Base Zumo F D
- 1L Base Zumo FP CLC
- 1L Prisma Leche FP PLH PoB 6 Bandas
- 1L Prisma Zumo FP PLH Pob 6 Bandas
- 1L Slim Leche F CLC
- 1L Slim Leche F CLC HeliCap
- 1L Slim Leche F D
- 1L Slim Leche F D HeliCap
- 1L Slim Leche FP CLC HeliCap
- 1L Slim Leche FP CLC HeliCap KLABIN
- 1L Slim Leche FP CLC KLABIN
- 1L Slim Leche FP CLC STORAENSO
- 1L Slim Zumo F CLC
- 1L Slim Zumo F D
- 1L Slim Zumo F D HeliCap
- 1L Slim Zumo F D y D FSC
- 1L Slim Zumo FP CLC HeliCap
- 1L Slim Zumo FP CLC HeliCap KLABIN
- 1L Slim Zumo FP CLC KLABIN
- 200 Base Leche F CLC
- 200 Base Leche F D
- 200 Base Leche FP CLC
- 200 Base Zumo F CLC
- 200 Base Zumo F D
- 200 Base Zumo FP CLC
- 200 Prisma Leche FP PoB
- 200 Prisma Zumo F PoB
- 200 Prisma Zumo FP MF
- 200 Prisma Zumo FP PoB
- 200 Prisma Zumo FP TF
- 200 Slim Leche F CLC
- 200 Slim Leche F D
- 200 Slim Leche FP
- 200 Slim Zumo F CLC
- 200 Slim Zumo F D
- 200 Slim Zumo FP
- 250 Prisma Leche FP MF
- 250 Prisma Zumo FP MF
- 250 Prisma Zumo FP MF H
- 250 Prisma Zumo FP PoB
- 250 Prisma Zumo FP PoB H
- 250 Prisma Zumo FP TF
- 250 Prisma Zumo FP TF H
- 330 Prisma Leche FP MF
- 330 Prisma Zumo FP PoB
- 330 Prisma Zumo FP MF
- 330 Prisma Zumo FP MF 6 Bandas
- 330 Prisma Zumo FP MF Dream Cap
- 330 Prisma Zumo FP MF Dream Cap 6 Bandas
- 330 Prisma Zumo FP MF PLH
- 330 Prisma Zumo FP PoB Dream Cap
- 330 Prisma Zumo FP PoB PLH
- 330 Prisma Zumo FP TF
- Formaci√≥n, Pruebas
- Mantenimiento Autonomo
- Mantenimiento Preventivo
- Parada/Arranque Fin de Semana
- TODO
- TODOS LOS PRODUCTOS M-12
- TODOS LOS PRODUCTOS M-16

Block Templates — Machine Type: Laminator

- 1L Base Leche
- 1L Base Leche Pasterizada
- 1L Base Zumo
- 1L Prisma Leche PLH PoB 6 bandas
- 1L Prisma Zumo PLH PoB 6 bandas
- 1L Slim Leche
- 1L Slim Leche HeliCap
- 1L Slim Leche HeliCap JAPON
- 1L Slim Zumo
- 1L Slim Zumo HeliCap
- 200 Base Leche
- 200 Base Zumo
- 200 Base Zumo H
- 200 Prisma Leche PoB
- 200 Prisma Zumo MF
- 200 Prisma Zumo PPH MF
- 200 Prisma Zumo PoB
- 200 Prisma Zumo PoB PPH
- 200 Prisma Zumo TF
- 200 Slim Leche
- 200 Slim Zumo
- 250 Prisma Leche MF
- 250 Prisma Zumo H
- 250 Prisma Zumo MF
- 250 Prisma Zumo MF H
- 250 Prisma Zumo PoB
- 330 Pisma Leche
- 330 Prisma Zumo MF
- 330 Prisma Zumo MF 6 Bandas
- 330 Prisma Zumo MF PLH
- 330 Prisma Zumo MF PLH DREAM CAP
- 330 Prisma Zumo PLH
- 330 Prisma Zumo PoB
- 330 Prisma Zumo PoB PLH
- 330 Prisma Zumo PoB PLH DREAM CAP
- Formacion / Pruebas
- LAMINACION PRISMA BLANCO
- LAMINACION PRISMA METALIZADO
- MODIFICACION MAQUINA
- Mantenimiento autonomo
- Mantenimiento preventivo
- Parada/Arranque Fin de Semana
- TODOS LOS PRODUCTOS M-22

Appendix VIII – Improvements in the model

While using the Arganda factory simulation model, which is not considered to be fully implemented yet, the writer of this thesis has come up with some suggestions on how to continue improving it:

1. Add short stops and breakdowns&repairs in the printers. Since they occur quite frequently in reality, the fact that they are not yet implemented in the model is causing some problems such as that the efficiency KPI is much higher than expected, among others. As well, other kind of losses could be implemented such as management loss, performance loss, and quality loss.

2. In the laminators, part of the short stops (the ones due to die cleaning and teflon changes) have already been modelled, and therefore, the current efficiency KPI provided by the model is quite close to reality. However, the unexpected short stops still have to be implemented, and as well the breakdowns&repairs and the quality losses.

3. Consider the PE wasted in the set-up paper generated in the laminators. Add this amount of PE to the KPI which refers to PE waste.

4. All kind of waste material could be introduced in the model. As explained in chapter 4.7, beside the set-up waste, more waste material is generated in both the printers and the laminators.

5. Reorganize the machine´s state names. Besides, if new losses are to be introduced into the model, more states will have to be defined. Also, check that machines are switching to the correspondent state when they change their task.

6. Considering that machines have training and maintenance shifts allocated differently depending on the week, it is needed that machine's timetables are defined longer than at a weekly basis (maybe a two weeks timetable would be enough). This way, it would be possible to run the model longer.

7. Make the required adjustments to the finishing area (since in the present time is not fully implemented yet), so that the whole

converting line can be simulated. In this case, the KPI *PerfectSlitable* (which involves too many assumptions) won´t be needed anymore because the *PerfectDelivered* would be used instead.

8. Remove old tables from the DB (the ones that are not used anymore or that have been replaced by new ones), so that the user doesn´t get confused.

List of figures

List of tables