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Analysis and Development of a Production Management Model

Sofia Miguel Freitas de Oliveira

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Presidente Professor Doutor Fernando Arménio da Costa Castro e Fontes
Professor Associado do Departamento de Engenharia Eletrotécnica e de Computadores da Faculdade de Engenharia da Universidade do Porto

Professor Doutor Samuel de Oliveira Moniz
Assistente Convidado da Escola Superior de Ciências Empresariais do Instituto Politécnico de Viana do Castelo

Professor Doutor Américo Lopes de Azevedo
Professor Associado do Departamento de Engenharia de Gestão Industrial da Faculdade de Engenharia da Universidade do Porto

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Autor - Sofia Miguel Freitas de Oliveira

Faculdade de Engenharia da Universidade do Porto

Abstract

The present study, which was conducted in the context of an Integrated Masters Degree in Electrical and Computer Engineering at Faculdade de Engenharia da Universidade do Porto, aims at the approach of the problematics of production and business processes analysis and improvement. The study lies within the frame of Processes Modeling and Analysis for Re-Engineering and the field of Lean Manufacturing.

The research – which sustains this Masters Dissertation – is based upon an observation approach of the production management problematics in a manufacturing oriented environment, having as reference a case study within the portuguese packaging industry. By means of processes modeling and lean analysis techniques and with the aid of a manufacturing simulation model, the conducted holistic analysis suggests a prototypical frame of implementation of global solutions and lean practices capable of improving the case study company's business processes as well as its production planning and control process.

Keywords: Business Characterization, Manufacturing Simulation, Lean Manufacturing, Processes Modeling, Processes Re-Engineering.

Resumo

Desenvolvido no âmbito do Mestrado Integrado em Engenharia Electrotécnica e de Computadores da Faculdade de Engenharia da Universidade do Porto, o presente estudo tem por propósito central a abordagem da problemática de análise e melhoria dos processos de produção e processos de negócio e enquadra-se na temática da Análise e Modelação de Processos para Re-Engenharia e no campo da *Lean Manufacturing*.

A investigação - que suporta a presente Dissertação de Mestrado – assenta numa abordagem de observação da problemática da gestão da produção num ambiente orientado à manufactura, tendo por referência um estudo de caso inscrito na indústria de embalagens portuguesa. Através do recurso a técnicas de modelação de processos e análise *lean*, e com o suporte de um modelo de simulação de produção, a análise holística realizada propõe um quadro prototípico de implementação de soluções globais e práticas *lean* susceptíveis de introduzir melhorias nos processos de negócios da empresa estudo de caso, bem como ao nível dos processos de planeamento e controlo de produção.

Palavras-chave: Caracterização de Negócios, Modelação de Processos, Lean Manufacturing, Re-Engenharia de Processos, Simulação de Produção.

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Table of Contents

Abstract .... **iii**

Resumo .... **vii**

Acknowledgements .... **ix**

Table of Contents .... **xi**

List of Figures .... **xiii**

List of Tables .... **xvii**

Abbreviations and Symbols .... **xix**

Chapter 1 .... **1**

Introduction 1
1.1. Motivation 1
1.2. Investigation Design 2
1.3. Dissertation Outline 4

Chapter 2 .... **6**

Theoretical Framework 6
2.1. Business Process Modeling 6
2.2. Manufacturing Systems and Strategies 12
2.3. Production Planning and Scheduling 14
2.4. Characteristics of the Process Industries 15
2.5. Pareto Principle 16
2.6. Lean Manufacturing 18
2.7. Manufacturing Simulation 24

Chapter 3 .... **26**

Case Study Description 26
3.1. Introduction 26
3.2. Organizational Structure 27
3.3. Manufacturing Strategy 29
3.4. Products and Raw Materials 29
3.5. Production Flow 30
3.6. Information Systems 32

Chapter 4 33

Business Characterization 33
4.1. As-Is Model 33
4.2. Other Characterization Aspects 58

Chapter 5 61

Manufacturing Simulation 61
5.1. The Factory Test Case Description 61
5.2. Simulation 64
5.3. Results 65
5.4. Problems with Quest 69
5.5. Benefits of using Quest 72

Chapter 6 73

Solution Analysis 73
6.1. Improvement Opportunities 73
6.2. To-Be Model 84

Chapter 7 89

Conclusions 89
7.1. General Overview 89
7.2. Directions for Further Research 91
7.3. Concluding Remarks 91

References 93

Appendix 97

List of Figures

Figure 1 - Investigation Design 3

Figure 2 - Outline of the Dissertation 5

Figure 3 - Example of a Flow Chart (Aguilar-Sáven, 2003) 8

Figure 4 - Example of a RID (Aguilar-Sáven, 2003) 9

Figure 5 - IDEF0 Graphical Diagram's Components (Aguilar-Sáven, 2003) 10

Figure 6 - Example of a Responsibility Assignment Matrix Model (Faria, 2013) 10

Figure 7 - Example of a Gantt Chart (Team Gantt, 2012) 11

Figure 8 - BPMN 2.0 Notation (BPMN, 2009) 12

Figure 9 - Schematic Representation of the Pareto Principle 17

Figure 10 - 80/20 Pattern in Business 18

Figure 11 - Example of a Visual Management Board (Lean Products, 2014) 23

Figure 12 - Quest's Interface (Delmia Quest, 2006) 25

Figure 13 - Examples of packages manufactured by the company 26

Figure 14 - Company's Sales Volume (k€) 27

Figure 15 - Company's Organizational Structure Diagram 28

Figure 16 - Examples of Raw Materials used by the Company 30

Figure 17 - Company's Section Flow 31

Figure 18 - Company's Production Flow 31

Figure 19 - Customer Oriented Core Processes Conceptual Model 34

Figure 20 - Level 0 Customer Oriented Core Processes Model 35

Figure 21 - Level 1 Customer Oriented Core Processes Model (Proposal Request Process) 35

Figure 22 - Level 1 Customer Oriented Core Processes Model (Production Process) 36

Figure 23 - Production Planning and Control Process Conceptual Model 37

Figure 24 - Level 0 Production Planning and Control Process Model 37

Figure 25 - Level 1 Production Planning and Control Process Model 38

Figure 26 - Level 0 Conceptual Diagram of the Integration Between Customer Oriented Core Process and the Production Planning and Control Process 39

Figure 27 - *Planificação*'s Interface (Analyze and Process Request) 40

Figure 28 - *Planificação*'s Interface (Calculate Budget) 41

Figure 29 - Plan 2013's Interface 42

Figure 30 - Conceptual Model of a Production Order (PO) 43

Figure 31 - Planificação's Interface (Allocate Production) 45

Figure 32 - Finished POs Designated Site (Cutting Section) 46

Figure 33 - Primavera ERP Interface (Evaluate Dispatch Resources' Availability) 48

Figure 34 - Product Families' Production Volume (Pareto Chart) 51

Figure 35 - Product Families by Manufacturing Sequence 52

Figure 36 - Groups of Product Families by Manufacturing Sequence 52

Figure 37 - Product Families' Groups' Production Volume (Pareto Chart) 54

Figure 38 - Value Stream Map (G1) 55

Figure 39 - Value Stream Map (G3) 57

Figure 40 - Top View of the Manufacturing Facility's Layout 62

Figure 41 - Part Codification Used in the Model 63

Figure 42 - Completed and Rejected Units Distribution 66

Figure 43 - Machine and Labor Utilization 67

Figure 44 - Average Buffer Length 68

Figure 45 - View of the Manufacturing Facility at the End of the Simulation 69

Figure 46 - Example of the Buttons Layout 70

Figure 47 - Data Insertion Problem Encountered in the "Product" Menu 71

Figure 48 – Chart Display Problem 72

Figure 49 - Conceptual Representation of the Current Delivery Date Definition Method 74

Figure 50 - Representation of the Internal Planning Concept 75

Figure 51 - Conceptual Model of a PO Including Internal Planning 76

Figure 52 - Conceptual Representation of the Purchasing Department Problem 77
Figure 53 - Conceptual Representation of a Purchasing Department Solution....................77
Figure 54 - Conceptual Representation of the Production Cycles Problem........................78
Figure 55 - In Progress and To Be Produced PO's Site (Printing Machine)..........................81
Figure 56 - Finished POs (Printing Machine)..81
Figure 57 - Prototype of a Visual Management Tool for Physical PO's..............................82
Figure 58 - Conceptual Prototype of a Dashboard for Computerized Visual Management 83
Figure 59 - Future Level 1 Customer Oriented Core Processes Model (Production Process)....85
Figure 60 - Future Level 1 Production Planning and Control Process Model.......................85
Figure 61 - Establish Delivery Date (CDD) and Internal Due Dates Activity Flow Chart..........86
Figure 62 - Future Value Stream Map (G1) 87
Figure 63 - Future Value Stream Map (G3) 88
Figure 64 - Project Long Term Planning (Gantt Chart) 98
Figure 65 - Company's Internal Documents: OGCAL 25/1 (Request Form).........................99
Figure 66 - Company's Internal Documents: OGCAL 88/8 (Request Form)....................... 100
Figure 67 - Company's Internal Documents: OGCAL 164/0 (Print) and OGCAL 159/1 (Model) 101
Figure 68 - Company's Internal Documents: OGCAL 157/2 (Budget Calculation) 101
Figure 69 - Company's Internal Documents: OGCAL 14/2 (Budget Presentation)............... 102
Figure 70 - Company's Internal Documents: OGCAL 20/6 (Order Confirmation)................ 103
Figure 71 - Company's Internal Documents: OGCAL 01/17 (Production Order) 104
Figure 72 - Company's Internal Documents: OGCAL 08/8 (Delivery Note) 105
Figure 73 - Company’s Manufacturing Plant Blueprint.. 111
Figure 74 - Delmia Quest Source Data... 112
Figure 75 - Future Production Order (G1) 114
Figure 76 - Future Production Order (G2) 115
Figure 77 - Future Production Order (G3) 116
Figure 78 - Future Production Order (G4) 117
Figure 79 - Future Production Order (G5) 118
Figure 80 - Future Production Order (G6) 119

List of Tables

Table 1 - Manufacturing Strategies' Characteristics (Dixon, 2009) 13

Table 2 - Examples of Production Planning and Scheduling Software Solutions Available in the Market (Singleton, 2014) 15

Table 3 - Examples of Manufacturing Simulation Software Solutions Available in the Market (2014) 24

Table 4 - Company's Flute Profiles 29

Table 5 - Actor Categories' Color Code 34

Table 6 – Identified Product Families 50

Table 7 - Product Families' Production Volume (2013) 50

Table 8 - Product Families' Groups Production Volume (2013) 53

Table 9 - Production Cycles' Alphabetical Code 58

Table 10 - Production Cycles' Numerical Code 59

Table 11 - Production Cycles 59

Table 12 - Color Code Attributed to each Machine Type 62

Table 13 - Processes Attributed to each Machine Type 64

Table 14 - Labour Simulation Data 64

Table 15 - Finished Products Data 66

Table 16 - Non Completed Products Data 69

Table 17 – Machine's List 110

Table 18 - Delmia Quest Creation Time Data 113

Abbreviations and Symbols

ATO	Assemble-to-Order
BCL	Batch Control Language
BPM	Business Process Modeling
BPMN	Business Process Model and Notation
CAD	Computer Aided Design
CDD	Client Due Date
DD	Due Date
ERP	Enterprise Resources Planning
ETO	Engineer-to-Order
IDEF	Integrated Definition for Function Modeling
ISO	International Organization for Standardization
IT	Information Technology
MRP	Material Requirement Planning
MTO	Make-to-Order
MTS	Make-to-Stock
OEE	Overall Equipment Efficiency
OGCAL	*Organização Gráfica Calheiros*
OHSAS	Occupational Health & Safety Advisory Services
OMG	Object Management Group
PDCA	Plan, Do, Check, Act
PME	*Pequena Média Empresa*
PO	Production Order
PPC	Production Planning and Control
RAD	Role Activity Diagrams
RID	Role Interaction Diagrams
RM	Raw Materials
SADT	Structure Analysis and Design Technique
SCL	Simulation Control Language

SGPS	*Sociedade Gestora de Participações Sociais*
SMED	Single Minute Exchange of Die
TPM	Total Productive Maintenance
TPS	Toyota Production System
VSM	Value Stream Mapping
WSBPEL	Web Services Business Process Execution Language
XML	Extensible Markup Language

Chapter 1

Introduction

In this introductory chapter, the motivation for this project elaboration is explained, as well as the adopted approach to address the study problem. Following the motivational section, the design of the investigation is disclosed by the means of a schematic representation, which is then described thoroughly. Finally, the dissertation outline is exhibited, once again with the support of a schematic diagram.

1.1. Motivation

Manufacturing companies operate in a very competitive field in operational terms. The increasing demand of customers, coupled with strong competitive forces, triggers a growing concern with the reduction of operating costs. In this context, the improvement of the production planning and control processes and customer oriented business processes is key to maintaining the competitiveness of the market since processes improvement has a positive impact on customer satisfaction, while allowing cost reductions associated with the production process.

Thus, this dissertation project is a response to the need to explore and develop a production management model for a company that operates in this competitive domain.

The analysis and consequent continuous improvement of a company's customer oriented business and planning processes, as well as the development of production management support tools are essential in relation to production management, embodying major topics of research. While processes enhancement may be performed with the support of lean techniques and strategic and transformational thinking, the development of production management tools, particulary aiming at order sequencing and scheduling, follows a quantitative approach, as it is dependable on computational methods and requires very accurate sets of input data. Hence, in the context of this dissertation, it is possible to cope with the problem of production oriented business improvement in two opposite directions: following a quantitative approach, focusing on the development of heuristics to support order sequencing problems, or following a qualitative path, based in an holistic principles, observing and analysing the company as a whole, rather than in respect to specific areas. In this dissertation, the adopted methodology follows the qualitative path.

The conducted study analyzes ways to improve the case study company's customer oriented and planning processes. In order to do so, a thorough business characterization was executed by mapping the company's processes and conducting a value stream analysis. The company's manufacturing plant behavior was also characterized by the means of a simulation model. These two elements will enable the detection of problems and improvement opportunities that will support solution analysis. The complete investigation design is addressed in the next section.

1.2. Investigation Design

Investigation design aims at providing a step-by-step design of the way in which the research was conducted in order to accomplish the project's objectives. In Figure 1, a schematic representation of the steps performed in the scope of this dissertation is exhibited.

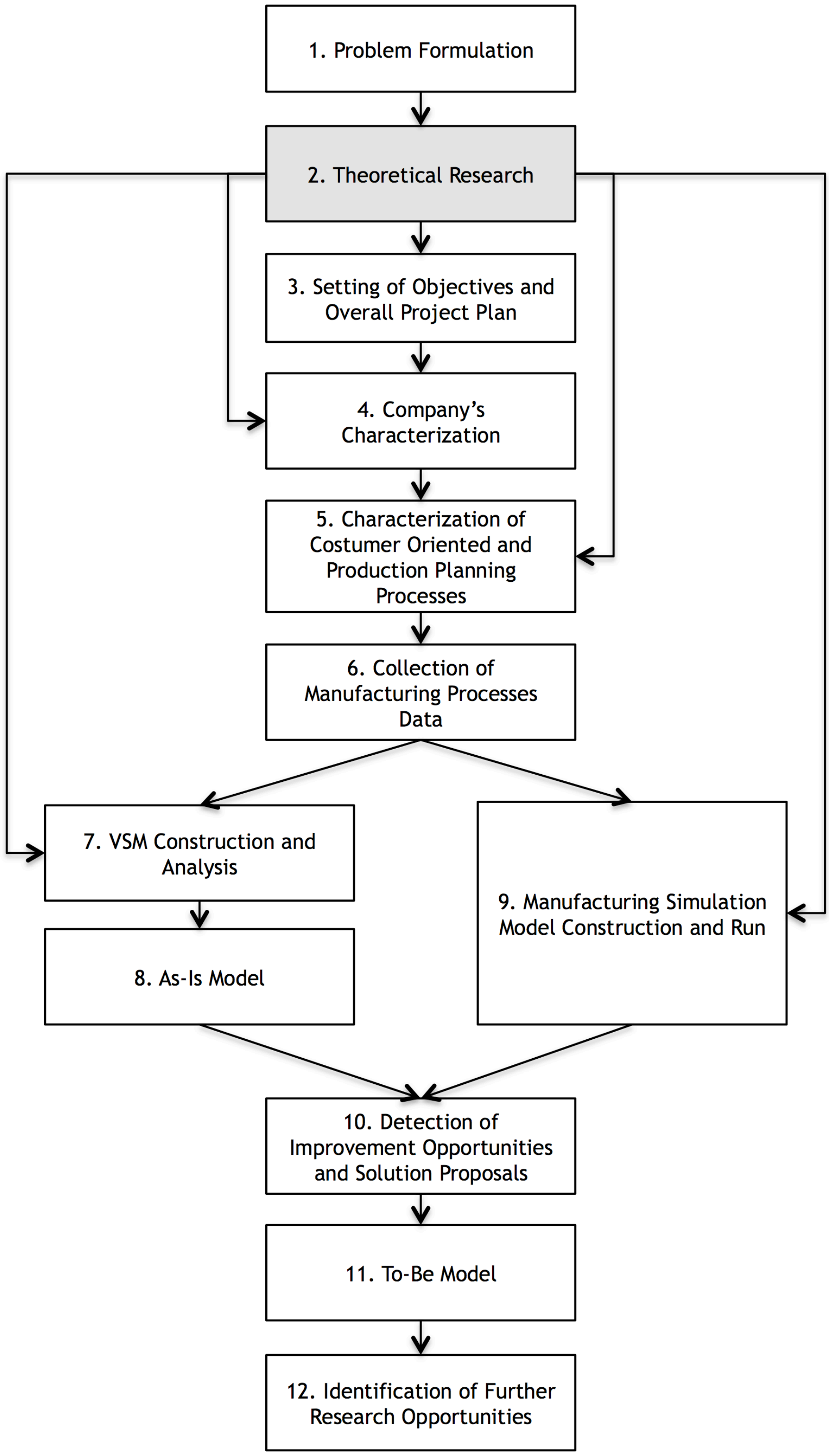


Figure 1 - Investigation Design

The first step of this investigation is affiliated with problem formulation, which consists in identifying and describing one of the company's prevailing problems. One of the company's most pressing issues, detected by the dissertation advisor, concerned the need to improve the company's production planning process, while simultaneously focusing on its business processes. This problem was chosen as the investigation object of this dissertation and its formulation is provided in the dissertation description. After problem's formulation, the author performed setting of objectives and overall project plan definition. This dwelled in choosing a problem approach, identifying project goals, and building a long-term project plan by the means of a Gantt Chart, exhibited in Appendix 1. In order to choose a problem approach, theoretical research regarding production planning and scheduling was performed. Once motivation and the project plan were defined, the company was characterized with emphasis on empirical information regarding its organizational structure, manufacturing strategy, raw materials and products, production flow and information systems. This overall characterization provided a general view of the company's structure and basic operation. In order to accurately characterize the company, a theoretical research regarding process industries and manufacturing systems and strategies was performed. After the understanding of the overall company operation, a more thorough business characterization was conducted, aiming at the characterization of production process and customer-oriented processes. Once more, a theoretical research on business process modeling was done in order to support processes' mapping. The next step in this investigation consisted in observing and collecting shop floor processes data, with the objective of supporting the construction of a Value Stream Map, know as VSM, as well as providing input data for a manufacturing simulation model. After the construction and analysis of the VSM, the As-Is Model construction was accomplished. VSM development was supported by theoretical research on lean manufacturing techniques and the Pareto principle. The manufacturing simulation main purpose was to simulate the manufacturing plant behaviour, enabling further company's manufacturing characterization. Once again, research on manufacturing simulation was performed in order to support the choice of simulation software and its functional principles. The company's As-is Model and manufacturing simulation results enabled the detection of some of the company's improvement opportunities and solution proposals. The detected improvement opportunities and respective solution proposals supported the construction of the company's To-Be Model. Finally, an identification of further research opportunities was conducted.

1.3. Dissertation Outline

In this introductory chapter, the object of study and the investigation design is presented. Furthermore, the way in which each step of the investigation is addressed in the remaining chapters is outlined. An overview is presented in Figure 2.

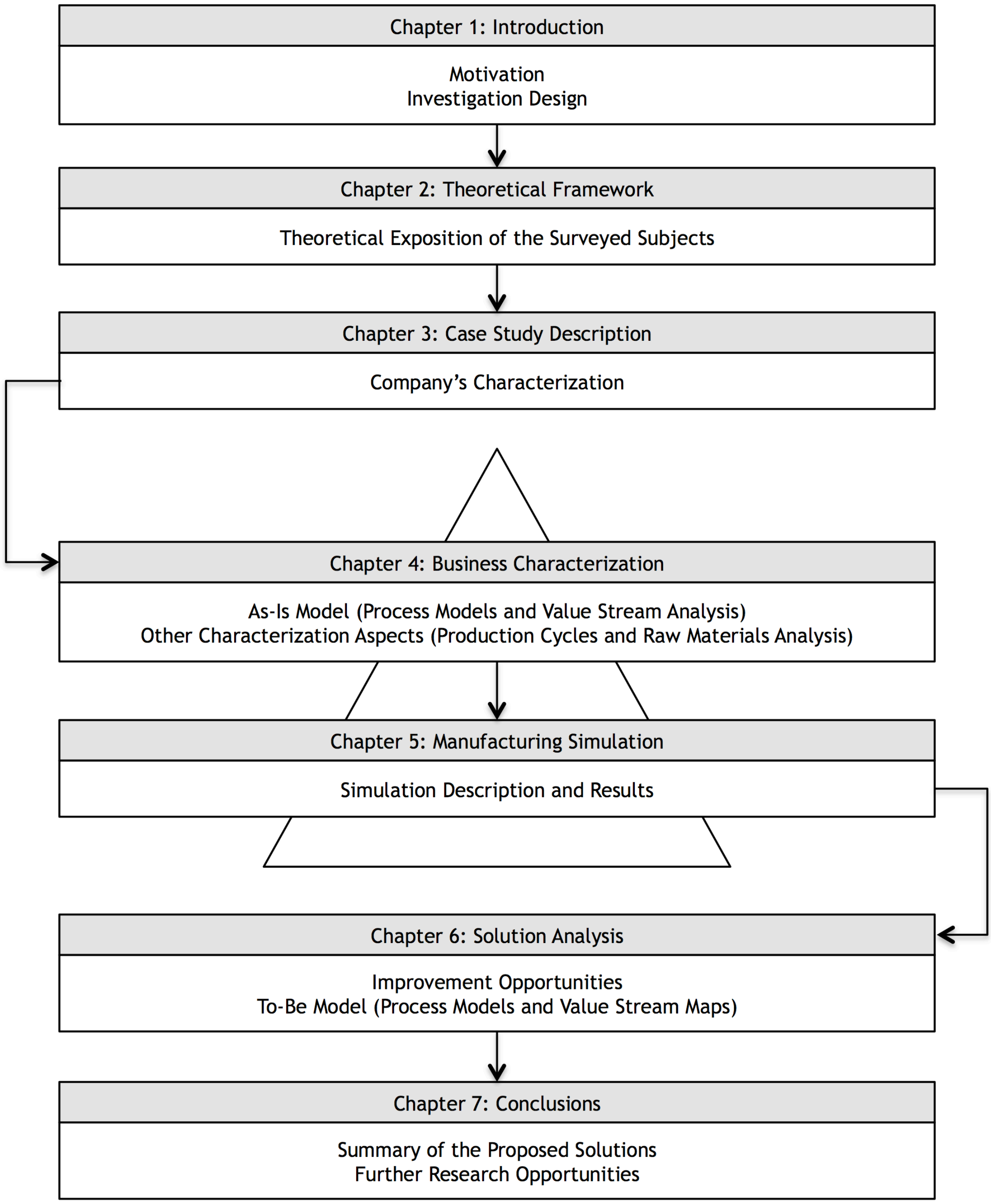


Figure 2 - Outline of the Dissertation

Chapter 2 presents a theoretical underpinning of the surveyed subjects that support the comprehension of this dissertation analytic aspects. Chapter 3 focuses in the case study description, providing the reader with empirical information regarding company's general aspects. Chapters 4 and 5 deal with aspects that will support the elaboration of the Solution Analysis exposed in Chapter 6. While Chapter 4 aims at the company's As-is Model, built with basis on observation, Chapter 5 focuses in manufacturing simulation, built on experimentation. Finally, Chapter 7 summarizes and problematizes the results of the study and general topics for further research are discussed.

Chapter 2

Theoretical Framework

In this chapter, a theoretical framework of the concepts involved in the body of this dissertation is presented. Those concepts include Business Process Modeling, Manufacturing Strategies and Systems, Production Planning and Scheduling, Characteristics of the Processes Industries, the Pareto Principle, Lean Manufacturing and Manufacturing Simulation Software.

2.1. Business Process Modeling

According to Oxford dictionary, a process is defined as a series of actions and steps taken in order to achieve a particular end (Oxford, 2014). Processes are present in every aspect of our daily lives, although we may not notice them. A few examples of processes might include preparing breakfast, putting gas in the car, writing a work order, developing a budget, among many others (Baird, 2013).

Overall, a process can consist of many actors, which may be people, organizations or systems that perform an array of tasks in a coordinated manner.

In business, a process is the combination of a set of activities within an enterprise with a structure describing their logical order and dependence whose objective is to produce a specific desired result. Business processes are distinguished as “core” and “supportive” processes. A core or primary process is initiated from outside an organization, and it can be, for example, the chain of activities that releases the delivery of a product to a costumer. On the other hand, a supportive or secondary process creates the conditions for the core process to be carried out.

A process model can provide a comprehensive understanding of a process, as it is able to represent the steps that are part of the process. An enterprise can be analyzed and integrated through its business processes, hence the importance of correctly modeling them.

Business Process Modeling (BPM) is the activity of creating visual representations of an enterprise’s processes with the aim of understanding how an organization works, and also to analyze and improve the current process efficiency and quality. Value-adding processes have more and more become the principle of organizing a business, rather than the functional hierarchy perspective (Agilar-Sáven, 2003).

Some of the potential uses of process models are program planning, baseline for continuous improvement, process visualization, training and program execution. Those models can be used to develop simulations to test the processes on inputs that have not occurred in the real world, as well as to develop systems that automate the processes they model. Experts in the field of Information Technology and Business Engineering have concluded that successful systems start with an understanding of an organization's business processes. Furthermore, business processes are a key factor when integrating an enterprise (Aguilar-Sáven et al., 2002, cited by Aguilar-Sáven, 2003). Conceptual modeling of business processes is deployed on a large scale to facilitate the development of software that supports the business processes, and also to provide for their analysis and re-engineering.

Although there is a multitude of benefits from modeling business processes, there are very few companies who have built useful process models, since most of the models that exist are often not well integrated and leave out key information that is required for a full critical analysis of the process.

Using the right model involves taking into account the purpose of the analysis and knowledge of the available process modeling techniques and tools. There is a wide amount of references on business modeling, thus making it time-consuming to get an overview of those techniques and tools, as well as understanding some of the concepts and vocabulary involved in each one.

The increasing popularity of business process orientation (Hammer and Champy, 1993, cited by Aguilar-Sáven, 2003) has yielded a rapidly growing number of methodologies as well as modeling techniques and tools to support it. As a result of the literature review, the following methods were found as the most frequently used and therefore are the only ones presented in this paper. The most important characteristics, mainly strengths and weaknesses, of each technique are discussed below.

2.1.1. Flow Chart Technique

The Flow Chart Technique "is defined as a formalized graphic representation of a program logic sequence, work or manufacturing process, organization chart or similar formalized structure" (Lakin et al.,1996, cited by Aguilar-Sáven, 2003, p. 134). The flow chart modeling method represents processes by means of a flow chart, using symbols to represent elements such as operations, data, flow direction and equipment. As a sequential flow of actions is used, this technique does not support a breakdown of activities.

The main characteristic of flow charts is their flexibility, since a process can be described in a wide variety of ways using the different building blocks, leaving their disposition to the designer of the chart. This way, it is easy to recognize the process described by looking at a flowchart representation.

Despite their flexibility, the real strength of this model is the communication ability since the flow chart's use is very intuitive and drawing a sketch of a process is not time consuming.

However, the weakness of the technique is that it is too flexible, which may lead to difficulties defining the boundary of the process. Another aspect is that flow charts tend to be too large, even in the evaluation phase. Also, there is no difference between main and sub-activities, which makes the chart hard to read. The worst drawback of this model is that there is no natural way of describing responsibilities or performers in the chart, thus making it hard to connect the organizational functions to activities.

The best use for the flow chart technique is when it is required to deal with processes whose analysis requires a high level of detail. On the contrary, it is not suitable for providing an overview.

Figure 3 depicts an example of a simple process modeled by a flow chart. The process starts when a costumer places an order, which is received by the company's Marketing Department. After that the Marketing Department introduces the order information into the company's information system and sends it forward to the Distribution Centre. Then, the Distribution Centre verifies the availability of the required product. In case it is in stock, it is shipped to the costumer along with the invoice. Otherwise, the Distribution Centre communicates the product's non-availability to the Marketing Department so that they may inform the customer.

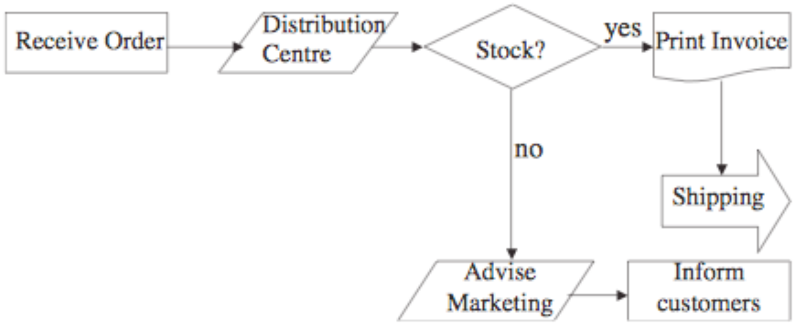


Figure 3 - Example of a Flow Chart (Aguilar-Sáven, 2003)

2.1.2. Role Interaction Diagrams

Role interaction diagrams, known as RIDs, consist of a graph of a process resulting from the combination of role activity diagrams (RADs) and Jacobson's object interaction diagrams (Boma, 1996 cited by Aguilar-Sáven, 2003). In this type of representation, activities are connected to roles in a matrix-type diagram. Those activities are shown vertically on the left axis while the roles are shown horizontally at the top. The process is represented by text and symbols. Human interactions are shown by horizontal lines (Boma, 1996, cited by Aguilar-Sáven, 2003).

Although slightly more complex than flow charts, RIDs are fairly intuitive to understand and easy to read but they have difficult construction and editing. The major drawback concerning this type of diagrams is that inputs to and outputs from the activities are not modeled, what may lead to the loss of important information. However, since each activity is bound to a performer, the responsibilities are well defined and thus the connection to the organization is easy to make. Furthermore, due to their notation and ability to break down activities, very complex processes can be displayed. The best use of RIDs is in workflow design as RID's are primarily used for processes that involve co-ordination of interrelated activities. Figure 4 shows the same process as in Figure 3, modeled using a RID.

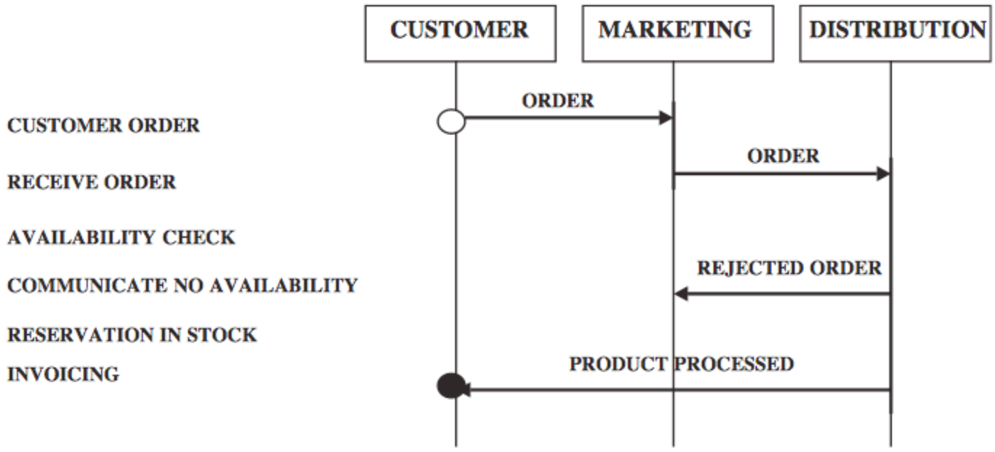


Figure 4 - Example of a RID (Aguilar-Sáven, 2003)

2.1.3. IDEF0

The Integrated Definition for Function Modeling (IDEF0) is a method designed to model the decisions, actions and activities of an organization or system. It was derived from a well-established graphical language, the Structure Analysis and Design Technique (SADT). IDEF0 is useful in establishing the scope of an analysis, especially for a functional analysis. This tool assists the modeler in identifying what functions are performed, what is needed to perform those functions, what the current system does right and what the current system does wrong. Three types of information compose these models: graphical diagram, containing boxes, arrows, box-arrow interconnections and associated relationships (IDEF, 2014).

The very strict IDEF0 rules make it suitable for implementation as computer software since working backwards along the chain, from outputs to inputs, allows data and control definition. Also, the hierarchical structure facilitates quick mapping at a high level. One drawback of this tool is the tendency of IDEF0 models to be interpreted as representing a sequence of activities. The activities may be placed in a left to right sequence within decomposition and connected with the flows, which is natural since if one activity's output is used as input by another activity, drawing the activity boxes and concept connections is clearer. Thus, activity sequencing may be embedded in the IDEF0 model without intent (Aguilar-Sáven, 2003). The IDEF0 format that describes the same process as in Figure 3 and Figure 4 is show in Figure 5.

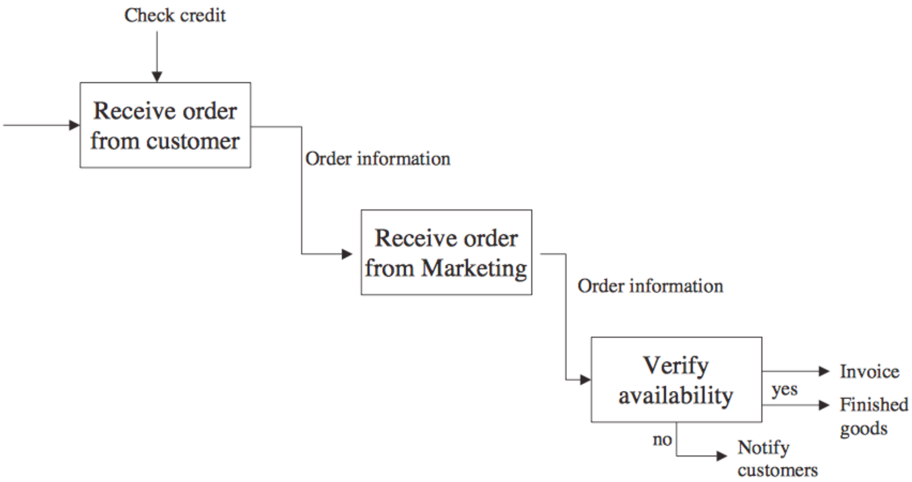


Figure 5 - IDEF0 Graphical Diagram's Components (Aguilar-Sáven, 2003)

2.1.4. Responsibility Assignment Matrix

A Responsibility Assignment Matrix, known as RAM, describes the participation by various roles, performed by actors, in completing tasks or deliverables for a project or business process (Tiziana, 2010). It is especially useful in clarifying roles and responsibilities in cross-departmental and cross-functional projects or processes (Brennan, 2009). An example of a RAM application in business process modeling is shown in Figure 6.

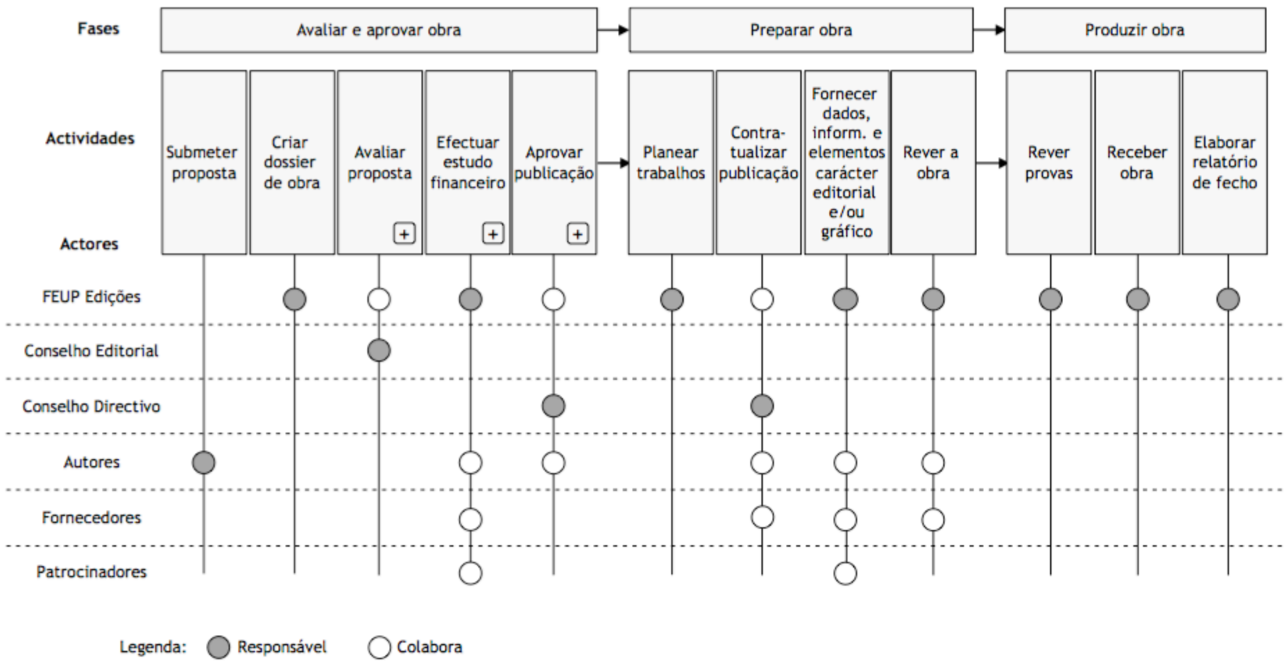


Figure 6 - Example of a Responsibility Assignment Matrix Model (Faria, 2013)

2.1.5. Gantt Chart

A Gantt Chart (Aguilar-Sáven, 2001, cited by Aguilar-Sáven, 2003) is a matrix that lists all the tasks or activities to be performed in a process on the vertical axis. In this model, each row contains a single activity identification, which usually consists of a number and a name. The horizontal axis is headed by columns indicating the estimated activity duration, skill level required to perform the activity and the name of the actor assigned to the activity followed by one column for each period of the projects' duration. Gantt charts relate a list of activities to a time scale. Thus, they might be used to represent a process graphically and control its current situation of performance. Gantt Charts' use in process analysis is quite limited, as these simple graphic representations do not show dependencies between activities (Aguilar-Sáven, 2003).

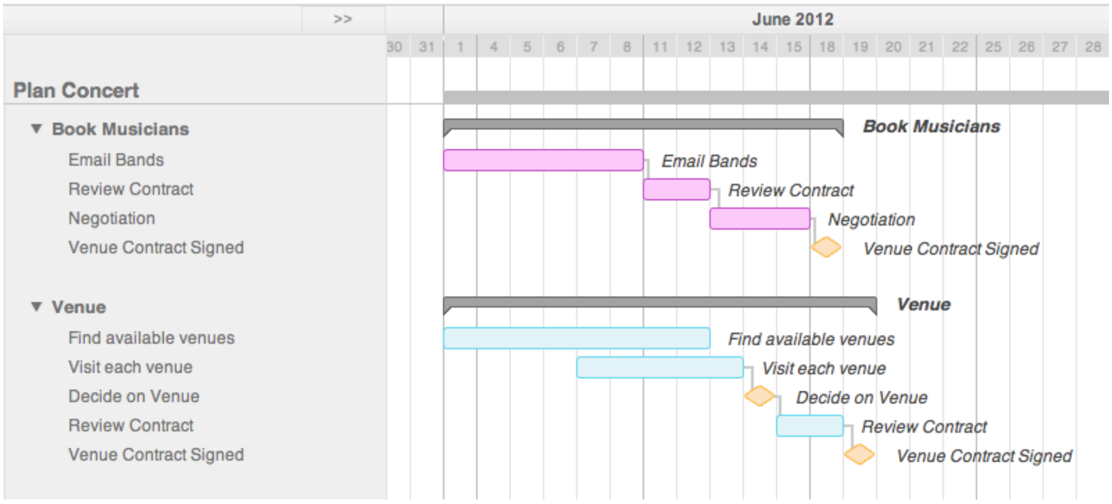


Figure 7 - Example of a Gantt Chart (Team Gantt, 2012)

2.1.6. BPMN 2.0

Business Process Model and Notation (BPMN) is a standard in business process modeling created by the Object Management Group (OMG). Its current version is the 2.0 version.

This model comprises two main goals: first, it provides "a notation that is readily understandable by all business users from the business analysts that develop initial drafts of the processes, to the technical developers responsible for implementing the technology that will perform those processes and finally, to the business people who will manage and monitor those processes" (BPNM, 2011, p. 1) and second it ensures "that XML languages designed for the execution of business processes, such as WSBPEL (Web Services Business Process Execution Language) can be visualized with a business-oriented notation" (BPNM, 2011, p. 1. One of the strengths of this model it that it bridges the gap between the business process design and its implementation, providing this way "a simple means of communication process information to other business users, process implementers, customers and suppliers" (BPNM, 2011, p. 1).

Figure 8 represents the amalgamation of best practices within the business modeling community to define the notation and semantics of Collaboration diagrams, Process diagrams and Choreography diagrams, thus providing a standardized business process model and notation system as opposed to the diversity of modelling notations and viewpoint systems.

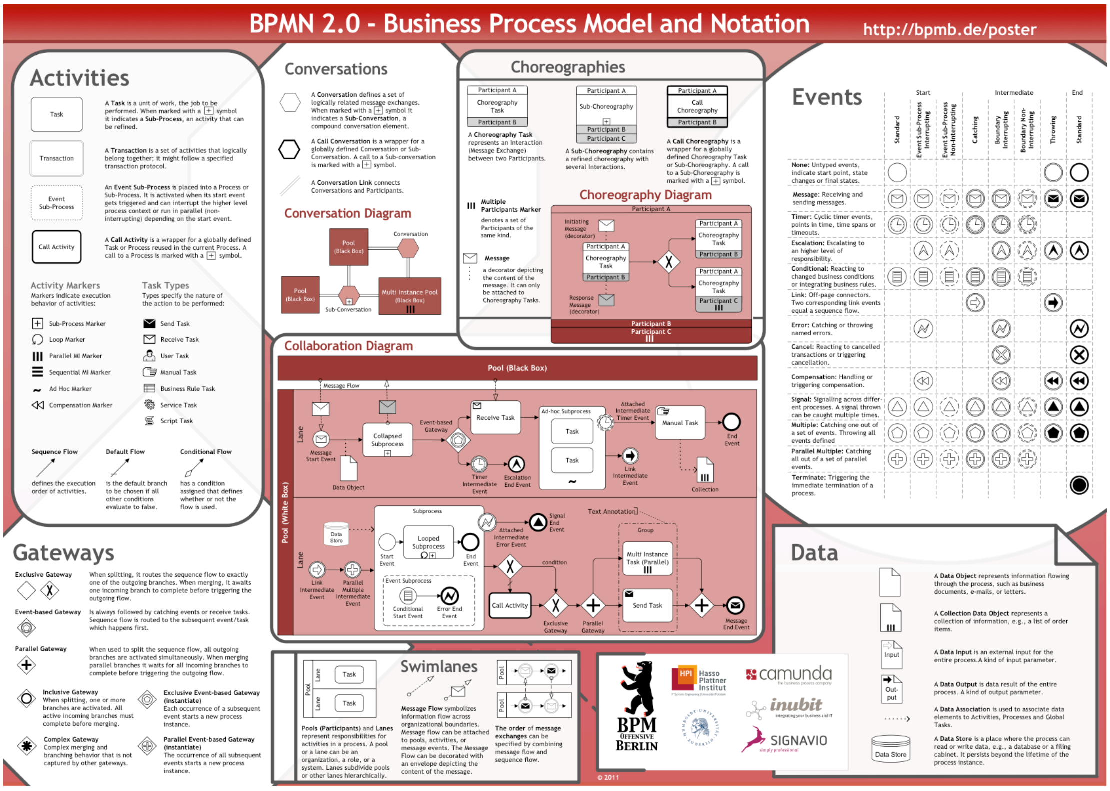


Figure 8 - BPMN 2.0 Notation (BPMN, 2009)

2.2. Manufacturing Systems and Strategies

Traditionally, supply chain strategies are often categorized as either push or pull strategies. This classification probably stems from the manufacturing revolution of the 1980s, in which manufacturing systems were divided into these categories (Ahn & Kaminsky, 2004).

Push type and pull type supply chain models are opposite in terms of a demand and supply relationship (Imaoka, 2008). In the most traditional type of supply chain, a push-based supply chain, production and distribution decisions are based on long-term forecasts, which leads to a slow reaction power to the changing marketplace. On the contrary, in a pull-based supply chain, production and distribution are demand driven, which allows the coordination with true customer demand rather than forecasted demand.

Pull systems tend to lead to a decrease in lead times, a decrease in system inventory, thus reducing inventory cost, a decrease in system variability and an increase in customer service levels. However, they make it more difficult to take advantage of economies of scale in manufacturing and transportation since systems are not planned far ahead in time (Ahn &

Kaminsky, 2004). Another disadvantage of pull systems is the incapability to fulfill an order in case the supplier sends a late shipment, since inventory levels are kept to a minimum.

Push systems, on the other hand, tend to lead to high inventory levels. Forecasts are often inaccurate as the sales tendency may vary over the time in an unpredictable manner, which may lead to overproduction or underproduction. However, in case forecasts are accurate, it is assured that costumer demand will be fulfilled.

Markets drive companies to a given manufacturing strategy, from a Make-to-Stock (MTS) approach on one end to an Engineer-to-Order (ETO) environment on the other, while Assemble-to-Order (ATO) and Make-to-Order (MTO) are "in between" strategies that cater to different customer needs (Dixon, 2009).

Table 1 describes the characteristics of each manufacturing strategy mentioned above.

Make-to-Stock (MTS)	**Assemble-to-Order (ATO)**	**Make-to-Order (MTO)**	**Engineer-to-Order (ETO)**
End item is stocked in fished goods.	“Pinch Point” subassemblies are stocked in process.	No finished goods or subassemblies are stocked.	No finished goods or subassemblies are stocked.
All raw materials and components are stocked.	All raw materials and components are stocked.	Possibly some raw material or components are not stocked.	One or more raw materials or components are not stocked.
Engineering is complete.	Engineering is complete, while configuration may need specification.	Minor one-off engineering may be required.	Significant engineering is required.

Table 1 - Manufacturing Strategies' Characteristics (Dixon, 2009)

Push-based supply chains are associated with the Make-To-Stock (MTS) strategy, while pull-based supply chains are associated with the Assemble-to-Order (ATO), Make-to-Order (MTO) and Engineer-to-Order (ETO) (Kaminsky & Kaya, 2007).

The advantages and disadvantages of push and pull supply chains have led companies to look for a new supply chain strategy that incorporates the best of both existing approaches. This hybrid approach is known as the *push-pull supply chain paradigm* (Simchi-Levi et al., 2003, cited by Ahn & Kaminsky, 2004), or combined MTO-MTS system, holding inventory of some components and producing others to order.

In addition to inventory decisions, the production scheduling of orders and the approach to lead time quotation to customers also have a strong impact on the performance of supply chains, particularly in MTO systems. Companies need to quote short and reliable lead times to their customers in order to remain competitive in the market and increase their profits. For a company that produces multiple products with different characteristics, the decision on when to produce each order affects not only the completion time of manufacturing but also the lead time for that product (Kaminsky & Kaya, 2007).

2.3. Production Planning and Scheduling

Nowadays, in order to prevail in the highly competitive economy, it is necessary to set up products in the market. The success relies on factors such as rapid reactions to market changes and a permanent strive for minimizing costs. In this context, better manufacturing schedules provide competitive advantage through minimized production cost and increased productivity (Chase et al. 2001, cited by Proença & Azevedo, 2003). In order to attain a competitive edge, goals such as optimization of capacities, minimization of lead times, compliance with deadlines and production flexibility should be supported by information systems oriented to operations management, know as production planning and control systems (PPC).

In general, PPC systems are responsible for scheduling and controlling the whole production process through the definition of order quantities, start and finish dates, and planning of routings for each order. One of the main goals of these systems is to co-ordinate the resources involved in fulfilling production orders. The planning process is based on descriptions of the products and of the required operations and resources, along with dynamic information concerning demand and capacities (Proença & Azevedo, 2003). Thus, it is possible to assert that while production planning consists of aggregate decisions with a tactical nature, scheduling has a more detailed and operational nature (Mehta, 2004). Although production planning and scheduling belong to different decision making levels in process operations, they are closely related since the result of planning problem is the production target of scheduling problem (Li et al., 2009).

The basic planning and scheduling problem at a manufacturing oriented company is to arrange customer orders in such a way the output of the production machines is maximized and the orders are delivered on time (Wanders, 2003), simultaneously guaranteeing that the work is completed as close as possible to its due date. Late work generates downstream delays, while early completion may be detrimental in case storage space is limited. It is also known that production planning and control manufacturing becomes more difficult with the increase of family products and the decrease in quantity (Proença & Azevedo, 2003).

Practical machine scheduling problems are numerous and varied. Their aim is to find sequences of jobs on given machines with the objective of minimizing job completion times. In a simpler version of those problems, flow shop scheduling, all jobs pass through all machines in the same order. A more complex case is represented by a job shop scheduling problem, where machine orderings can be different for each job. These scheduling problems are further characterized below.

2.3.1. Flow Shop Scheduling

Flow shop scheduling is one of the most important problems in the area of production management. In this type of problems there is a set of *m* machines and a set of *n* jobs. Each job comprises a set of *m* operations, which must be done on different machines and all jobs have the same processing operation order when passing through the machines. However, operations cannot be interrupted and each machine can only process one operation at a time. There are no precedence constraints among operations of different jobs.

The problem is to find the job sequences on the machines that minimize the makespan, i.e. the maximum of the completion times of all operations. Mean flow time, completion time variance and total tardiness can also be used on the objective function. In terms of computational complexity, the flow shop scheduling problem is NP-complete and thus it is usually solved by approximation or heuristic methods such as simulated annealing, tabu search and genetic algorithms.

2.3.2. Job Shop Scheduling

In the classical job shop scheduling problem, there is a set of *m* machines and a set of *n* jobs. Each job consists of a sequence of operations, each of which needs to be processed during an uninterrupted time period of a given length on a given machine. Each machine can process at most one operation at a time as in flow shop scheduling. However, it is assumed that any successive operations of the same job are processed on different machines, which consists in the main difference between job shop and flow shop scheduling (Šeda, 2007).

PPC systems may be developed in order to attend for a company's production planning and scheduling. However, due to the complexity of the mathematical models which support those systems and the lack of sufficient IT resources in most small and medium size manufacturing companies, sometimes it may be more reasonable to invest in a manufacturing scheduling software solution, best suited for operations that specialize in MTO or ATO systems. In Table 2, there is a list of ten recommended production planning and scheduling software systems currently available in the market (Singleton, 2014).

Software	**Supplier**
Fishbowl Inventory	Fishbowl
E2 Shop System	Shoptech Corporation
NetSuite Manufacturing Edition	NetSuite
One System ERP Solutions	Global Shop Solutions
Exact JobBOSS	Exact
M1	ECI
Exact MAX	Exact
EPICOR ERP	EPICOR
MIE Trak Pro	MIE Solutions
Infor SyteLine ERP	Godlan

Table 2 - Examples of Production Planning and Scheduling Software Solutions Available in the Market (Singleton, 2014)

2.4. Characteristics of the Process Industries

Process Industries are those where the primary production process are either continuous, or occur on indistinguishable batches of products, as opposed to discrete manufacturing. As an example, a food processing company producing sauce may produce the sauce in a continuous, uninterrupted flow from receipt of ingredients through packing, or batches may be produced depending on the cook kettle sizes but immediately combined and re-routed. Examples of process industries include food, beverages, chemicals, textiles, paper and paper products, among others (Institute of Industrial Engineers, 2014). There are a few characteristics regarding the manufacturing plant, products and production processes that generally apply to the process industries. Those characteristics are showed below.

2.4.1. Plant Characteristics

- Expensive and single purpose capacity leads to limited product variety and high volumes. Additionally, this leads to a flow shop oriented factory design.
- Long set-up times between different product types.

2.4.2. Product Characteristics

- Volume or weights are used, in contrast to discrete manufacturing that uses fixed entities.

2.4.3. Production Process Characteristics

- Processes have a variable yield and processing time.
- At least one of the processes deals with homogeneous products.
- The processing stages are not labor intensive.
- Production rate is mainly determined by capacity.

The combination of plant, product and process characteristics indicate that process industries have complex planning problems (Wanders, 2003).

2.5. Pareto Principle

For a very long time, the Pareto Law (the 80/20 Principle) has lumbered the economic scene like an erratic block on the landscape: an empirical law which nobody can explain.

Josef Steindl

The 80/20 principle asserts that a minority of causes, inputs or effort usually lead to a majority of the results, outputs or rewards. Therefore, this principle states that there is an inbuilt balance between causes and results, inputs and outputs, and effort and reward. A good benchmark for this imbalance is provided by the 80/20 relationship: a typical pattern will show that 80 per cent of outputs result from 20 per cent of inputs; that 80 per cent of consequents flow from 20 per cent of causes; or that 80 per cent of results derivate from 20 per cent of the effort. Figure 9 represents these typical patterns.

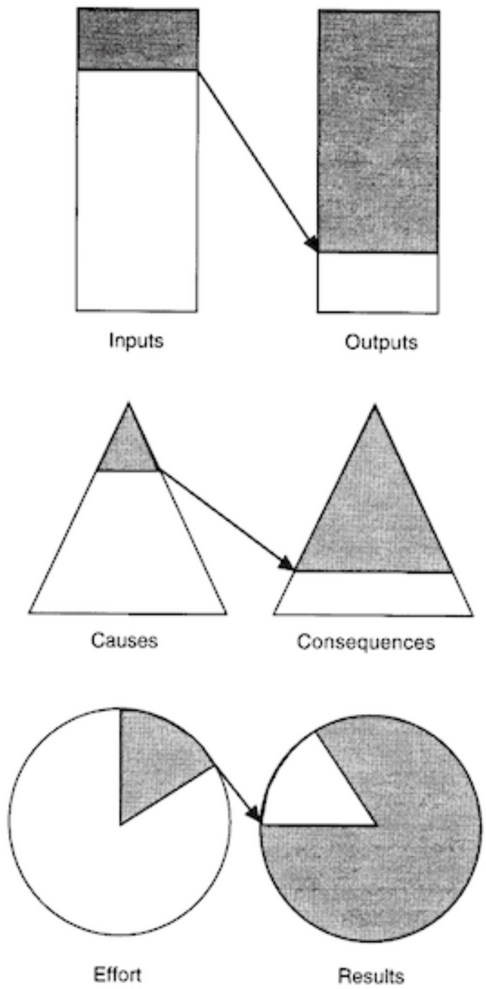


Figure 9 - Schematic Representation of the Pareto Principle

The pattern underlying the 80/20 Principle was discovered by Italian economist Vilfredo Pareto (1848-1923) in 1897. Since then, his discovery has been given many designations, including the Pareto Principle, the Pareto Law, the 80/20 Rule, the Principle of Least Effort and the Principle of Imbalance. In this dissertation the adopted designation is Pareto Principle.

The reason why the Pareto Principle is so valuable is that it is counterintuitive, given the tendency of assuming that 50 per cent of the causes or inputs will account for 50 per cent of results or outputs, meaning that causes and results are generally equally balanced. The Pareto Principle asserts that when two sets of data, relating to causes and results, are examined and analyzed, it is most likely that there will be a patter of imbalance, which may be 65/35, 70/30, 75/25, 80/20, 95/5, or any set of numbers in between.

In the business context, many examples of the Pareto Principle have been validated. 20 per cent of products usually account for about 80 per cent of sales value; so do 20 per cent of costumers. Also, 20 per cent of products or customers usually account for about 80 per cent of an organization's profits. As mentioned in the previous paragraph, it is necessary to keep in mind that the 80/20 relation is only a benchmark, and the real relationship may be more or less imbalanced than 80/20. However, the Principle asserts that in most cases the relationship is much more likely to be closer to 80/20 than to 50/50 (Koch, 1998).

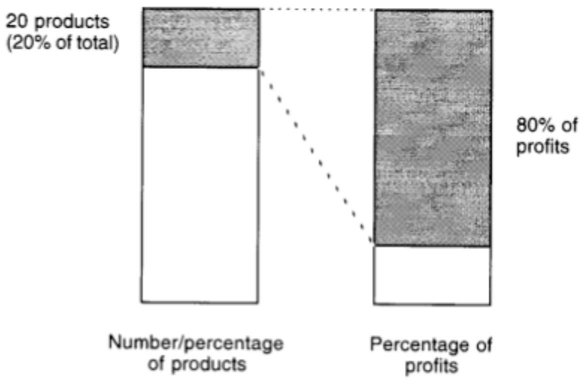


Figure 10 - 80/20 Pattern in Business

Also, the manufacturing volume for each product will most likely behave according to the Pareto's Principle, which means that usually, 20 percent of a company's products represent 80 percent of the company's manufacturing volume in a typical year (The Fabricator, 2009).

2.6. Lean Manufacturing

Lean Manufacturing, also known as Lean Enterprise or Lean Production is a management philosophy derived mostly from the Toyota Production System (TPS), which is renowned for its focus on reduction of the original Toyota seven wastes in order to improve overall costumer value (Womack et al., 1990). The steady growth of Toyota, from a small company to the world's largest automaker (Telegraph, 2014), has focused attention on how it has achieved its success.

The core idea of lean manufacturing is to improve efficiency, effectiveness and profitability by focusing relentlessly on eliminating all aspects of the manufacturing process that add no value from the costumer's perspective (Lean Production, 2014). Those aspects that do not add value to the manufacturing process are called waste. In Lean Manufacturing, there are eight categories of waste that should be monitored, seven from the original TPS system and one added by American experts as the concept became more accepted by mainstream business: overproduction, waiting, inventory, transportation, over-processing, motion, defects and non-utilized workforce (Stack, 2010).

Lean involves a fundamental paradigm shift from conventional "batch and queue" mass production, based on potential or predicted customer demands, to a product-aligned "one pierce flow" pull production in which production activities are rearranged in a way that processing steps of different types are conducted immediately adjacent to each other in a continuous flow. This shift requires highly controlled processes that are operated in a well maintained, ordered and clean environment that incorporates principles of employee-involved, system-wide and continual improvement.

Most organizations begin by implementing lean techniques and tools in a particular production area or facility, expanding the methods usage over time (United States Environmental Protection Agency, 2011).

There are a large number of tools that support lean thinking. However, a collection of 25 essential lean tools can be highlighted. Of this 25 essential lean tools there are a few of them who are most commonly used and play an extremely important role in waste reduction and the improvement of a company's global performance, namely: 5S, Bottleneck Analysis, Gemba (The Real Place), Jidoka (Automation), Just-In-Time, Kaizen (Continuous Improvement), Kanban (Pull System), Muda (Waste), OEE (Overall Equipment Effectiveness), PDCA (Plan, Do, Check, Act), SMED (Single Minute Exchange of Die), TPM (Total Productive Maintenance), VSM (Value Stream Mapping) and Visual Factory (Lean Production, 2014).

Of the above, the tools used in the scope of this dissertation are VSM and Visual Process Management. Therefore, a most accurate description of the mentioned tools and how they are used is provided below.

2.6.1. Value Stream Mapping

A Value Stream is the set of all actions, both value added and non value added, required to bring a specific product or service from raw material through to the costumer.

VSM is a simple diagram that seeks to map the value stream, representing every step involved in the material and information flows required to bring a product from order to delivery while identifying delays and non-value adding processes (Lean Enterprise Institute, 2002). In other words, VSM is an invaluable tool used to identify waste in day-to-day operations.

This lean manufacturing tool provides a top view of a company rather than a detailed look at the individual processes, making it one of the most powerful and user friendly mapping tools which can lead to a rapid and significant improvement to any business (Lean Manufacturing Tools, 2014).

The methodology adopted to map the current value stream consists of 9 steps, which are described below.

1. Gather Preliminary Information

In order to start the construction of the Value Stream Map, there is some information that needs to be collected such as a history of all the products manufactured the previous year and the manufacturing volume for each product manufactured the previous year.

The mentioned information will support the creation of a history of the product mix.

2. Identify and Quantify Products Families

A product family can be described as a group of products derived from a product platform, which use similar or same production processes, share similar physical characteristics and may share costumer segments, distribution channels and pricing methods, among other elements of the marketing mix (Business Dictionary, 2014). According to this methodology, the first step within VSM construction consists in identifying and listing the company's products that differ in function, form, fit and build. Referencing previous year's gathered data, the next step is to determine the production volume for each product family, or in other words, the percentage of production that each product family represents from the total number of units sold. Following the determination of the production volume, it is possible to identify the 20% of products that represent around 80% of the production. That mix will be what is important to map, since by mapping the 20% of the products that represent 80% of the production it is possible to identify and eliminate waste from those in-demand products so that a majority of the production becomes more efficient.

3. Sort Products Families by Build Sequence

The next step consists in building a process quantity routing analysis to identify which product families have a similar build sequence. This information enables the knowledge of what is being mapped through the flow of the involved operations.

Considering there are a variety of work centers through which the end products flow for processing, it is required to know what parts and products flow through each work centre and in what order. This helps seeing which products follow the same routing sequence that logically makes sense to group together. The result is having distinct product families that have nearly identical build sequences, which can be merged into groups of families.

4. Choose One Value Stream to Begin With

Once similar product families are grouped together as a value stream, it is necessary to identify the 80% of those family groups, which are important to map. In order to keep things simple, value streams should be mapped one at a time. Although this analysis is examining around 80% of the production volume, it might be useful to group together products or piece parts from the other 20% with different value streams. This could arise because products follow the same build sequence and have similar form, fit, and function. Despite considering the 80-20 rule, room for flexibility should be left when opportunities arise that are logical to include in the analysis.

To sum up, when choosing a value stream to start with, the impact that value stream has on the business unit should be considered, such as the highest percent of production volume, highest percent of sales volume, profit margins of individual products, most enthusiasm from the company, among others.

5. Create an Operations Flow Chart

Next, it is necessary to create a flow chart of all the operations in the value stream, referring to work order routings or the bill of materials for the product value stream as needed to identify the steps and create a starting point.

6. Walk the Shop Floor

When it is time to map the product family group, it is required to take a walk around the shop floor, through the steps of the value stream where the work is being processed, starting at the end of the process and working the way upstream to the beginning, in order to get a customer-supplier perspective at each step. This way, it is possible to observe any waste that is occurring and whether it is unnecessary or acceptable. A common mistake is to rationalize waste and assume it is happening due to a new operator in training or a new product design, as opportunities improvement identification will be missed. Also, the temptation of using data ran from the MRP system without stepping onto the shop floor should be avoided since that is a way of missing wasteful activity that the MRP system does not report.

7. Collect the Data

Although data collection is important, it is not at the expense of taking months to get something implemented. When applicable, time studies should be conducted and the results reviewed with the operators. If the operators and the team agree with the results, the collected data can be used to fill in the gaps of the data box. When the data is unavailable and it is impossible to conduct a time study, operators can be the best source for information.

Another option is to use data from similar jobs. Referring back to the process quantity routing analysis, similar part numbers in the value stream should be able to identify.

To take into account shared resources, the weighted average method should be used. Determine operator cycle time, machine cycle time, setup time, available shift hours and yield percentage.

8. Construct the VSM

The construction of the Value Stream Map should begin on a separate sheet of blank paper, using symbols to indicate what is happening at each process. The appropriate metrics should be measured at each step as they apply to the process, in order to provide a good picture of each process’ current status. Choosing the metrics depends on your process and the aim of the study, since the purpose of VSM is not data collection but to show where value is created and waste is accumulated.

Points of outsourcing are an important factor to include in the VSM. Therefore, all points of outsourcing in the process, whether due to capacity constraints or lack of adequate equipment must be identified.

Also, a VSM should show not only the flow of material, but also the flow of information. Information flow is often the cause for long lead times. When a VSM is created for everyone to see, people begin to understand that the problem does not lie in manufacturing alone.

9. Summarize the Data and Get the Big Picture

Once all the steps in the value stream are identified and the data filled, it is possible to analyze the flow through the process. In order to aid the search for waste, the process must be examined and one must wonder “If the customer were to walk through each step of this value stream with his check book in his hand, would he be willing to pay for each step he sees?”

In addition, by looking at the VSM, a list of kaizen opportunities identified in this process should be taken, followed by their prioritizing by level of impact an improvement would make to the value stream. This will be on the basis of the development of an organized plan of action from where to start making improvements to the value stream (The Fabricator, 2009).

Once the agreed version of the current state map is completed, the creation of the ideal and future state maps should take place.

The ideal state value stream map requires a firm understanding of lean manufacturing principles in order to enable the visualization of an ideal lean process. This would often be a single dedicated cell controlled through a pull kanban system rather than a grouping of shared processes, each scheduled from an MRP system pushing products onto the next process, with periodical deliveries to costumer and from supplier.

As it is widely difficult to transition straight from the current state to the ideal state, there is a need to develop a future state map to work towards on the journey to the ideal state. The future state map becomes the basis for an action plan, which can consist in standardizing and improving processes in order to improve cycle times and reduce defects, as well as other pressing issues from the business highlighted on the VSM (Lean Manufacturing Tools, 2014).

2.6.2. Visual Process Management Tools

Lean practitioners have developed visual process management tools as communication aids with the function of helping to drive operations and processes in real time (Parry &Turner, 2007).

Visual management can be displayed by the means of scoreboards, production control charts, team communication boards, among others. It keeps vital information flowing between managers and employees, as well as between cells and departments. This tool opens communication and information sharing within the lean enterprise.

Figure 11 - Example of a Visual Management Board (Lean Products, 2014)

Visual management applications may be used widely, including goal setting and performance tracking, scheduling and production control, idea sharing and team communication, and kaizen results and awards report, which are specified below.

Goal setting and performance tracking

Visual displays are intended for employees to know what is expected of them and they provide important feedback on how they are performing against those expectations. Hence, display boards are an invaluable tool in the quest for success as they indicate performance levels, preferably in real time.

Scheduling and production control

Using display boards also makes time and task management more efficient as employees get the relevant information related to schedules, work orders and due dates visually, cutting back on top-down supervision.

Idea sharing and team communication

Communication boards facilitate cooperative and collaborative team work, providing the right tool for a thought provoking and interactive environment, in which discussing around core problems is essential.

Report kaizen results and awards

Kaizen event teams benefit with visual display of outcomes and accomplishments, especially in the impossibility of face-to-face interaction (Brady, 2014).

2.7. Manufacturing Simulation

Nowadays, it is inconceivable to design and improve manufacturing processes without the support of advanced software. Integration of Computer-Aided-Design (CAD) and Computer-Aided-Manufacturing (CAM) is a key method of improving the quality of products and optimizing manufacturing times.

Simulation software is at the base of designing and improving flexible manufacturing systems (Gale, 2009). This type of software is based on the process of modeling a real phenomenon with a set of mathematical formulas. In other words, simulation software allows the user to observe an operation through simulation without actually performing that operation (Free Dictionary, 2014). There is an array of simulation software for manufacturing purposes in the market, each having its own advantages and disadvantages. In Table 3 there is a list of some simulation software available in the market (Robinson, 2004, cited by Gale, 2009).

Software	Supplier
Arena	Rockwell Automation
AutoMod	Applied Materials
Enterprise Dynamics	INCONTROL Simulation Solutions
ExtendSim	Imagine That
FlexSim	FlexSim Software Products, Inc.
Quest	Delmia Corporation
Micro Saint	Allion Science and Technology
ProModel	ProModel Corporation
ShowFlow	INCONTROL Simulation
Simul8	Simul8 Corporation

Table 3 - Examples of Manufacturing Simulation Software Solutions Available in the Market (2014)

Simulation involves designing a model of a system and carrying out experiments on it as it progresses through time. Models enable seeing how a real-world activity will perform under different conditions and test various hypotheses at a fraction of the cost of performing the actual activity.

One of the main benefits of a model is that it can start with a simple approximation of a process and gradually get more refined as the understanding of the process improves. This “step-wise refinement” enables the achievement of good approximations of very complex problems surprisingly quickly. As refinements are added, the model more closely imitates the real-life process (Extend Sim, 2014).

Of all the tools presented on Table 3, the chosen software used to prepare, setup and perform the simulation for the project one was Delmia/Quest Version V5-6R2013 due to its ease of familiarization.

Quest is an environment that allows the improvement of practices throughout the production design process. Its functionalities range from industrial engineering to manufacturing engineering and management development. The development, analysis and validation of Quest's simulation models provide an opportunity to visualize and improve the manufacturing process and to minimize problems and costs associated with unplanned facility startup.

Quest incorporates actual production variables such as length between particular machines and laborers' moving and operating speeds, as well as its acceleration and deceleration (Gale, 2009). With Quest, one can create virtual factories described in 2-D or 3-D formats. Quest contains pre-defined machines, parts, labor and conveyor elements that allow users to build an efficient simulation model. Within Quest models, users can also design the facility layout, process flow, staff schedules, machine's arrangement and incorporate ergonomic constraints.

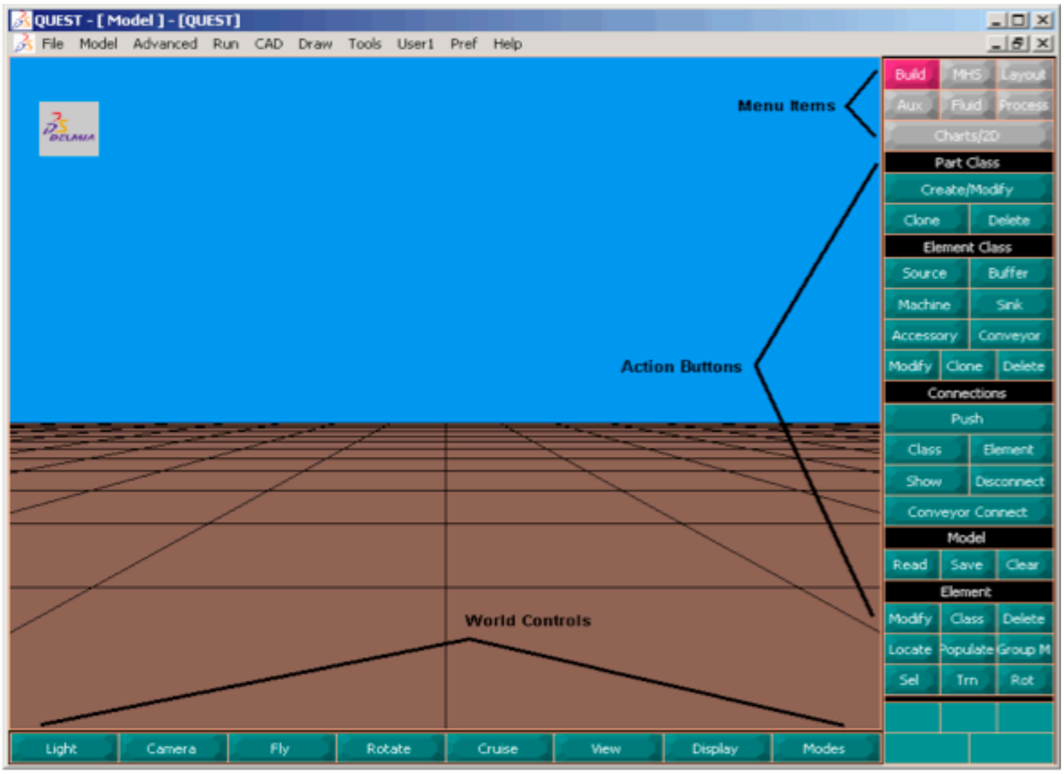


Figure 12 - Quest's Interface (Delmia Quest, 2006)

Simulation Control Language (SCL) or Batch Control Language (BCL) may be incorporated into the simulation model for more complex models.

In the end of the simulation, data can be extracted from the model and exported into other analysis tool such as Microsoft Excel (Bzymek et al., 2008).

Chapter 3

Case Study Description

In this chapter, the case study company[1] is characterized. Firstly, the company is presented with focus on its operational domain, business principles and background. Posteriorly, its organizational structure, manufacturing strategy, products and raw materials, production flow and information systems are summarily characterized in order to allow the perception of aspects mentioned throughout this dissertation.

3.1. Introduction

Established on October 1968, the case study company is Portugal's leader operating in the packaging with offset printing on cardboard and corrugated board domain. Some of the packages manufactured by the company can be seen in Figure 13.

Figure 13 - Examples of packages manufactured by the company

[1] Calheiros Embalagens, S.A.

The company employs around one hundred people and its headquarters, factory and warehouses are located in Ermesinde, Porto. It has a production area of 9.000 m^2 and 3.000 m^2 raw materials and finished goods warehouse.

In 2012, the organization accomplished approximately an 11€ million sales volume, as can be seen in Figure 14, obtaining the status of PME Leader on October 2012. Since then, its growth has continued, increasing sales volume by around 1.7€ million in 2013.

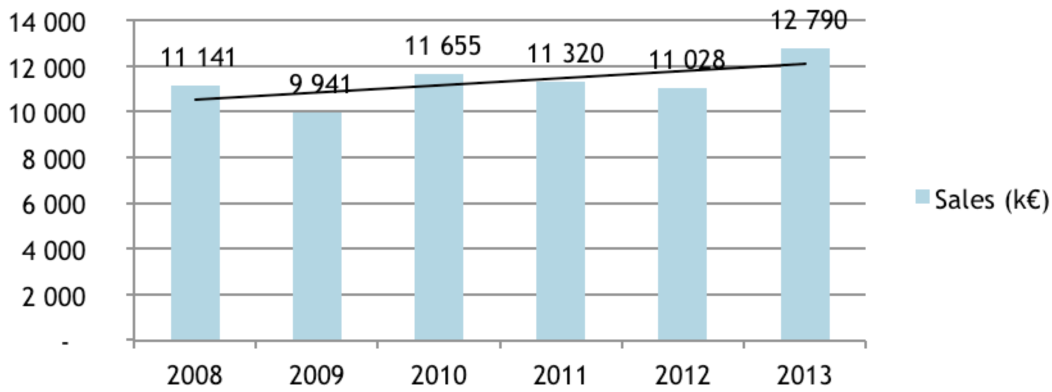


Figure 14 - Company's Sales Volume (k€)

The company holds a series of corporate business principles and associated policies concerned with activities related to consumers, employees, suppliers, customers and the environment and designed to guide the way in which the organization operates, which are the basis of the company's culture and aim to protect the trust of its consumers and other stakeholders. The main organization policy is associated with the continuous improvement of the Integrated Management System (Quality, Environment and Security), which is certified by the NP EN ISO 9001:2008, NP EN ISO 14001:2004 and OHSAS 19001:2007 standards.

The corporation works within the secondary sector of industry, creating and supplying products to costumers. It converts raw materials into finished goods for costumers to resort. Raw materials used in most of its products are sourced from the primary sector. As an example, most of the packages produced by the company contain cardboard sourced from paper suppliers around the world. The company operates on national and international markets, exporting its products to Germany, Spain, France, Morocco, Switzerland, Angola, Denmark and Sweden (2013).

3.2. Organizational Structure

The Organizational Structure Diagram of the corporation is presented in Figure 15.

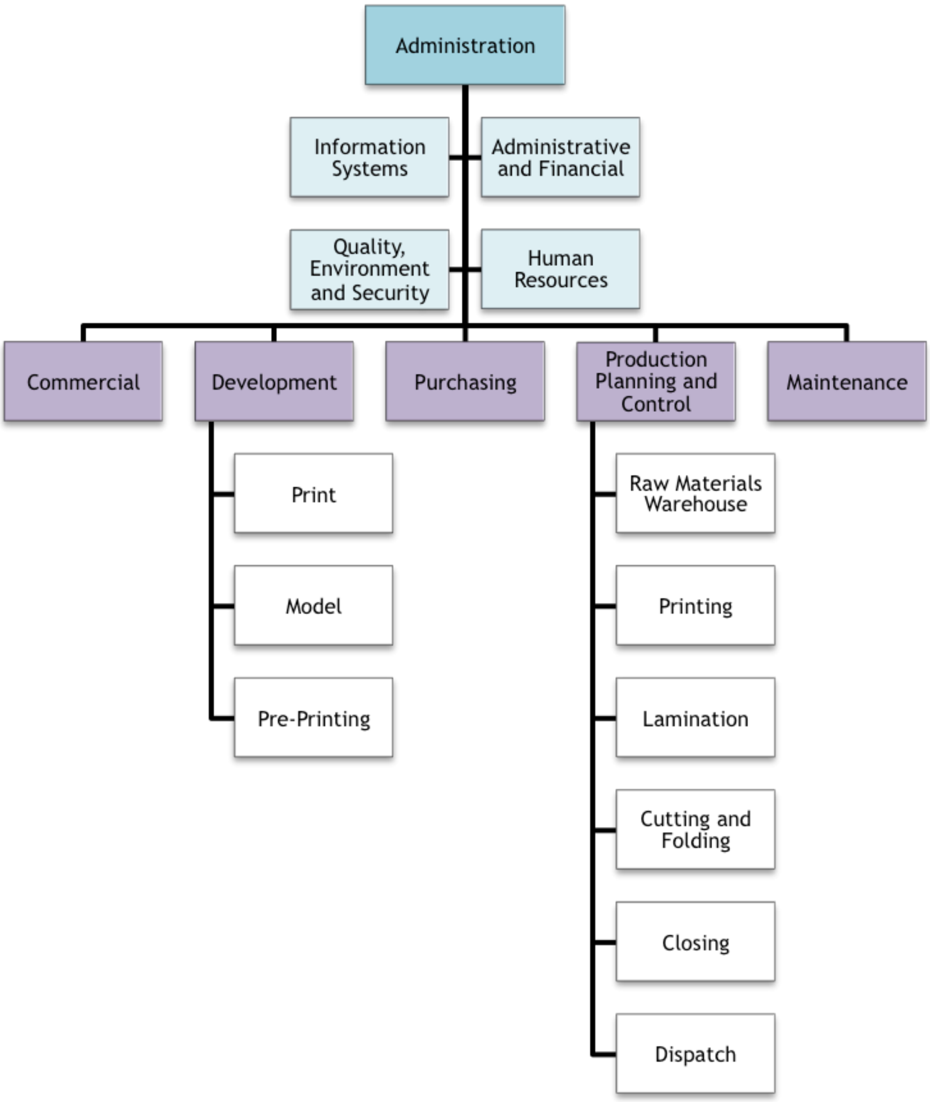


Figure 15 - Company's Organizational Structure Diagram

As may be seen in Figure 15, the company's organizational structure is essentially divided in five areas, represented by the purple rectangles: Commercial, Development, Purchasing, Production Planning and Control and Maintenance, which are managed by the company's Administration, exhibited in the top blue rectangle. The Information Systems Department, Quality, Environment and Security Department, Administrative and Financial Department and Human Resources Department (light blue) support the company's administration. The Development Department has the function of developing the products' Prints and Models. The Pre-Printing section, which is part of the Development Department, is responsible for developing or separating printing plates. Also, the Production Planning and Control Department is responsible for managing the sections involved in the manufacturing process: Raw Materials Warehouse, Printing, Lamination, Cutting and Folding, Closing and Dispatch.

3.3. Manufacturing Strategy

Due to extremely high product variety and customization, as each package is often provided with a unique print and model according to the costumer's specifications, the manufacturing strategy adopted by the company can be classified as Make-To-Order (MTO), meaning that the manufacturing process starts after a costumer order is received.

When a costumer places an order for a new package, the manufacturing process starts with the designing development of the package. In this case, the strategy approaches an Engineer-To-Order (ETO), since manufacturing starts with development planning. This strategy also applies to orders placed by existing costumers who require modifications on a package that has already been manufactured by the company.

On the other hand, if a costumer places an order for a package that has already been manufactured by the company, but without modifications, work is repeated. Therefore, as there is no need for designing development, the manufacturing process begins with the obtaining of raw materials and parts.

The packages are produced in bulk quantities, with each order containing from 500 to 1 million units, as opposite to discrete manufacturing, which categorizes this company into a process industry.

3.4. Products and Raw Materials

The understanding of the company's business specifications involves the characterization of the raw materials used in the manufacturing process, as well as the characterization of the products developed and manufactured by the company. Therefore, this section provides a description of the company's main raw materials and products.

3.4.1. Products

The company specializes in offset printed packaging manufacturing, in simple cardboard or corrugated board, with five distinct flute profiles. It also manufactures exhibitors and PLV packaging, although these are less common.

In the corrugated board domain, the flute profiles the company works with are as exposed in Table 4.

Designation	Flute profile	Height range (mm)
Minimicro	F Flute	0,8-1
Micro	E Flute	1,2-1,7
B Flute	B Flute	2,5-3
EE Flute	Double Flute	2,4-3,4
EB Flute	Double Flute	3,7-4,7

Table 4 - Company's Flute Profiles

Although the company is specialized in offset printed packaging, there is a percentage of costumers who place orders for packages without printing (Non-Printed Packages).

As each product is developed according to its costumer's specifications concerning prints and models, and the corporation's client portfolio ranges from extremely distinct industries, such as food industry, shoe industry, steel mill, among others, there is an extremely wide variety of characteristics among different orders.

3.4.2. Raw Materials

The main raw material used to produce packages consists of cardboard, which can be transformed into lining paper and corrugated paper.

Raw materials are ordered from suppliers around the world periodically, depending on the demand. The most commonly used raw materials are bought to stock, while the special raw materials are only bought when an order is placed.

Despite the existence of other materials involved in the manufacturing process, such as ink, glue and polish, the most significant raw material used by the company is cardboard.

In Figure 16, examples of raw materials used by the company are presented. On the left picture, cardboard used as lining paper is shown, while cardboard used to corrugate is shown on the right picture.

Figure 16 - Examples of Raw Materials used by the Company

3.5. Production Flow

In this section, the company's manufacturing Section Flow is represented (Figure 17) as well as its Production Flow (Figure 18). Subsequently, the relation between the two flows and the productive process is explained.

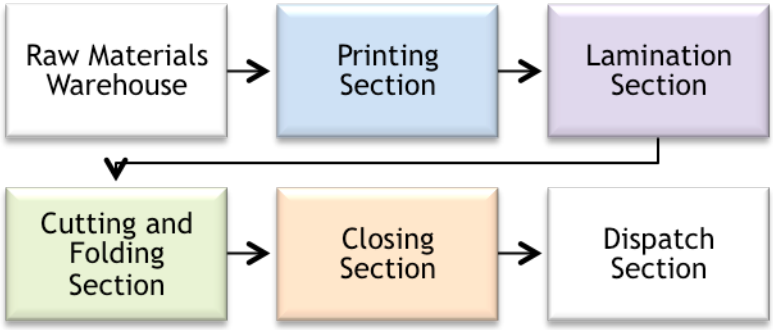


Figure 17 - Company’s Section Flow

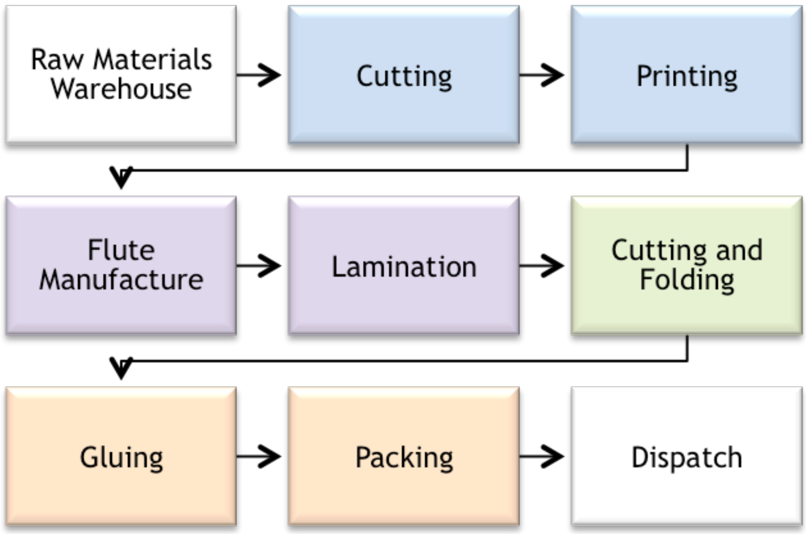


Figure 18 - Company’s Production Flow

According to Figure 17 and Figure 18, and as can be interpreted by the color code, Printing Section production steps consist of Cutting and Printing; Lamination Section production steps are Flute Manufacture and Lamination, while Closing Section is divided in Gluing and Packing steps.

The production process starts with the reception of the cardboard coils with the required characteristics for the order that is going to be processed, from the Raw Materials (RM) Warehouse. After their reception, the coils are put in the cutting machine where they are cut according to a stipulated length. Afterwards, the cut paper is inserted in the printing machine, which prints the respective design using an offset process. If color intensification and improvement of the image quality are required, an UV polish is applied after the printing.

The next step consists of flute manufacturing. The cardboard coils intended for corrugation, which are kept next to the flute-manufacturing machine, are put on the flute manufacture machine in order to produce the required flute. After the flute production is complete, the printed lining paper and flute are laminated and cut according to the linings paper’s length.

In the Cutting and Folding Section, a die cutting tool is introduced in the machines, which is pressed against the product, forming its original shape. Die cutting tools are designed and built according to the desired packaging format and are constituted by a series of blades attached to a wooden support.

Next, the product is transported to the Closing Section. In the gluing machine, packages are glued so that it is easier for them to acquire their final form. In the packaging zone, workers place the final product in pallets so that it can be dispatched.

Afterwards, pallets are moved to the Dispatch Section, where they are shipped to the costumer.

The process described above refers to the complete production flow. However, there are some order types that do not require the performance of all the above steps, which are listed below:

- Orders for packages that are not printed are moved directly from the Cutting Machine to the Flute Manufacturing Machine.

- Orders for packages that are not corrugated are transported directly from the Printing Machine to the Cutting and Folding Machine.

- Orders for packages that are not glued are transported from the Cutting and Folding Section to the Packaging zone.

3.6. Information Systems

There are two major integrated information systems available in the company: *Primavera* ERP and *Planificação*. The ERP system, *Primavera*, is a business software solution developed and commercialized by Grupo Primavera SGPS (Primavera, 2014), which consists of a platform that supports order management, stock management, shipment orders and financial and accounting aspects, including billing. This system is back office oriented.

The system used to support production planning and control, also known as *Planificação*, was developed internally in response to the need to trace products as they flow through the manufacturing process. There is an additional system developed internally, named Plan2013, which aids production planning by providing means for capacity evaluation required to establish the due date associated to each order. Plan 2013 is integrated with *Planificação*.

Chapter 4

Business Characterization

In this chapter, a characterization of the company's business is presented, focusing on its business processes, which are modeled and provided with a detailed description. Customer Oriented Core Processes are depicted, as well as Production Planning and Control Processes. Posteriorly, a value stream analysis is conducted through Value Stream Maps built based on a family product analysis. Those process models and value stream maps integrate the company's As-Is Model, enabling the detection of restraining aspects and improvement opportunities. Finally, the production cycles mechanism implemented in the company is presented, as well as a brief analysis of raw materials.

4.1. As-Is Model

4.1.1. Processes Models

The Level 0 process models developed in the scope of this dissertation consist of activity sequencing diagrams. In turn, the developed Level 1 process models are an adaptation from Responsibility Assignment Matrixes integrated with phases and activity sequencing, as shown in Chapter 2. In the adopted representation, the main process phases and activities are presented horizontally at the top. Process phases are sequenced at a first level, followed by phases' activities, which are sequenced at a second level. Process actors, which may include people, departments, factory sections, warehouses and software, are shown vertically on the left axis. Phases and/or activities are connected to actors using dots. Those dots are grey in case the actor represents software to support the process. Actors are highlighted according to their category. The adopted color code is presented in Table 5.

Actor Category	Color
Customer	
Departments and Sub-Departments	
Sections	
Software	
Supplier	
Warehouses	

Table 5 - Actor Categories' Color Code

4.1.1.1. Customer Oriented Core Processes Model

Figure 19 depicts a conceptual diagram of the Customer Oriented Core Processes Model. Customer oriented core processes are processes that directly create value to the customer.

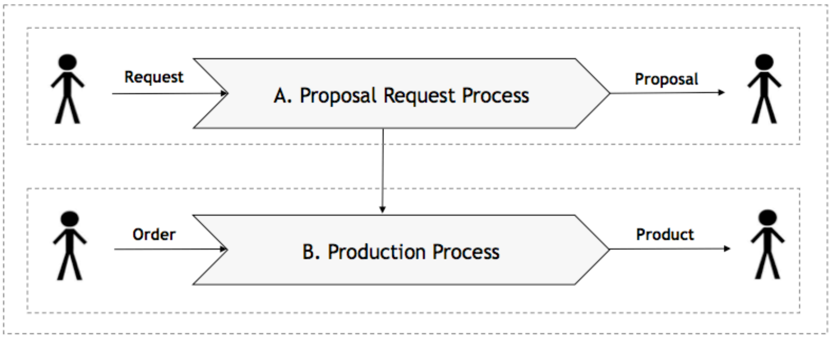


Figure 19 - Customer Oriented Core Processes Conceptual Model

The process starts when the customer places a request, which is the input to the Proposal Request Process (A). After this process is complete, a proposal is originated and submitted to customer's approval. Once the approval is obtained, the proposal becomes an order, which is the input to the Production Process (B). The production process output is the final product that is then delivered to the customer.

In the adopted representation, the Proposal Request Process and the Production Process are mapped individually so that more emphasis on each process may be provided.

1. Level 0 Customer Oriented Core Processes Model

The Level 0 Customer Oriented Core Processes Model consists of a more detailed version of the costumer oriented core processes conceptual model shown in Figure 19. Level 0 model is show in Figure 20.

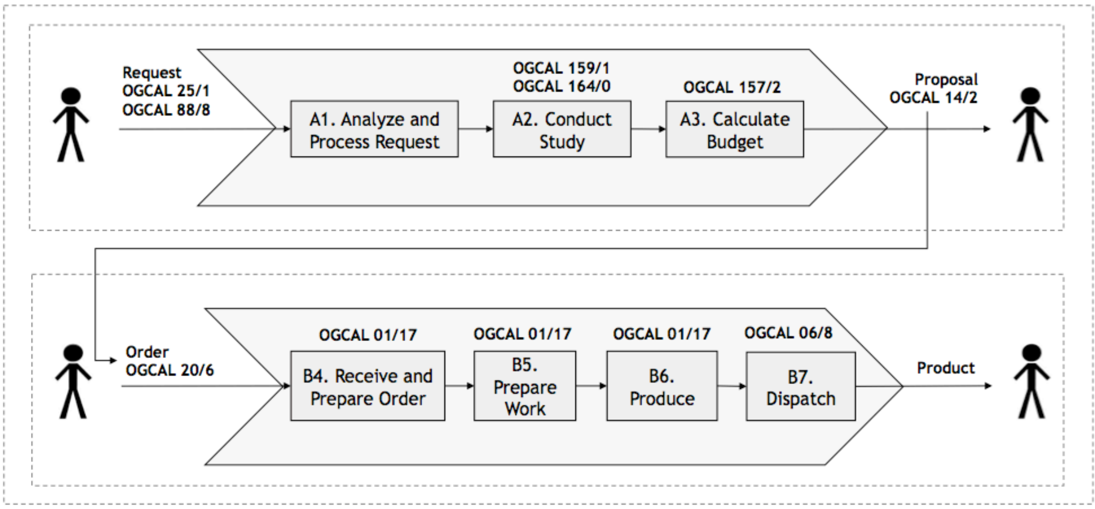


Figure 20 - Level 0 Customer Oriented Core Processes Model

Based on Figure 20 analysis, it can be seen that the Proposal Request Process (A) is divided into three phases: Analyze and Process Request (A1), Conduct Study (A2) and Calculate Budget (A3). In turn, the Production Process is divided in four phases: Receive and Prepare Order (B4), Prepare Work (B5), Produce (B6) and Dispatch (B7).

OGCAL 25/1, OGCAL 88/8, OGCAL 159/1, OGCAL 164/0, OGCAL 157/2, OGCAL 14/2, OGCAL 20/6, OGCAL 01/17 and OGCAL 06/8 represent physical documents that are created by the company in order to accompany the processes' phases. Those documents may also be a result of the corresponding phase completion. All the mentioned documents are available for consultation in Appendix 2.

2. Level 1 Customer Oriented Core Processes Model

Level 1 Customer Oriented Core Processes Model provides a more detailed description of each process' phases.

The Level 1 Customer Oriented Core Processes Model for the Proposal Request Process (A) is presented in Figure 21, while Level 1 Customer Oriented Core Processes Model for the Production Process (B) is presented in Figure 22.

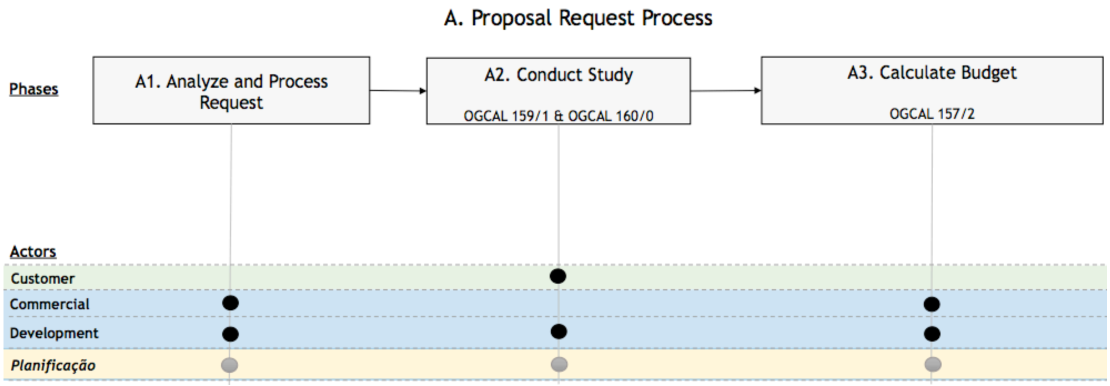


Figure 21 - Level 1 Customer Oriented Core Processes Model (Proposal Request Process)

In this representation, actors for each process phase are depicted. Based on Figure 21 it is possible to observe that phases A1 and A3 are performed by the Commercial and Development Departments, supported by *Planificação* system. As a result of A3 phase completion, OGCAL 157/2, which consists in the budget, is issued. In turn, phase A2 is performed by the Customer and the Development Department. This phase is also supported by *Planificação* system. OGCAL 159/1 and 164/0 are the documents used to accompany this process' phase.

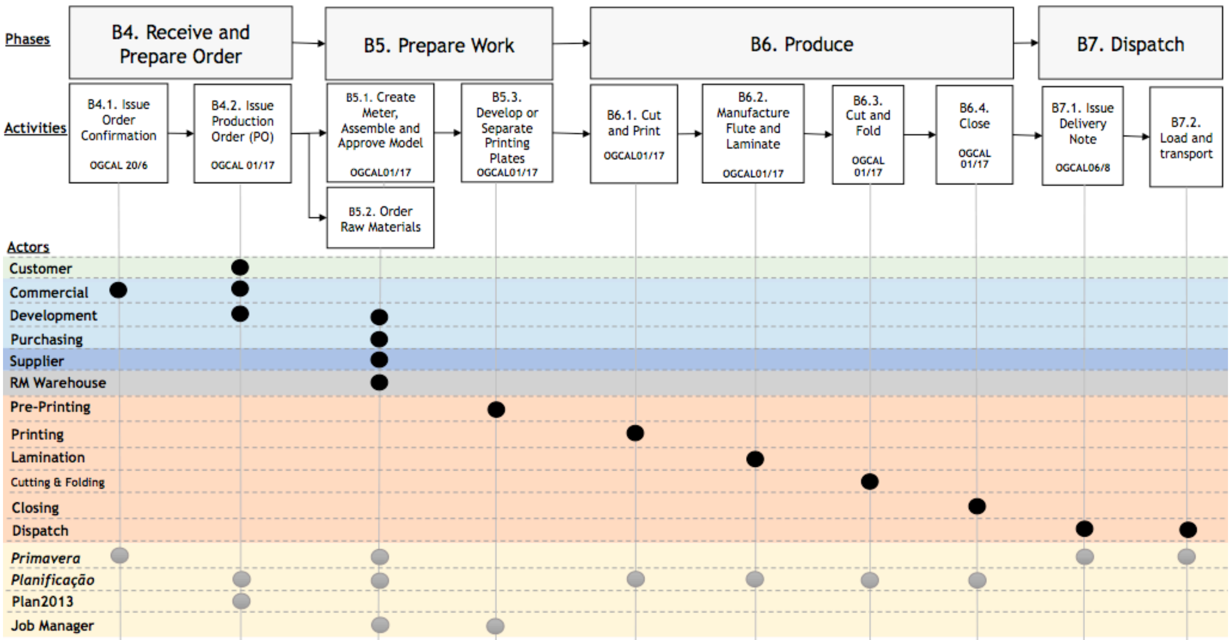


Figure 22 - Level 1 Customer Oriented Core Processes Model (Production Process)

Based on Figure 22, it is seen that each process phase of the production process was further divided into activities due to its complexity and high level of detail. The production process' first phase, Receive and Prepare Order (B4), has two main sequential activities: Issue Order Confirmation (B4.1) and Issue Production Order (B4.2). In Figure 22 it can be read that B4.1 activity is performed by the Commercial Department and supported by *Primavera* system, while activity B4.2 is performed by the Customer and the Commercial and Development Departments and supported by *Planificação* and Plan2013 systems. As a result of B4.1 activity, document OGCAL 20/6, which consists of the Order Confirmation, is issued. OGCAL 01/17, which consists of the Production Order that will follow the order along its productive flow, is originated as a result of B4.2 activity.

The second phase, Prepare Work (B5) has three main activities: Create Meter, Assemble and Approve Model (B5.1), Order Raw Materials (B5.2) and Develop or Separate Printing Plates (B5.3). Activities B5.1 and B5.2 are performed in parallel by the Development and Purchasing Departments, supported by *Primavera*, *Planificação* and Job Manager systems. The Supplier and RM Warehouse are also performers in this activity. In turn, the Pre-Printing Section conducts B5.3 activity with the aid of Job Manager software. As shown in Figure, the PO (OGCAL 17/1) accompanies the order through activities B5.1 and B5.3, which are performed sequentially.

The next phase, Produce (B6), is divided in four main sequential activities that correspond to the production section flow: Cut and Print (B6.1), Manufacture Flute and Laminate (B6.2), Cut and Fold (B6.3) and Close (B6.4). Each of those activities is performed by its respective section: B6.1 is performed by Printing, B6.2 is conducted by Lamination, B6.3 is conducted by Cutting & Folding, while Closing Section conducts B6.4. *Planificação* system supports all those activities. As in B5, the PO accompanies the order through all the productive steps.

Finally, the Dispatch (B7) phase is divided in two sequential activities: Issue Delivery Note (B7.1) and Load and Transport (B7.2). B7.1 and B7.2 are both conducted by Dispatch Section with the aid of *Primavera* ERP. OGCAL 06/8 corresponds to the Delivery Note that is issued after B7.1's completion.

4.1.1.2. Production Planning and Control Process Model

In this section, Level 0 and Level 1 Production Planning and Control Processes Models are presented. The Production Planning and Control Process consist of all the planning steps performed since the proposal is placed until the dispatch plan is defined. Its' conceptual model is shown in Figure 23.

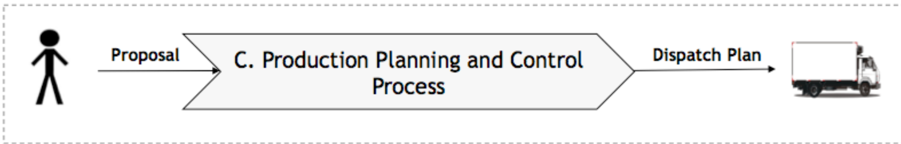


Figure 23 - Production Planning and Control Process Conceptual Model

The process starts when a Proposal is generated, which is the input to the Production Planning and Control Process, and ends with the emission of a Dispatch Plan.

1. **Level 0 Production Planning and Control Processes Model**

Level 0 Production Planning and Control Processes Model, which consists of a more detailed version of its conceptual diagram, is shown in Figure 24.

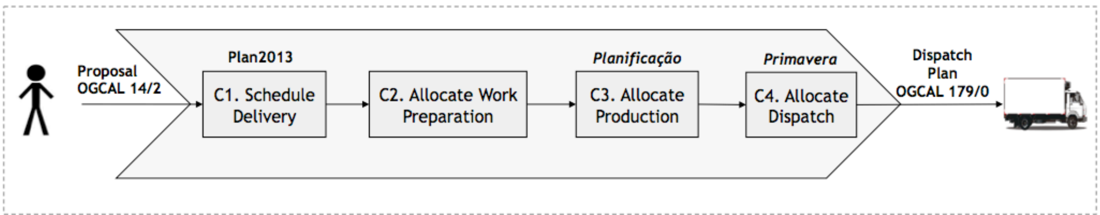


Figure 24 - Level 0 Production Planning and Control Process Model

Four main phases in the Production Planning and Control Process (C) were identified: Schedule Delivery (C1), Allocate Work Preparation (C2), Allocate Production (C3) and Allocate

Dispatch (C4). Software that supports the Planning and Control Process (Plan2013, *Planificação* and *Primavera* ERP) is specified on top of each phase.

2. Level 1 Production Planning and Control Process Model

Level 1 Production Planning and Control Process Model is presented in Figure 25.

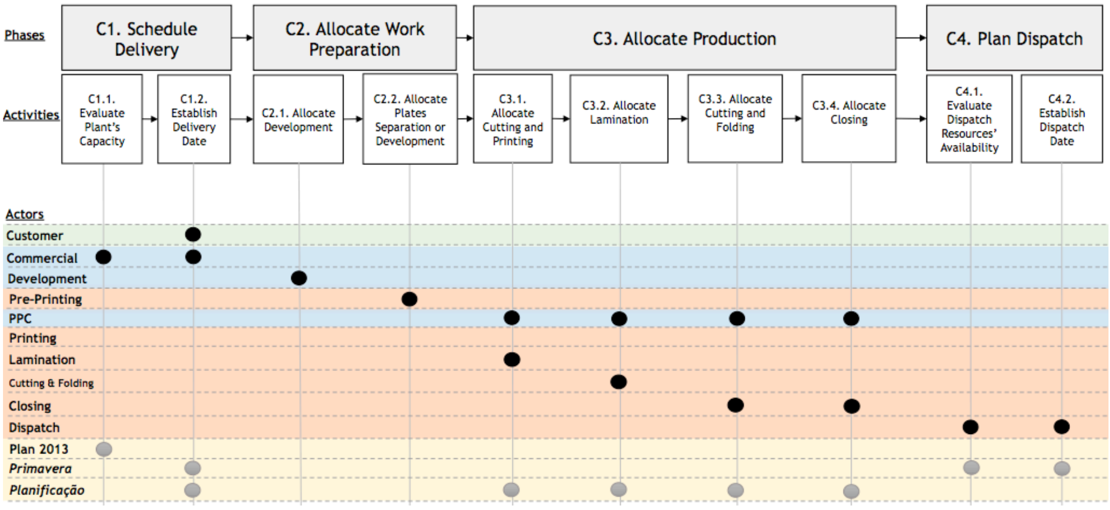


Figure 25 - Level 1 Production Planning and Control Process Model

The first phase, Schedule Delivery (C1), has two main sequential activities: Evaluate Plant's Capacity (C1.1) and Establish Delivery Date (C1.2). C1.1 activity is conducted by the Commercial Department and is supported by Plan2013 software. In turn, activity C1.2 is performed by the Customer and the Commercial Department and is supported by *Primavera* and *Planificação* systems.

The next phase, Allocate Work Preparation (C2) is divided into two activities performed sequentially: Allocate Development (C2.1) and Allocate Plates Separation or Development (C2.2). C2.1 and C2.2 activities are performed manually, therefore there is no IT system supporting them.

Allocate Production (C3) is divided into four main activities performed sequentially that correspond to the allocation of work along each production section: Allocate Cutting and Printing (C3.1), Allocate Lamination (C3.2), Allocate Cutting and Folding (C3.3) and Allocate Closing (C3.4). Each of these activities is performed by its respective section: C3.1 is performed by Printing, C3.2 is conducted by Lamination, C4.3 is conducted by Cutting & Folding, while Closing Section conducts C3.4. PPC Department also performs all those activities, supported by *Planificação* system.

Finally, the Plan Dispatch (C4) phase is divided into two sequential activities: Evaluate Dispatch Resources' Availability (C4.1) and Establish Dispatch Date (C4.2). These activities are both conducted by Dispatch Section and supported by *Primavera* ERP.

4.1.1.3. Detailed Description of the Modeled Processes

In this section, a detailed description of the Customer Oriented Core Processes and Production Planning and Control Processes is provided. Although these two major groups of processes were modeled independently, it is necessary to keep in mind that they happen sequentially and following the same timeline, which allows grouping them into a conceptual model that shows the sequence in which they occur. The sequential description of the Customer Oriented Core Processes and Production Planning and Control Processes enables a full comprehension of how the company operates. The conceptual diagram is presented in Figure 26.

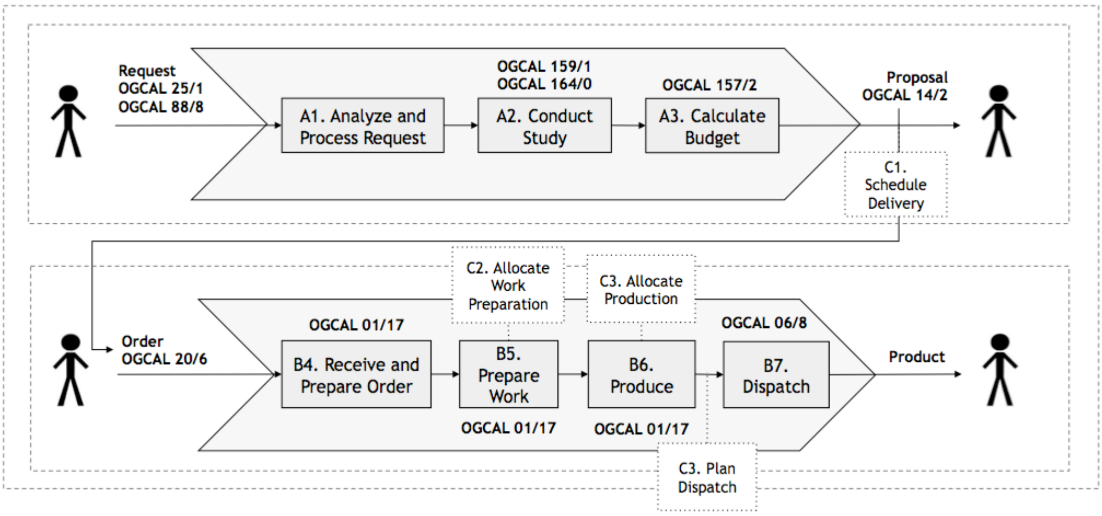


Figure 26 - Level 0 Conceptual Diagram of the Integration Between Customer Oriented Core Process and the Production Planning and Control Process

In order to simplify the processes description, only the highest-level activities or phases of each process (A, B and C) are described, with the exception of the "Allocate Production (C3)" phase, which is described in two levels. Therefore, in order to illustrate the processes detailed description, it may be necessary to consult Figure 22 and Figure 25.

Request

The process starts when the customer places a request, which can be done verbally (by telephone), in person or by e-mail. If the request is placed through a commercial agent, following a meeting, the documents used to register the specifications of the request are OGCAL 25/1 and OGCAL 88/8. Despite the various means available for placing a request, the Commercial Department must formalize all requests by e-mail.

A1. Analyze and Process Request

In this stage, after its e-mail formalization, the request is registered in the *Planificação* system by the Commercial Department. In order to do so, a product file is created and its general specifications are filled in the respective spaces, with the Development Department's aid. In Figure 27, a print screen of the *Planificação* interface is presented.

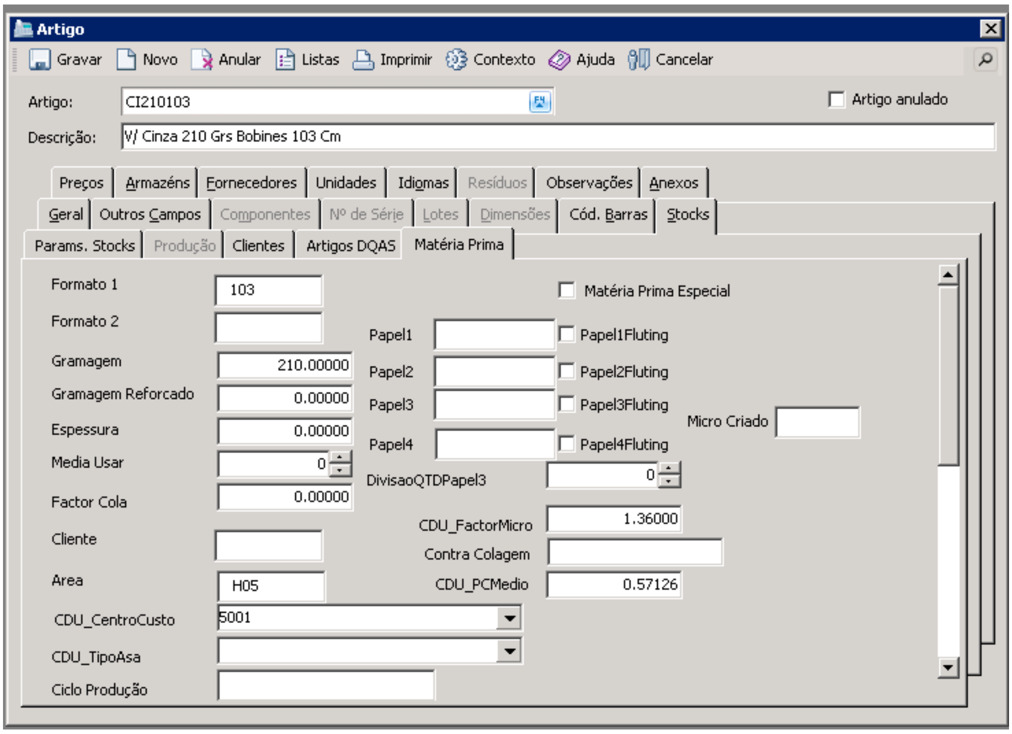


Figure 27 - *Planificação*'s Interface (Analyze and Process Request)

A2. Conduct Study

After the request's analysis and processing, a need for a study concerning the requested product's design may incur. In this case, the Development Department conducts a study concerning the product's print, the product's model, or both. The company's internal documents used to accompany this activity are OGCAL 164/0 (print) and OGCAL 159/1 (model).

In case the product is repeated, there is no need to perform this activity. Another situation when this activity may be skipped is if the customer provides his own product design.

A3. Calculate Budget

Budget calculation is supported by *Planificação* system and conducted by the Commercial and Development departments. In order to perform this step it is merely necessary to introduce the requested product's complete specifications as the calculation is automatically computerized. *Planificação* system's interface is shown in Figure 28.

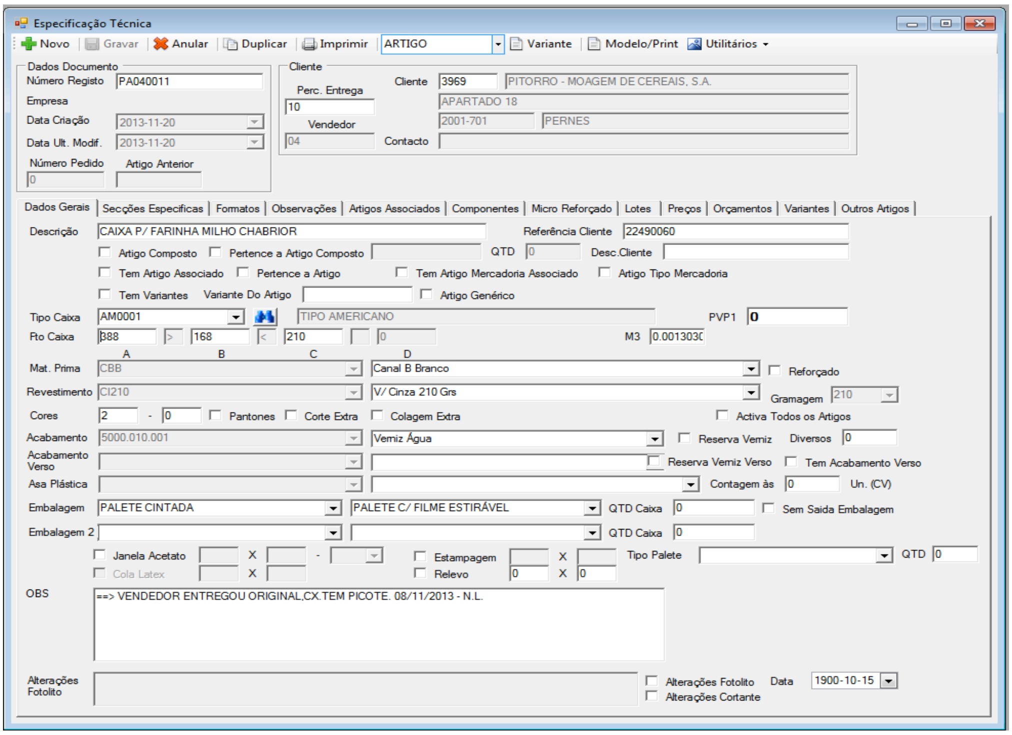


Figure 28 - *Planificação*'s Interface (Calculate Budget)

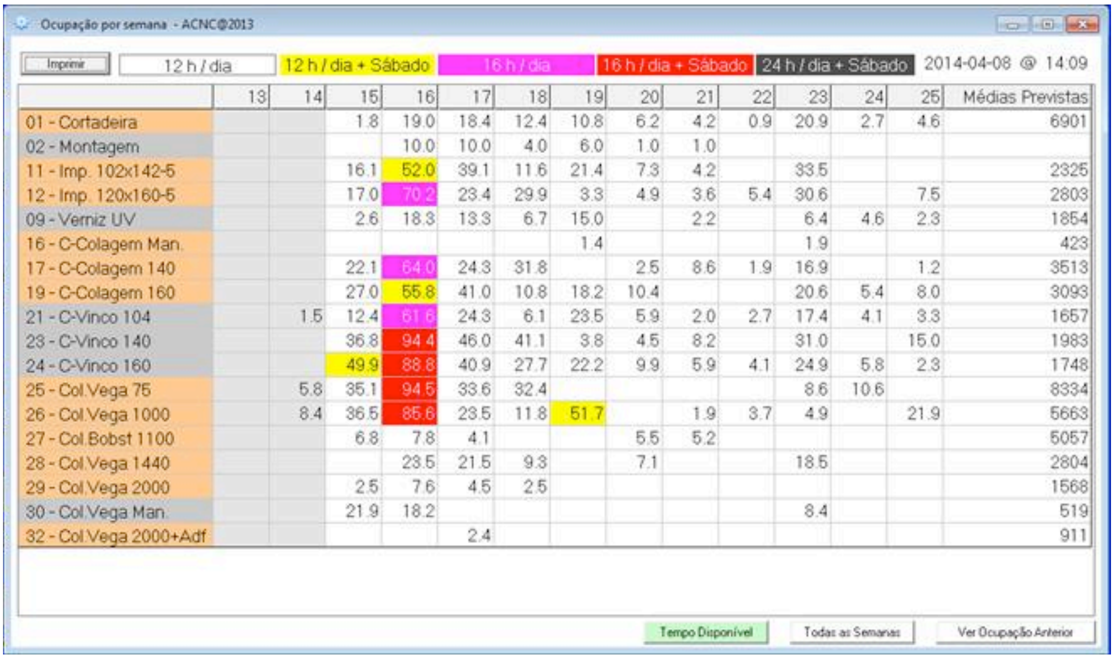
In budget's calculation, it is required to estimate the necessary raw material's quantity in order to produce the requested product's quantity. The estimation of the quantity of raw materials to order is done considering raw material's waste in set-up and raw material's waste in production, which are based on medium values collected over a designated period of time. The calculation is done from the last stage of the productive flow (Closing) to the first (Cutting). After the budget is calculated, OGCAL 157/2 (Budget) is issued.

Proposal

After the budget's calculation, a proposal (OGCAL 14/2) is presented to the customer. This proposal is constructed in *Primavera* ERP, which is integrated with *Planificação* System. When a proposal is presented, the delivery's date is not yet defined.

C1.1. Evaluate Plant's Capacity

After the approval of the budgeted proposal, an evaluation of the available resources in the manufacturing plant is performed so that delivery date can be scheduled. This capacity evaluation is performed by the Plan2013 system, which is integrated with *Planificação*. Plan2013 shows the resources actual occupation based on machine's production rate, mean values and confirmed orders currently registered in the system. After the consultation of Plan2013, a delivery date is concerted with the customer.



	13	14	15	16	17	18	19	20	21	22	23	24	25	Médias Previstas
01 - Cortadeira			1.8	19.0	18.4	12.4	10.8	6.2	4.2	0.9	20.9	2.7	4.6	6901
02 - Montagem				10.0	10.0	4.0	6.0	1.0	1.0					
11 - Imp. 102x142-5			16.1	52.0	39.1	11.6	21.4	7.3	4.2		33.5			2325
12 - Imp. 120x160-5			17.0	70.2	23.4	29.9	3.3	4.9	3.6	5.4	30.6		7.5	2803
09 - Verniz UV			2.6	18.3	13.3	6.7	15.0		2.2		6.4	4.6	2.3	1854
16 - C-Colagem Man.							1.4				1.9			423
17 - C-Colagem 140			22.1	64.0	24.3	31.8		2.5	8.6	1.9	16.9		1.2	3513
19 - C-Colagem 160			27.0	55.8	41.0	10.8	18.2	10.4			20.6	5.4	8.0	3093
21 - C-Vinco 104		1.5	12.4	61.6	24.3	6.1	23.5	5.9	2.0	2.7	17.4	4.1	3.3	1657
23 - C-Vinco 140			36.8	94.4	46.0	41.1	3.8	4.5	8.2		31.0		15.0	1983
24 - C-Vinco 160			49.9	88.8	40.9	27.7	22.2	9.9	5.9	4.1	24.9	5.8	2.3	1748
25 - Col.Vega 75		5.8	35.1	94.5	33.6	32.4					8.6	10.6		8334
26 - Col.Vega 1000		8.4	36.5	85.6	23.5	11.8	51.7		1.9	3.7	4.9		21.9	5663
27 - Col.Bobst 1100			6.8	7.8	4.1			5.5	5.2					5057
28 - Col.Vega 1440				23.5	21.5	9.3		7.1			18.5			2804
29 - Col.Vega 2000			2.5	7.6	4.5	2.5								1568
30 - Col.Vega Man.			21.9	18.2							8.4			519
32 - Col.Vega 2000+Adf					2.4									911

Figure 29 - Plan 2013's Interface

C1.2. Establish Delivery Date

In case the order is urgent, its delivery date is anticipated as most as possible, considering the costumer's relevance and the availability of the manufacturing plant's resources. If the order is not urgent, its date is scheduled accounting for the customer's preference and the availability of the manufacturing plant's resources.

Order

After the proposal's approval and the delivery date scheduling, the proposal becomes an order.

B4.1. Issue Order Confirmation

In this step, an order confirmation (OGCAL 20/6) is issued in *Primavera* ERP.

B4.2. Issue Production Order

Once an order is confirmed, a production order (OGCAL 01/17) is issued in the *Planificação* system, and posteriorly printed. A conceptual model of a PO is show in Figure 30.

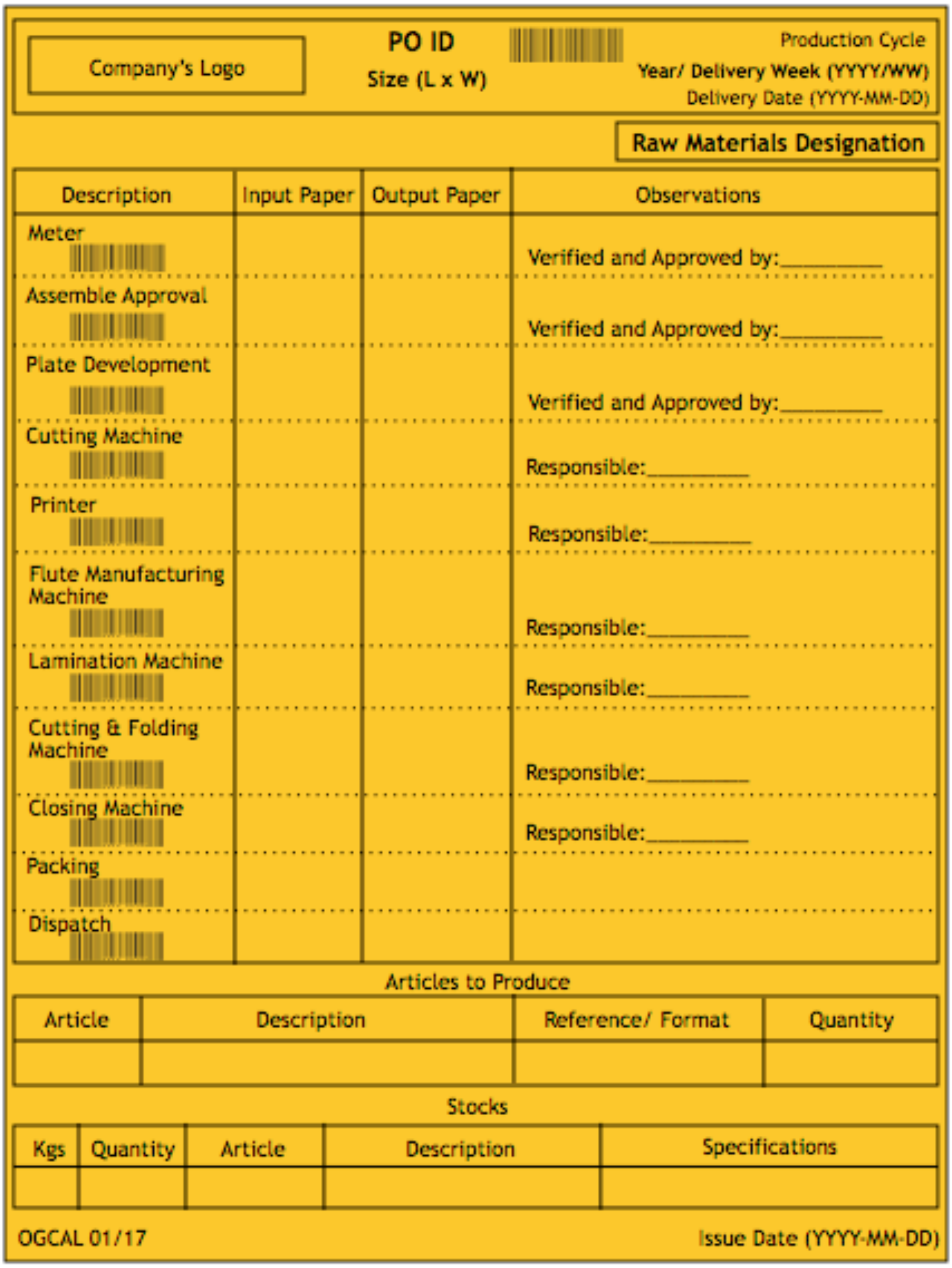


Figure 30 - Conceptual Model of a Production Order (PO)

The production order consists of a yellow sheet that follows the order along its whole productive flow. Although the PO information is registered in the information system and available for employees of all departments and sections, nothing is produced without the physical PO.

The PO groups information from the scheduling and budgeting activities. In the PO, every stage of the productive flow is presented, followed by the quantity of paper it requires. Specifications associated with each stage are also provided, followed by an empty space for the chiefs of departments and sections to sign once work in their departments and sections is finished. Issue and delivery dates are also presented.

Once the PO is printed, the Commercial Department transports it to the upstream section, which is the Development Department.

C2.1. Allocate Development

The Development Department performs development work's allocation. Work (POs) is ordered manually uniquely by its delivery date, in ascending order.

B5.1. Create Meter, Assemble and Approve Model

The Development Department creates the model's meter, which is available in software Job Manager. Then, an internal approval, as well as a customer's approval is performed. When work in this department is finished, the PO is signed by the department chief and the information regarding this department's work conclusion updated in *Planificação*. Then, the chief of department delivers the PO in the upstream section (Pre-Printing Section).

B5.2. Order Raw Materials

All the POs created by the Commercial Department are stored under a list in *Planificação* software. The Purchasing Department collects that list three times a week, on Mondays, Wednesdays and Fridays, using *Primavera* ERP, which is integrated with *Planificação*.

The Purchasing Department's function consists in processing the PO list with the purpose of allocating raw materials to their production site. The basic operation of the Purchasing Department is the following:

- If the customer's order requires a special type of raw materials, the Purchasing Department orders raw materials from the respective suppliers. Raw Materials are then delivered to the RM Warehouse.

- If the customer's order requires an ordinary type of raw materials:

  - If there are enough raw materials in the RM Warehouse, the Purchasing Department issues a request for collection of raw materials in the warehouse.
  - If the supplier has the required raw materials in stock, the Purchasing Department requests a shipment. The raw materials are then received in the RM Warehouse.

B5.1 and B5.2 activities may be performed in parallel, since they are both triggered by the creation of POs. However, it is necessary to keep in mind that while B5.1 can only be started after the physical PO's arrival, activity 5.2 is done by computerized means.

C2.2. Allocate Plates Development or Separation

Like the Development Department, the Pre-Printing Section orders work (POs) manually uniquely by its delivery date, in ascending order.

B5.3. Develop or Separate Printing Plates

If work is new or with changes, the Pre-Printing Section responsible performs plate developing. On the other hand, if work is repeated, plate separation is performed. Once work in this section is concluded, the Pre-Printing Section responsible signs and transports the PO to the upstream section (Printing Section – Cutting Machine).

C3. Allocate Production

Production Planning and Control Department has the function of allocating work to each manufacturing section and monitor the work's progress. The activities conducted by PPC Department are supported by *Planificação* system. PPC Department employees have access to a list of all the POs grouped by week of delivery in *Planificação*. This list of POs can be filtered by section. This allows the PPC Department to know exactly which orders need to be produced in each section, which are then visible to each section's chief. *Planificação*'s interface for this activity is presented in Figure 31.

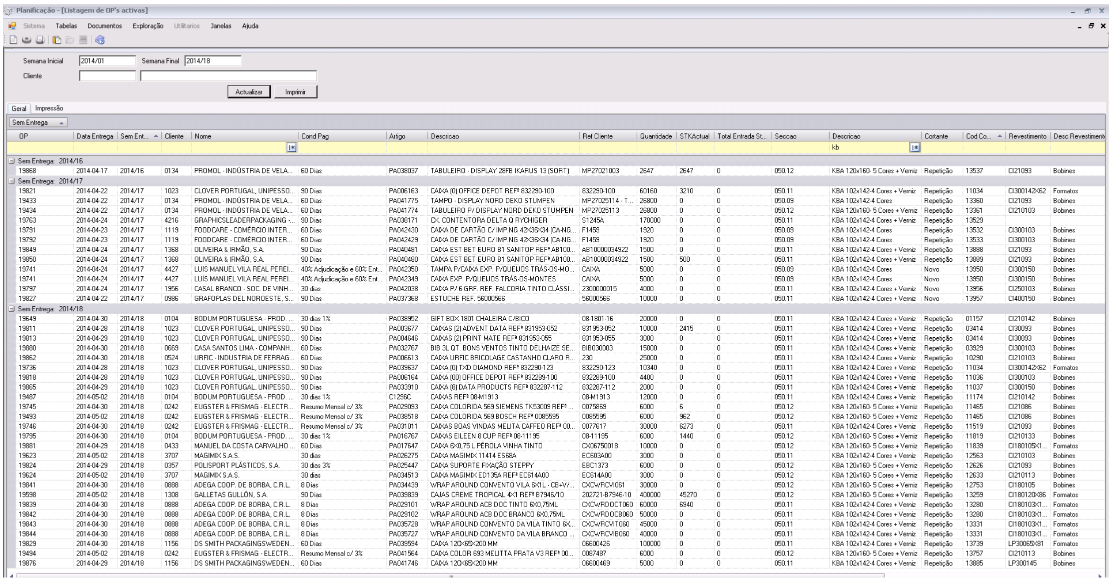


Figure 31 - Planificação's Interface (Allocate Production)

In Figure 31, it is possible to observe that POs are disposed by week of delivery. In this example, PO's are filtered by Printing Section, which means that all the orders shown in Fig. are the ones that need to be printed, therefore allocated to the Printing Section. This filtering procedure can be applied to all manufacturing sections.

PPC employees also receive client feedback concerning possible delivery date modifications and perform the required alterations in *Planificação* system. These changes are then visible to all sections employees.

C3.1. Allocate Cutting and Printing

Printing Section (Cutting and Printing) employees have access to *Planificação* system, with permission to access information related to their section and downstream manufacturing oriented sections (in this case, Pre-Printing Section). Although PPC Department allocates POs to this section daily, there are a few parameters that despite not being officially implemented in the company are used to optimize and guide work in the printing area. The application of those rules is decided by the chief of section, based in the queued POs. Those criteria are the following:

- Use of Color: Sometimes there is a machine printing direct colors and another printing quadricolor. This enables set-up reductions.
- Equal formats.

Despite those guidelines, if an order is urgent it takes priority since delivery date satisfaction is always the strongest criterion.

B6.1. Cut and Print

An employee from the Pre-Printing Section transports the finished POs to the Cutting Machine site, where paper coils are cut according to a desired length. After work's completion, POs are placed in another designated site, which is presented in Figure 32, so that printing machines' workers can collect them.

Figure 32 - Finished POs Designated Site (Cutting Section)

Once POs are transported to the printing machines site, there are once more held in another designated site, next to the printing machines. When printing work in this section is concluded, the chief of section signs the PO and places it on his desk so that employees of the upstream section (Lamination) can collect it.

C3.2. Allocate Lamination

Like in the Printing Section, Lamination Section employees have access to *Planificação* system, with permission to access information related to their section and downstream sections.

When possible, production order follows the following criteria:

- Flute Type
- Coil Width

In general, there is one machine that only produces exclusively F Flute and E Flute and another machine dedicated to B Flute and Double Flute (EE and EB) production. Despite those criteria, if an order is urgent it takes priority since delivery date satisfaction is always the strongest criterion. This optimizing procedure is further characterized in Section 4.2 – Production Cycles.

B6.2. Manufacture Flute and Laminate

Most of the times, flute manufacturing and lamination occur sequentially. However, when there is a high volume of POs that require the same flute profile in a specific time range, flute manufacturing is performed independently. The manufactured flute is then stored next to the lamination machine in order to provide a more efficient production response.

Once work in this section is collected, performed and concluded, the chief of section signs the PO and places it on a designated site so that employees of the upstream section (Cutting and Folding) can collect it, following an identical procedure to the one in Printing Section.

C3.3. Allocate Cutting and Folding

Cutting and Folding section employees have access to the *Planificação* system, with permission to access information related to their section and downstream sections.

Production order is done only according to the same die cutting tools. However, if an order is urgent it takes priority since delivery date satisfaction is the strongest criterion.

B6.3. Cut and Fold

In this section, packages are cut and fold according to their format, by the means of die cutting tools that are inserted in the machines.

Once work in this section is collected, performed and concluded, the chief of section signs the PO and places it on a designated site so that the employees of the upstream section (Closing) can collect it.

C3.4. Allocate Closing

Once more, Closing Section employees have access to the *Planificação* system, with permission to access information related to their section and downstream sections.

Production order is done according to boxes type and dimension. However, if an order is urgent it takes priority since delivery date satisfaction is the strongest criterion.

B6.4. Close

The first step performed in this section is gluing. This step is optional since there are customers who do not require glued packages. The second step consists in putting the packages in pallets, which are then sealed using blister technology. Although the first step of this section is optional, all packages need to be packed in order to proceed to their delivery. After packing, pallets are transported to the Finish Goods Warehouse (Dispatch Section), where they are displayed according to their arrival order.

C4.1. Evaluate Dispatch Resources Availability

The Dispatch Section has access to the *Primavera* ERP system, where they can consult orders that are waiting to be delivered. *Primavera* allows the Dispatch Section employees to consult the dispatch resources availability.

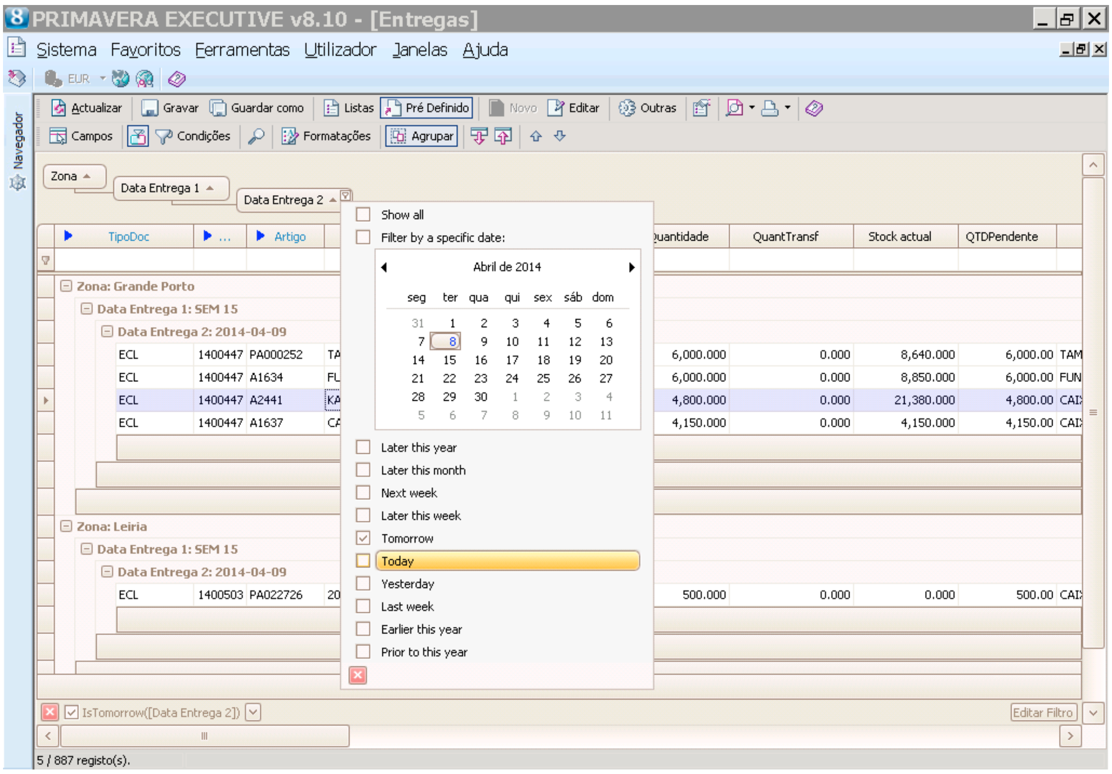


Figure 33 - Primavera ERP Interface (Evaluate Dispatch Resources' Availability)

C4.2. Establish Dispatch Date

After the availability consultation, the Dispatch Department establishes a dispatch date and schedules it in *Primavera*.

B7.1. Issue Delivery Note

Once a dispatch date is established, a Delivery Note (OGCAL 06/8) is issued, once more in *Primavera*.

B7.2. Load and Transport

At last, the transportation vehicles are loaded from the Finish Goods Warehouse (Dispatch Section). Loading can be a slow process since pallets are displayed in the Finished Goods Warehouse according to their arrival order, which may sometimes lead to situations where it is needed to move finished products from the warehouse. Once vehicles are loaded, products are transported to the costumer.

In the end of the process, the Dispatch Department chief transports finished POs to the Administrative and Financial Department so that they can be stored in the documents' room. Printing Plates are stored in a designated place in the Pre-Printing Section in case they need to be reutilized following a repeated order request from existing customers.

4.1.2. Value Stream Analysis

In this section, a Value Stream Analysis is conducted. The adopted methodology for Value Stream Mapping is the one described in Chapter 2. First, a product family analysis is performed based on company's data. Then, the most prominent products families' value streams are mapped.

4.1.2.1. Product Family Analysis

In order to conduct a product family analysis, company's data regarding last year's manufacturing volume and product mix was collected. The analysis of the mentioned data enabled the detection of twelve product families, labeled from A to L. However, it is important to mention that as the company manufactures very specific products, it would be possible to further decompose the identified product families. As an example, every family that consists of flute packaging could be decomposed into five sub-families as the company works with five different flute profiles. The existing product families could also be further divided in glued packages or non-glue packages. The insertion of a high number of product families would hamper analysis, as there would be low differentiation between each family.

Though, the categories presented in Table 6 were considered the most prominent and therefore no further division was performed.

Product Family	Designation
A	Printed Packages with Flute (New)
B	Printed Packages with Flute (Repetition)
C	Printed Packages with Flute (Changes)
D	Printed Packages without Flute (New)
E	Printed Packages without Flute (Repetition)
F	Printed Packages without Flute (Changes)
G	Non-Printed Packages with Flute (New)
H	Non-Printed Packages with Flute (Repetition)
I	Non-Printed Packages with Flute (Changes)
J	Non-Printed Packages without Flute (New)
K	Non-Printed Packages without Flute (Repetition)
L	Non-Printed Packages without Flute (Changes)

Table 6 - Identified Product Families

In Table 6 it is shown that products ranging from A to C and from G to I correspond to corrugated board packages, since they require a flute profile. Products A-C require printing, while products G-I do not. On the other hand, products ranging from D to F and from J to L consist of simple cardboard packages, which do not require fluting. Products D to F require printing, while products J-L do not. Ultimately, products A, D, G and J are new products, while products B, E, H and K correspond to repeated products. Products C, F, I and L are products previously manufactured by the company, but with changes.

After the identification of the main product families, a statistical analysis regarding the product mix was conducted. This provides knowledge on the production volume each product family represents. The results of the statistical analysis are shown in Table 7.

Product Family	Designation	Production Volume (2013)
A	Printed Packages with Flute (New)	18,57%
B	Printed Packages with Flute (Repetition)	52,77%
C	Printed Packages with Flute (Changes)	6,10%
D	Printed Packages without Flute (New)	1,51%
E	Printed Packages without Flute (Repetition)	12,04%
F	Printed Packages without Flute (Changes)	1,55%
G	Non-Printed Packages with Flute (New)	1,54%
H	Non-Printed Packages with Flute (Repetition)	4,03%
I	Non-Printed Packages with Flute (Changes)	0,22%
J	Non-Printed Packages without Flute (New)	0,92%
K	Non-Printed Packages without Flute (Repetition)	0,64%
L	Non-Printed Packages without Flute (Changes)	0,11%

Table 7 - Product Families' Production Volume (2013)

According to the information presented in Table 7, it is possible to notice that Product Family B, which corresponds to Printed Packages with Flute (Repetition) represents more than a half of the company's production volume, according to 2013 data. Although product families A and E are also responsible for a significant amount of production, followed by product families C and H, the rest of the product families' production volume can be considered residual. Further analysis is enabled by the presentation of a Pareto Chart, represented in Figure 34.

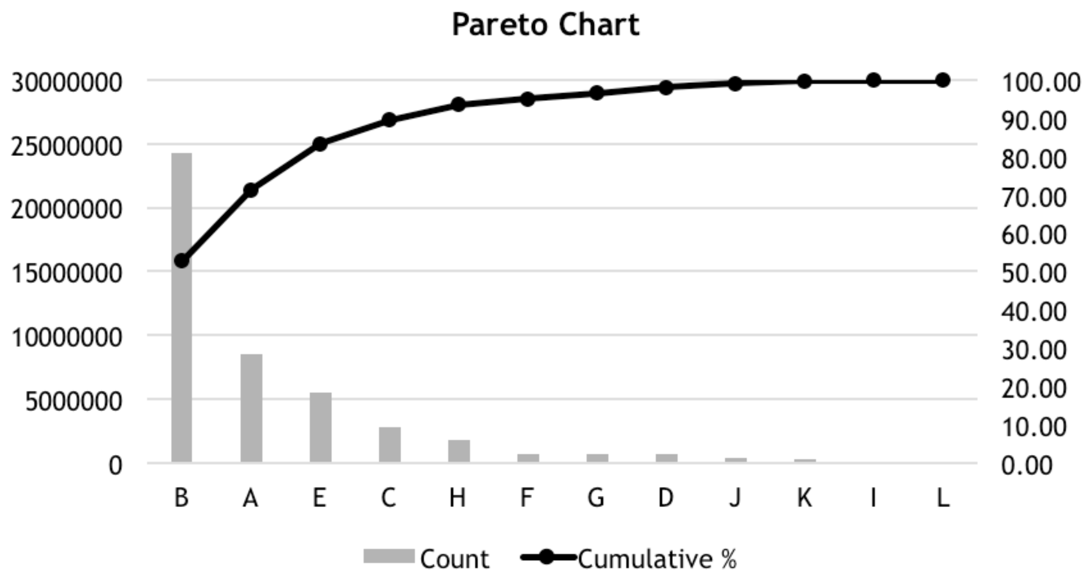


Figure 34 - Product Families' Production Volume (Pareto Chart)

The left vertical axis of the Pareto Chart represents the number of packages. Each vertical bar, colored in light grey, represents the count of manufactured packages of each product family. As the bars are placed in rank order, from left to right, it is possible to clearly identify families that have the highest contribution to production volume, in units. Once more, it is possible to conclude that Family B has a very high contribution, followed by families A, E, C and H.

On the right axis of the Pareto chart, percentage demarcations are shown. A cumulative line is used to add the percentages from each bar, starting at the left bar. Thus, the cumulative line makes it possible to address product families to the percentage of production volume.

As the aim of the Pareto analysis is to distinguish the "vital few from the trivial many", the analysis focuses on identifying the few product families on the left side of the Pareto diagram that account for most of the production volume. A reference value, as explained in Chapter 2, would be 80%. Observing the chart, it is possible to conclude that product families B, A and E account for around 80% of the production.

The next step in product family analysis consists in grouping product families according to their build sequence. The build sequence consists of all the productive stages an order has to go through in order to be transformed into the final product. Those include development and production stages. In Figure 35, the manufacturing sequence for each product family is presented.

Family	Development	Pre-Printing		Printing		Lamination		Cutting and Folding	Closing	
	Prepare Work	Develop Plates	Separate Plates	Cut	Print	Manufacture Flute	Laminate	Cut and Fold	Gluing	Packing
	01	02	03	04	05	06	07	08	09	010
A	x	x		x	x	x	x	x	x	x
B			x	x	x	x	x	x	x	x
C	x	x		x	x	x	x	x	x	x
D	x	x		x	x			x	x	x
E			x	x	x			x	x	x
F	x	x		x	x			x	x	x
G	x					x	x	x	x	x
H						x	x	x	x	x
I	x					x	x	x	x	x
J	x							x	x	x
K								x	x	x
L	x							x	x	x

Figure 35 - Product Families by Manufacturing Sequence

Although each product family has different characteristics, it is observed in Figure 35 that some product families go though a very similar manufacturing sequence, which may even be equal in some cases. This enables grouping product families into product family groups, which are constituted by one or more product families with an equal or very similar manufacturing sequence. Groups of product families by their manufacturing sequence are exhibited in Figure 36.

Group	Development	Pre-Printing		Printing		Lamination		Cutting and Folding	Closing	
	Prepare Work	Develop Plates	Separate Plates	Cut	Print	Manufacture Flute	Laminate	Cut and Fold	Gluing	Packing
	01	02	03	04	05	06	07	08	09	010
G1 (A,C)	x	x		x	x	x	x	x	x	x
	x	x		x	x	x	x	x	x	x
G2 (G,I,H)	x					x	x	x	x	x
	x					x	x	x	x	x
						x	x	x	x	x
G3 (B)			x	x	x	x	x	x	x	x
G4 (E)			x	x	x			x	x	x
G5 (D,F)	x	x		x	x			x	x	x
	x	x		x	x			x	x	x
G6 (J,L,K)	x							x	x	x
	x							x	x	x
								x	x	x

Figure 36 - Groups of Product Families by Manufacturing Sequence

Observing Figure 36, it is possible to identify six product families. G3 and G4 consist of only one product family, B and E, respectively. These product families were grouped alone since they represent a significant percentage of production volume, as may be seen in Table 7 and Figure 34. Therefore, due to G3 and G4's weight in manufacturing, the need for individual focus incurs. Product families A and C have exactly the same manufacturing sequence; therefore, they were grouped together in G1. The same applies to G5, constituted by families D and F. In G2, not all product families possess the same manufacturing sequence, despite being very similar. Even though, it was decided to group these families together since product H's weight in manufacturing is low and therefore there is no need to map this family individually. The same applies to G6, with family K bearing an even lower weight in manufacturing volume.

In Table 8, a quantitative analysis of each product family group is presented.

Company's Products %	Group	Product Family			Partial %	Total Production Volume %
25,00%	G1	A	C		24,67%	77,44%
		18,57%	6,10%			
	G3	B			52,77%	
		52,77%				
75,00%	G4	E			12,04%	22,56%
		12,04%				
	G2	G	I	H	5,78%	
		1,54%	0,22%	4,03%		
	G5	D	F		3,06%	
		1,51%	1,55%			
	G6	J	L	K	1,67%	
		0,92%	0,11%	0,64%		
100,00%					100,00%	100,00%

Table 8 - Product Families' Groups Production Volume (2013)

Based on Table 8 data, it is concluded that G1 and G3 are responsible for 24,67% and 52,77% of the company's production volume, respectively. The rest of the groups have a lower contribution, which goes from 12,04% (G4) to 1,67% (G6). G1 and G3 represent 25% of the company's products, and together they account for 77,44% of the production volume. Therefore, due to their high contribution to manufacturing volume, the chosen value streams to map correspond to G1 and G3. To conclude, a Pareto Chart of the product families' groups' production volume is presented, where the contribution of G1 and G3 is shown.

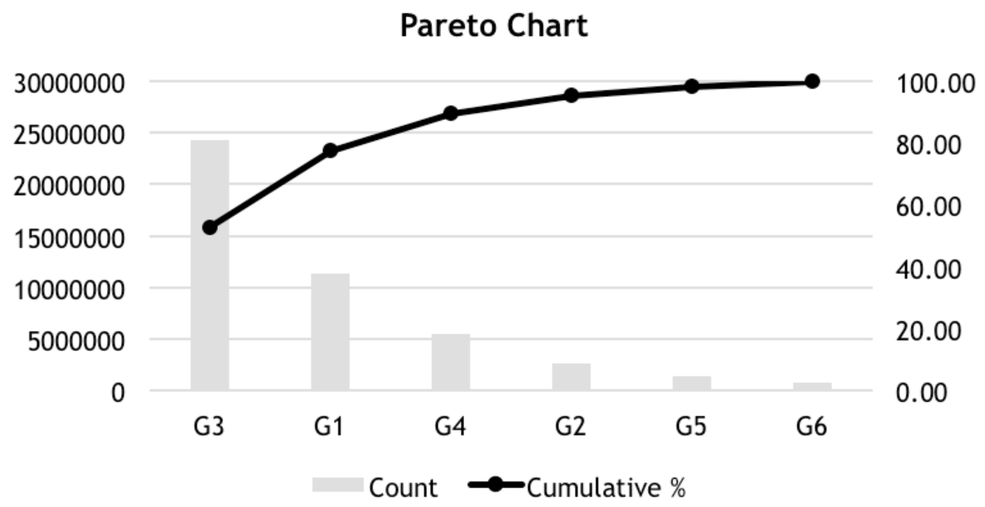


Figure 37 - Product Families' Groups' Production Volume (Pareto Chart)

4.1.2.2. Value Stream Maps

In this section, two VSM Diagrams are shown. One VSM is intended for Product Families' Group G1 while the other is intended for Group G3. Value Streams were mapped using Microsoft Visio©. In order to calculate process lead-time and value added time, information regarding machines' cycle time was collected from the PPC Department. The cycle times presented in the VSM are based on medium values and were calculated in Microsoft Excel©. Inventory waiting time was based on values estimated by the PPC Department, since there were no means to count the inventory between sections, due to daily in between stock variations and time restrictions to conduct proper measurements. The calculus sheet that supported the determination of cycle times is available for consultation in Appendix 3. Information concerning each manufacturing section machine's set up was also collected for reference and is therefore presented in the VSM's data boxes. The aim of this value stream mapping is to provide an overall view of waste and process efficiency in the company; therefore a summarized analysis is conducted.

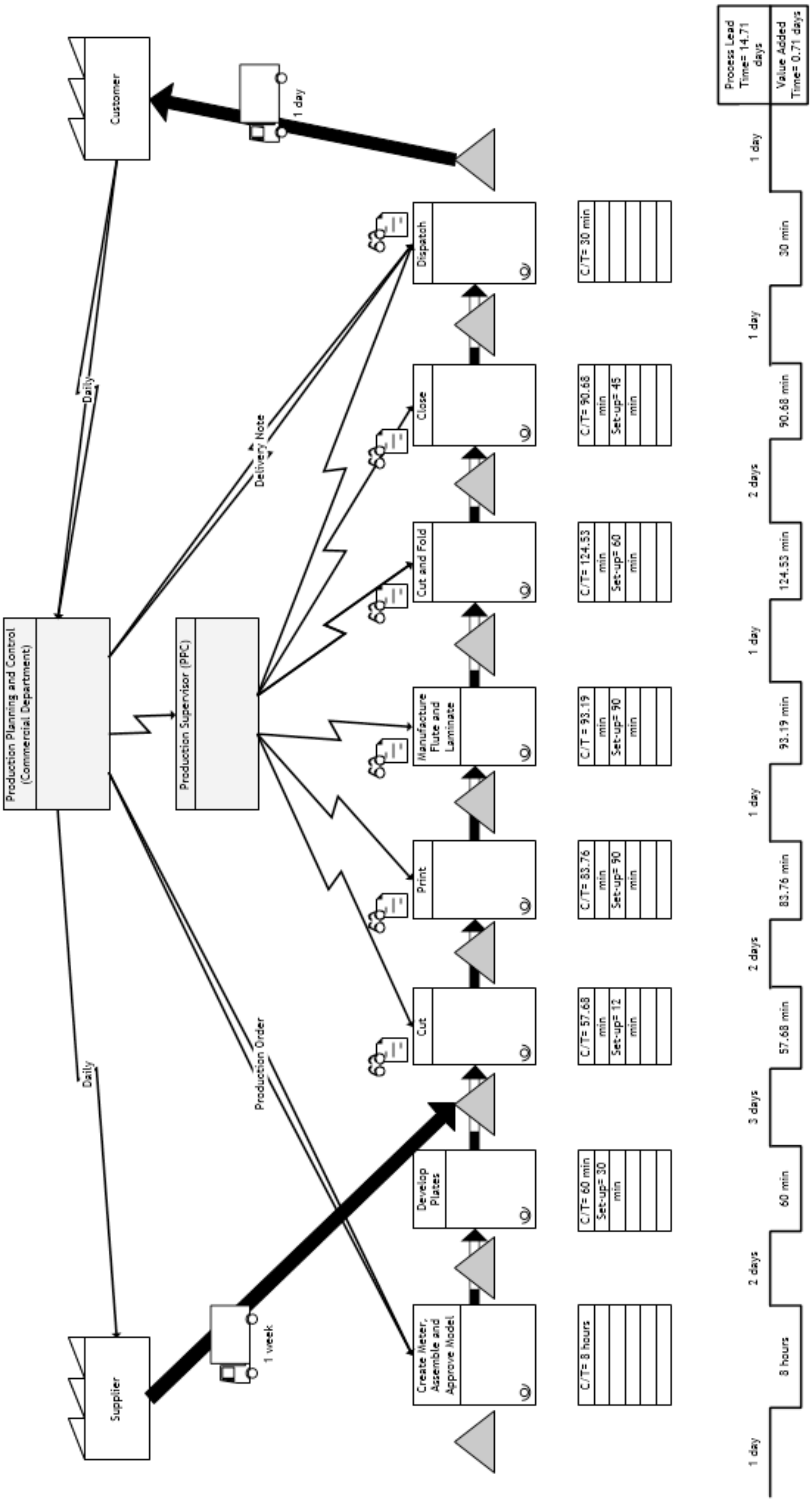


Figure 38 - Value Stream Map (G1)

Figure 38 depicts Group 1 (G1) VSM. In this case, it is possible to observe that the manufacturing strategy approaches an Engineer-To-Order (ETO) since manufacturing starts with the development of the product. As described in the previous sub-section, high-level planning is conducted by the Commercial Department, while the PPC Department displays production allocation and supervising functions. The Process Lead Time for this value stream is 14,71 days, which means that when a client places an order for a G1 product it will take 14,71 days to be produced, in average. In turn, value added time for this value stream is 0,71 days. This means that all the manufacturing activities that create value to the costumer take 0,71 days to be performed, in average. Based on these values, the process's cycle efficiency is 4,83% meaning that during the whole manufacturing process, only 4,83% of the time value is being created to the customer. This value was calculated dividing value added time by process lead time and multiplying the result by one hundred, in order to obtain a percentage value.

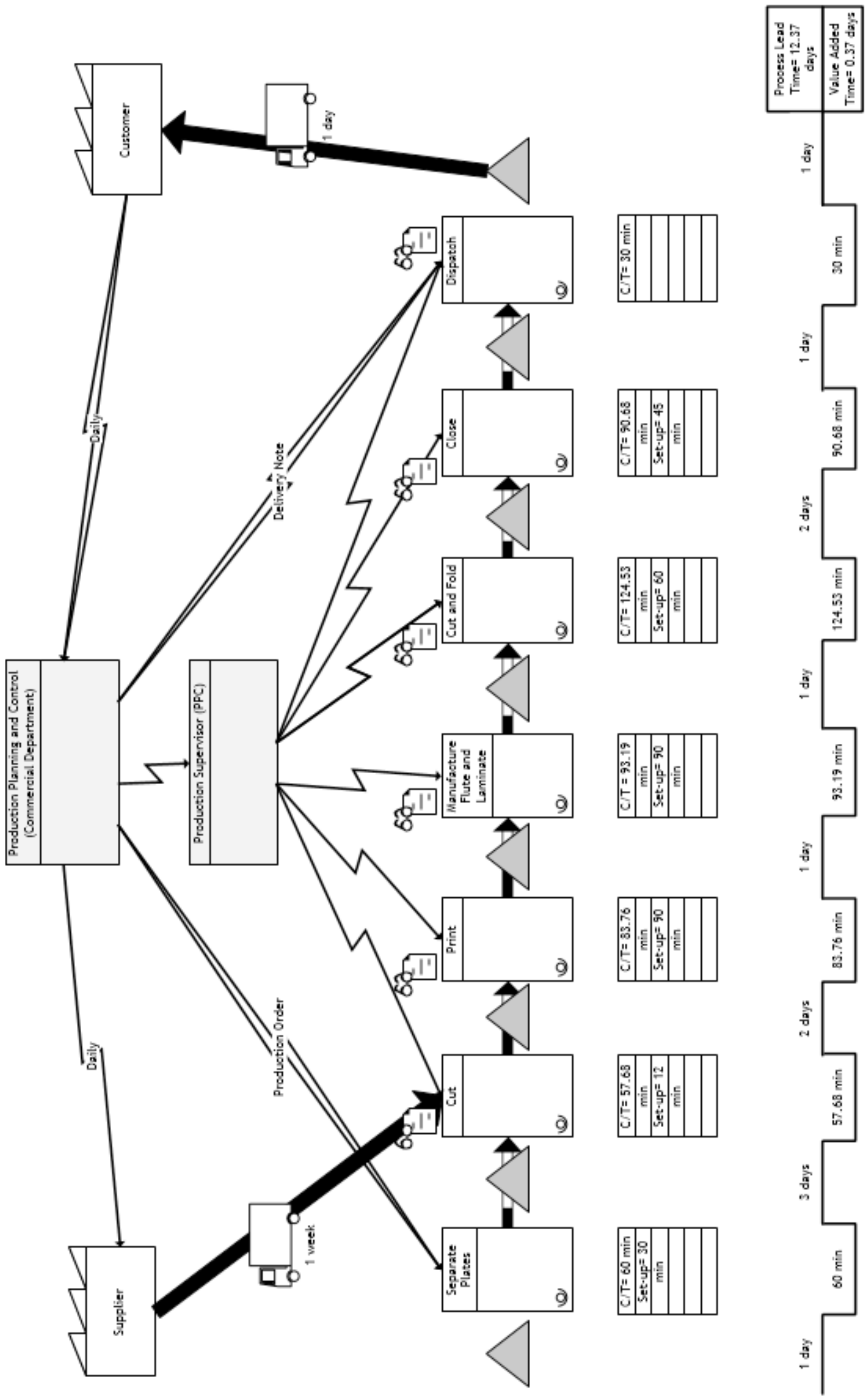


Figure 39 - Value Stream Map (G3)

In Figure 39, Group 3's (G3) VSM is depicted. In this case, it is possible to observe that the manufacturing strategy approaches general make-to-order (MTO) manufacturing since the production process starts with the separation of plates. Therefore, there is no need to conduct product development. Process lead time for this value stream is 12,37 days, which means that when a client places an order for a G3 product, it will take in average 12,37 days to be produced. In turn, value added time for this value stream is 0,37 days. This means that all the manufacturing activities that create value to the costumer take 0,37 days to be performed, in average. Based on these values, the process's cycle efficiency is 2,99% meaning that during the whole manufacturing process, only 2,99% of the time value is being created to the customer.

Comparing the two VSM diagrams, it is seen that while G3's process lead time is lower than G1's, which means that the manufacturing process takes less time to perform due to the lack of product development, However, G3 has a lower process cycle efficiency time, which means that the process is less efficient than G1's.

4.2. Other Characterization Aspects

4.2.1. Production Cycles

The company developed a mechanism for optimizing production, which consists of Production Cycles. Although this mechanism is currently not fully implemented it was documented and is therefore described in this section.

The optimization obtained with Production Cycles focuses essentially in the Lamination Section. Its main goal is to reduce paper waste that happens during the Flute Manufacturing and Lamination machines set-up. It also aims at reducing the high set-up times verified in this manufacturing section.

Each Cycle is associated with a flute profile and coil width. An alphabetical code is attributed to each Flute Manufacturing + Lamination machine groups, while a numerical code is attributed to each standard coil width the company works with. The mentioned codes are presented in Table 9 and Table 10.

Machine Group[2]	**Flute Profile Produced**	**Alphabetical Code**
Machine 017	E + F	A
Machine 019	B + Double	B

Table 9 - Production Cycles' Alphabetical Code

[2] A complete list of the manufacturing plant's machines is avaliable in Appendix 4.

Coil Width (cm)	Numerical Code
74	1
86	2
93	3
103	4
105	5
113	6
123	7
133	8
142	9
150	10
160	11

Table 10 - Production Cycles' Numerical Code

The full production cycles designation is presented in Table 11.

Cycle	Flute Profile/ Coil Width	Week
1-B	B Flute 74	Odd
2-A	E Flute 86	Odd
2-B	B Flute 86	Odd
3-A	E Flute 93	Odd
3-B	B Flute 93	Odd
4-A	E Flute 103	Odd
4-B	B Flute 103	Odd
5-A	E Flute 105	Odd
5-B	B Flute 105	Odd
6-A	E Flute 113	Even
6-B	B Flute 113	Even
7-A	E Flute 123	Even
7-B	B Flute 123	Even
8-A	E Flute 133	Even
8-B	B Flute 133	Even
9-A	E Flute 142	Even
9-B	B Flute 142	Even
10-B	B Flute 150	Even
11-B	B Flute 160	Even
12-A	F Flute/ E Flute Coils	Odd
13-A	E Flute Coils	Odd
14-B	EB Flute	Odd
15-B	EE Flute	Odd

Table 11 - Production Cycles

Cycles ranging from 1 to 11 represent single flute orders. According to this planning scheme, cycles 1-B to 5-B are produced in odd weeks, while cycles 6-A to 11-B, highlighted in light grey, are produced in even weeks.

On the other hand, production cycles that range from 12 to 13, highlighted in medium grey, correspond to the production of F Flute and E Flute Coils to stock, in case the company is experiencing a high demand of these types of flute. In this case, Flute Manufacturing and Lamination processes do not occur sequentially. This type of production takes place in odd weeks.

Finally, 14 and 15 production cycles correspond to double flute POs, highlighted in dark grey. In this type of production, it is necessary to produce E Flute independently, which is then stocked in order to be posteriorly laminated, in line, with E or F Flute. This type of production also takes place in odd weeks.

Although this method is documented by the company's PPC Department, it is not strictly implemented. However, some of its basic notions were used to develop production rules in the Lamination Section. When possible, there is one group of Flute Manufacturing + Lamination machines producing B Flute, while the other group of machines produces E Flute.

4.2.2. Raw Materials Analysis

According to 2013 data, there were eight types of cardboard (used for corrugation) ordered and eighty-six types of cardboard (used for lining purposes) ordered.

From these eight-six types of cardboard, only seven (8.14%) are considered regular, while the other seventy-nine (91.86%) are special. However, the percentage of regular cardboard ordered in 2013 was 82,56%, while the percentage of special cardboard was 17,44%. Pareto's Theory supports these results.

Chapter 5

Manufacturing Simulation

In order to enable the observation of the manufacturing plant's behavior, a simulation model of the company's factory was built using Delmia Quest© software. The aim of this simulation consists in detecting possible unfavorable situations, such as bottlenecks, that occur during the factory oriented production process. A description of the factory test case is therefore presented, as well as data used in the simulation. Results of the simulation are exhibited and analyzed. Problems and advantages of using Quest© are also discussed.

5.1. The Factory Test Case Description

The company's manufacturing floor's layout was analyzed and modeled with some simplifications, with basis on the company's manufacturing blueprint presented in Appendix 5. The production of ink, which occurs in the Printing section was not considered, as well as die cutting tools manufacturing in the Cutting and Folding section. In the Closing Section, the influence of manual work was modeled by increasing process' cycle time. Also, in this section, its two main activities, gluing and packing, were agglomerated into one major closing activity for simplification purposes.

Given the referred simplifications, the company's manufacturing plant has five different sections, sixteen machines and five conveyors. The machines at the factory follow a process layout in which machines are grouped by their function.

5.1.1. Machines

There are a total of seventeen machines[3] involved in this project, which may be separated into six groups. Each section can have more than one group of machines. A color code, which may be consulted in Table 12, is attributed to each machine group for better visualization.

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[3] A complete list of the manufacturing plant's machines is available in Appendix 4.

Section	Machine Group	Color
Printing	Cutting	
	Printer	
Lamination	Flute Manufacturing	
	Lamination	
Cutting and Folding	Cutting and Folding	
Closing	Gluing	

Table 12 - Color Code Attributed to each Machine Type

The machines were disposed according to their real configuration in the factory's floor. In order to do so, the company's manufacturing floor's blueprint, available in Appendix 5, was analyzed and the factory's layout was transposed to the simulation model, considering its real distances and proportions.

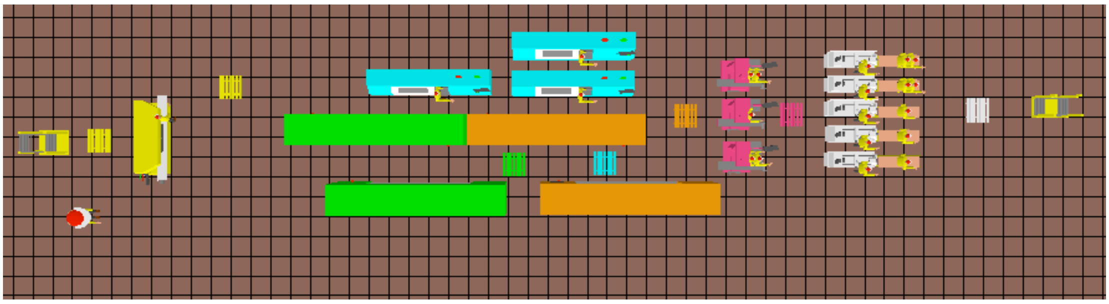

Figure 40 - Top View of the Manufacturing Facility's Layout

5.1.2. Parts

There is an infinity of products that can be manufactured in the facility, since products are highly customized and often unique, which leads to different machine configurations between different orders. In the adopted model, each part represents a different product. 26 parts were used in the model to represent a typical week's work, which means that the model represents a week in which 26 products were manufactured. These parts are labeled Prod1x through Prod26x for simplicity.

When a part enters the manufacturing system, it suffers a set of transformations before it becomes the final product. All parts go though all productive stages included in this model. Although the company manufactures products that do not need to go through all productive stages (for example, a non-printed product does not need to go through the printing machine and a product without flute does not need to go through the flute manufacturing and lamination machines), the percentage of products that represent the most prominent value streams, based on data collected from the product family analyses, go through all productive stages. Therefore, the built model is focused on those value streams and only products from families A, B and C are inserted in the model.

Taking Prod1x as an example, the manufacturing process starts when Prod1, which provides from the only Source in the model, goes through the cutting machine (yellow). After Prod1 is cut, it becomes Prod1a. Next, Prod1a enters the printer (cyan blue), where it is transformed into Prod1b. Prod1b enters the flute-manufacturing machine (bright green) becoming Prod1b1. Then, Prod1b1 goes through the lamination machine (orange), becoming Prod1c. After cutting and folding, Prod1c is transformed into Prod1d. Finally, Prod1b enters the closing machine, becoming the final product, Prod1e. This logic is applied to all the 26 products considered in the model. Figure 41 sums up this information.

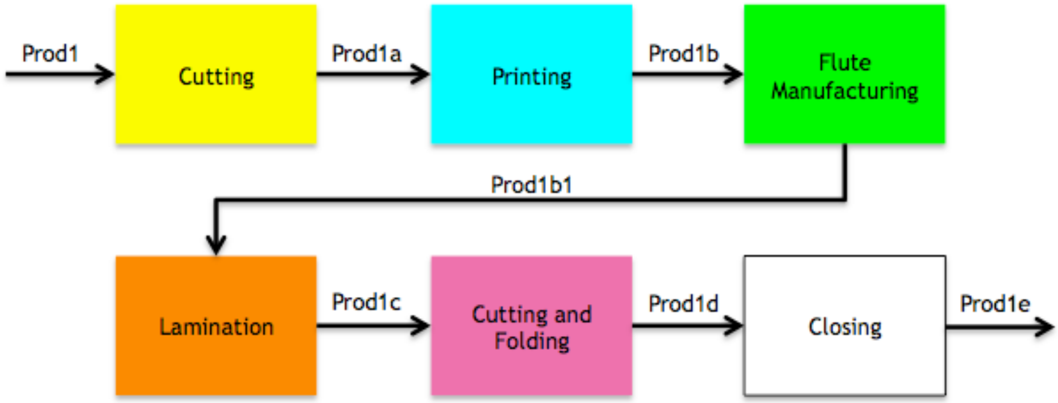

Figure 41 - Part Codification Used in the Model

5.1.3. Source

The Source's function is to create parts. In this model, parts were created by a single source, using file based source logic. In the source file, the quantity of each part (product) is specified, as well as its arrival time. As the quantities of each part in the company are often in the order of 5k-50k, a conversion factor was used so that the model would become lighter and more responsive. This way, the real number of parts was divided by one hundred. Source data is available for consultation in Appendix 6.

5.1.4. Buffers

Buffers are represented by the colored squares on the manufacturing floor. The machine color code exhibited in Table 12 is also applied to buffers, which means that machine groups and their respective buffer are presented in the same color.

5.1.5. Conveyors

Gluing is done in the gluing machines (represented in white). Once products are glued, they are transported by conveyors, which are placed immediately next to each machine in order to be packed by workers who are placed at the end of the conveyor. There are a total of five conveyors in this model.

5.2. Simulation

In order to prepare for the simulation, company's data regarding manufacturing processes and labor was collected from the Planning and Control Department. All data and simulation processes related information was summarized in Microsoft Excel© format, which is available for consultation in Appendix 3.

5.2.1. Processes

Every machine has an associated process, which is exhibited in Table 13.

Section	Machine Group	Process
Printing	Cutting	Cut
	Printer	Print
Lamination	Flute Manufacturing	Manufacture Flute
	Lamination	Laminate
Cutting and Folding	Cutting and Folding	Cut and Fold
Closing	Gluing	Close

Table 13 - Processes Attributed to each Machine Type

At the same time, each product follows the same processes sequence. As an example, Prod1's sequence is Cut1, Print1, Manufacture_Flute1, Laminate1, Cut_Fold1 and Close1. The same rule applies to each of the 26 products.

5.2.2. Labour

The Printing Section, which has Cutting Machines and Printers, has specific labour designated to perform the Cutting process, as well as specific labour for Printing. In the Lamination Section, Lamination labourers perform both Flute Manufacturing and Lamination. Cutting and Folding is performed by Cutting and Folding labourers, while Closing is performed by Closing Labourers. This information is summarized in Table 14, as well as schedules, shifts and number of labourers for each labour category.

<table>
<tr><th>Section</th><th>Machine Group</th><th>Labour Category</th><th>Schedule</th><th>Shifts</th><th>Number of Labourers</th></tr>
<tr><td rowspan="2">Printing</td><td>Cutting</td><td>Cutting</td><td>7am-6pm</td><td>1</td><td>2</td></tr>
<tr><td>Printer</td><td>Printing</td><td rowspan="4">6am-22pm</td><td rowspan="4">2</td><td>12</td></tr>
<tr><td rowspan="2">Lamination</td><td>Flute Manufacturing</td><td rowspan="2">Lamination</td><td rowspan="2">12</td></tr>
<tr><td>Lamination</td></tr>
<tr><td>Cutting and Folding</td><td>Cutting and Folding</td><td>Cutting and Folding</td><td>12</td></tr>
<tr><td>Closing</td><td>Gluing</td><td>Closing</td><td>8:15am-5:15pm</td><td>1</td><td>20</td></tr>
</table>

Table 14 - Labour Simulation Data

In order to simplify the model's construction, a single shift was considered in all sections. This way, the Printing, Lamination and Cutting and Folding number of labourers was considered to be half its true number, which corresponds to the situation in which there is no change of labourers during work hours. Although this does not happen in reality, this simplification was considered, as the aim of this simulation is not to analyze labour, but to focus in the manufacturing process. Therefore, approximations in labour are not considered relevant. Another simplification introduced in labour was the consideration of a single labour controller for the entire factory, covering all sections. Although in the company's factory there is a labour controller for each section, who corresponds to the chief of section, this approximation was also introduced in order to simplify the model.

In the company, as there are at least two workers designated to each machine, breaks are taken individually, so that machines operate during all work hours. Therefore, breaks were not considered in the model.

5.2.3. Running the Simulation

The simulation was run considering a regular five days week's work, from 6am to 10pm. Results are discussed in the following section.

5.3. Results

After running the simulation, a report on all the data pertaining to the run may be obtained by using Quest's single run output functionality. The report is broken down by element class (machines, buffers, labour, conveyor, among others), and then by individual element (machines_1, buffer_1, labor_1, conveyor_1, among others) at a second level. The results exhibited in this section were obtained based in this report's data, which was exported to Microsoft Excel©, and then analysed. A finished product analysis, labour and machines utilization calculation and bottleneck detection analysis were conducted.

5.3.1. Finished Product Analysis

After running the simulation and performing a part analysis, it was noticed that of the 2630 units that were ordered to be manufactured in the simulation, only 1715 were created. This corresponds to Prod1 to Prod15, which means that products Prod16 to Prod26 did not complete all manufacturing steps. Completed finished products' details are shown in Table 15.

	Created Parts	Destroyed Parts	Finish Section
Prod1	200	180	Closing
Prod2	200	184	Closing
Prod3	200	192	Closing
Prod4	200	186	Closing
Prod5	200	191	Closing
Prod6	60	55	Closing
Prod7	30	28	Closing
Prod8	30	27	Closing
Prod9	30	27	Closing
Prod10	70	63	Closing
Prod11	40	40	Closing
Prod12	50	46	Closing
Prod13	5	5	Closing
Prod14	200	188	Closing
Prod15	200	129	Closing
Total	1715	1541	

Table 15 - Finished Products Data

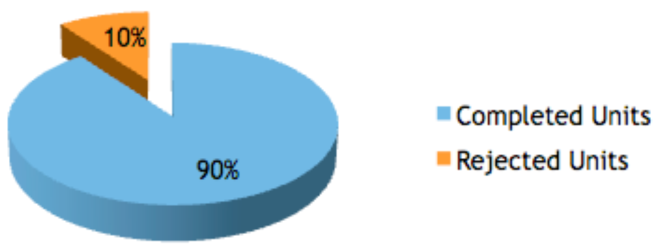

Figure 42 - Completed and Rejected Units Distribution

Figure 42 shows that approximately 10% of the total number of units produced in orders from 1 to 15 were rejected. By generalization, this means that approximately 10% of an order's quantity subjected to the manufacturing processed is rejected.

5.3.2. Utilization Analysis

In Figure 43, machine and labour's rate of utilization is depicted. The simulator calculates machine and labour's utilization considering a 24h working time. Therefore, as the manufacturing plant is on duty 16h a day, it was necessary to perform a conversion, adding 30%, which corresponds to the 8h non working time, to the machine and labour utilization rate the simulator showed in the report. Labour utilization is considered constant within each section.

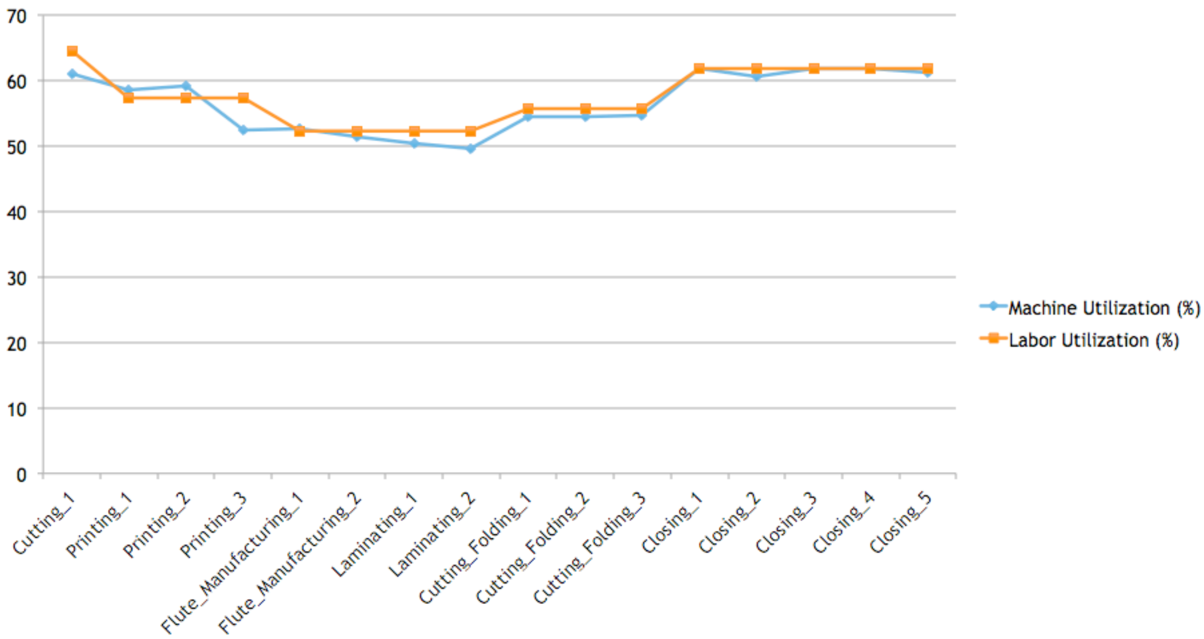

Figure 43 - Machine and Labor Utilization

Observing Figure 43, it is seen that machine and labour utilization follow a very similar pattern. Therefore, as machine utilization varies its labour utilization also suffers a variation modeled by a similar curve, since machines' operation is dependent on labourers. Although data shows that this is a valid generalization principle, there is an exception in the Printing Section, on machine Printing_3. This variation can be explained due to fact that labour was considered constant for each section and the machine Printing_3 shows a significantly lower utilization rate in relation to the other printing machines. This does not happen in the rest of the sections, since machine's utilization varies very slightly in all other sections.

Machine's utilization rate ranges from approximately 50% to 62%, with labour utilization rate ranging from approximately 52% to 65%. This means that 38% to 50% of the work time machines are either stopped, being maintained, or, most commonly, suffering in between order adjustment, known as set-up. On the other hand, 35% to 48% of the time workers are either stopped or performing other non-adding value activities such as set-ups and maintenance.

Results show that Flute Manufacturing and Lamination machines have the lowest utilization rate, while Closing machines have the highest utilization rate. These outcomes match the manufacturing plant's employees' testimonial, which have identified the Lamination section as the most critic section in what concerns set-up time. Consequently, the manufacturing section with a lower labour utilization rate is also Lamination Section, while Cutting Section shows the higher labour utilization rate.

5.3.3. Bottleneck Analysis

Due to the configuration of the built model, as mentioned in the Simulation sub-section, all of the queues occur at the buffers. Therefore, bottlenecks are located at the buffers. Figure 44 shows the average buffer lenght, in units, per part at each buffer. Examining this Figure, it is noticed that a bottleneck is located at Buffer1_1, at the Cutting Machine, and a second bottleneck is at Buffer 4_1, at the Cutting and Folding Section. The rest of the buffer's lenght is residual, in the order of 1 to 6, and therefore is not noticeable in the Figure 44.

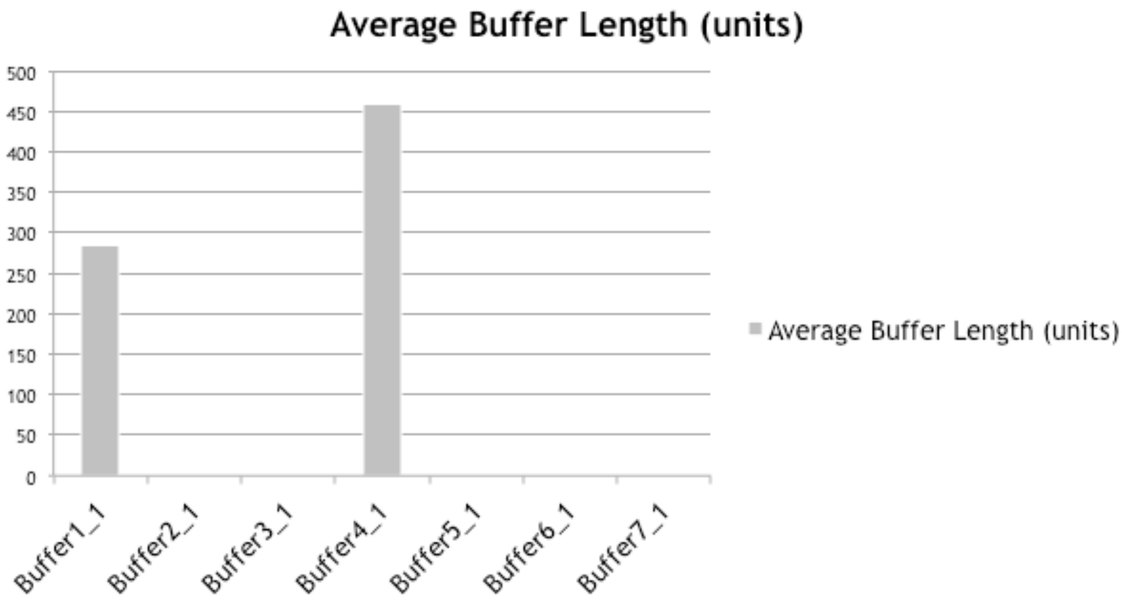

Figure 44 - Average Buffer Length

As mentioned at the beginning of the Results section, products from 16 to 26 were not completed, despite having been created and introduced in the manufacturing system. By analysing the simulation report, it was noted that these products completed some manufacturing steps, despite not having been transformed into the final product. Products 16 from 24 manufacturing cycle finished at Buffer_4, before Cutting and Folding section, while products 25 and 26 did not make it to the Cutting Machine, being held in the system at Buffer_1 in the end of the simulation. Non-completed products details are shown in Table 16.

	Created Parts	Parts in System	Location
Prod16	200	186	Buffer_4
Prod17	200	190	Buffer_4
Prod18	200	193	Buffer_4
Prod19	60	54	Buffer_4
Prod20	30	29	Buffer_4
Prod21	30	28	Buffer_4
Prod22	30	27	Buffer_4
Prod23	70	67	Buffer_4
Prod24	40	39	Buffer_4
Prod25	50	47	Buffer_1
Prod26	5	5	Buffer_1

Table 16 - Non Completed Products Data

Figure 45 shows the manufacturing model it the end of the simulation. Bottlenecks are clearly visible at Buffer_1, before the Cutting Machine and Buffer_4, before Cutting and Folding Section.

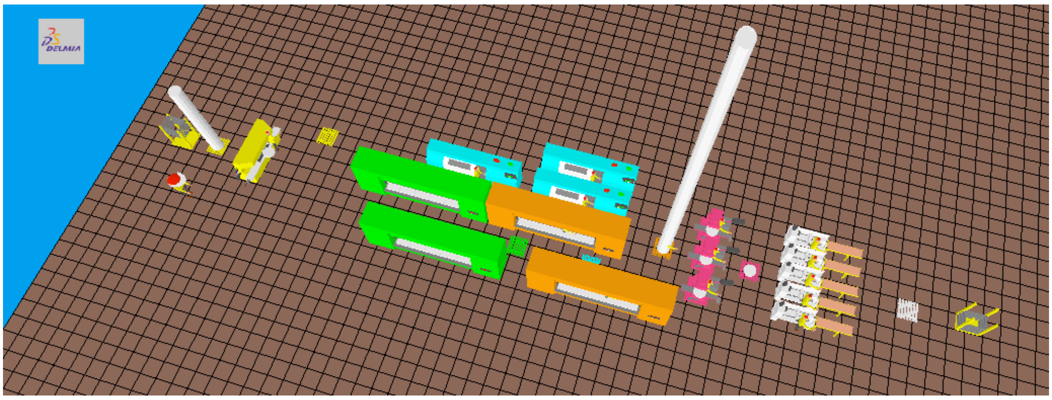

Figure 45 - View of the Manufacturing Facility at the End of the Simulation

5.4. Problems with Quest

Quest has proven to be a very helpful tool in the design and optimization of manufacturing facilities. Despite being a very powerful tool, there are some drawbacks in the program, which were encountered during the construction of the model. These problems are summarily mentioned.

5.4.1. User Interface

One problem encountered while building the model was the user interface. In Quest's interface, menu items and action buttons are located on the right, while navigational controls, which are known as "World Controls", are located at the bottom. Its unique interface is difficult to understand at the beginning, which makes the adaptation to the program's interface slow, especially in what concerns "World Controls". Although Quest's user manuals are extensive and helpful, they are not sufficient for a complete knowledge of the control's operation, which leads to the requirement of instructor's help. Another interface problem is the complexity of the buttons layout. When creating a wide number of parts, machines and processes it becomes extremely easy to miss or overlook on the many input variables, which can lead to simulation failure or inaccurate results. An example of the buttons layout can be seen in Figure 46.

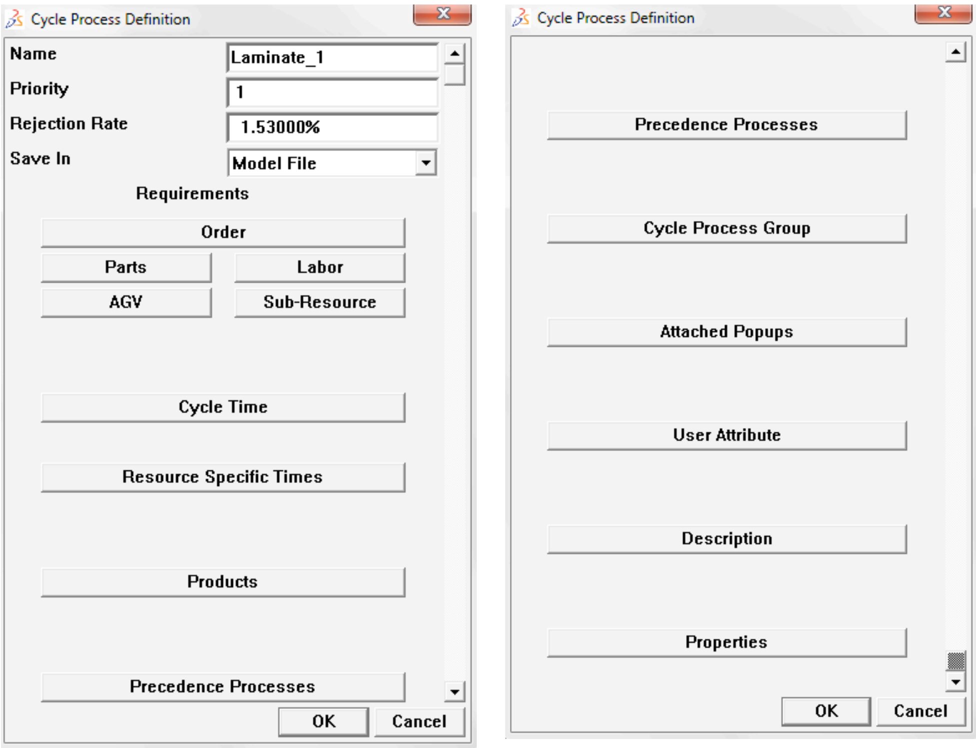

Figure 46 - Example of the Buttons Layout

5.4.2. Data Insertion

Data insertion is very time consuming, especially in what concerts Products data in the Cycle Process Definition menu, since every fields comes with a predefined option, which may need to be changed individually. In this model's case, since there are 156 sub products (26x6) and a total of 156 processes, this operation was performed manually 24336 times, which took a very large amount of time.

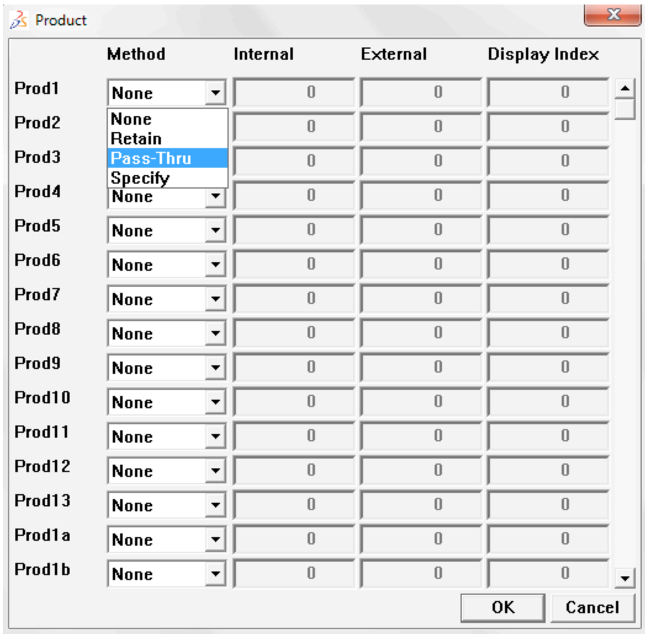

Figure 47 - Data Insertion Problem Encountered in the "Product" Menu

5.4.3. Program Exiting Problem

Another problem detected while using Quest was the exiting mechanism. When a user exits Quest, the program prompts the user to confirm the exit. However, unlike most commercial programs, it will not give the user the option of saving before exiting. There were some instances where part of the work was lost as a result of exiting the program.

5.4.4. Chart Display Problem

The 2D Chart functionality enables the possibility of watching parts flowing through the manufacturing elements as they are created, showing the contents for each element as the model is running. This functionality is very useful for debbuging purposes. However, the chart display is restricted to 10 parts, which is a limiting aspect in cases where heavier models containing more that 10 parts are being run. In this case, since there were 26 parts, the input file had to be decomposed into 3 smaller files so that this type of testing could be conducted. Figure 48 illustrates this problem, showing Buffer7's contents as an exemple.

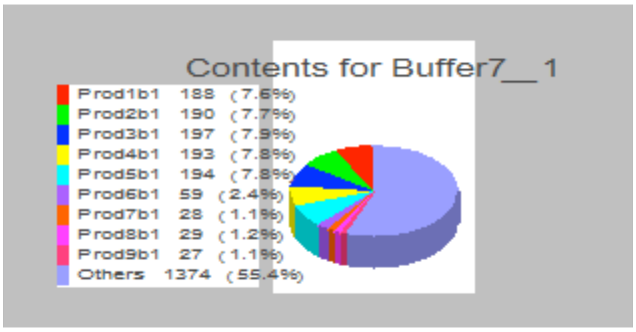

Figure 48 - Chart Display Problem

5.5. Benefits of using Quest

Before the introduction of general simulation software, from which Quest is an example, production managers would normally write their own programs using general computer languages or special simulation software on a case-to-case basis. The introduction of simulation tools proved to be very useful for designing, development and optimization of manufacturing processes.

Those tools allow verification of the floor design, manufacturing cell configuration, as well as machining and production processes' performed in the designed cell. Quest's industrial application can greatly lead to manufacturing costs reduction, enhance production rates and efficiency and help in the planning and testing of manufacturing layouts. Through the integration of Quest, companies could potentially be more efficient and adopt a "leaner" manufacturing paradigm.

Chapter 6

Solution Analysis

Detected problems and improvement opportunities for the company, as well as a solution analysis are presented in this section. Those improvement opportunities were identified based in the Processes and Value Stream Analysis conducted in Chapter 4, as well as the Manufacturing Simulation results presented in Chapter 5. The identification of these aspects supports the elaboration of a solution analysis.

6.1. Improvement Opportunities

6.1.1. Production Planning

An identified problem in the company was the fact that delivery dates are defined by the Commercial Area, which is office based and does not have any contact with the productive process that takes place in the factory floor. Production Planning and Control Department does not intervene in the delivery date definition. Instead, its main function is to allocate work to each factory section and control the productive process. The PPC Department is located at the shop floor and its employees are also in touch with clients so that they can provide them with information regarding possible order lateness, or receive client's information letting the PPC know of an order's urgency or if an order's production may be delayed. Therefore, the high-level production planning is exclusively performed by the Commercial Department, which is supported by *Planificação* and Plan2013 information systems.

Given the company's operating nature in a MTO environment, its structural organization and its small dimension, it was concluded that commercial based high level planning might be an adequate planning solution for the company since the introduction of a PPC team would require major structural changes in the organization that could not produce immediate results, since intensive studies and evaluations would have to be conducted. However, in order to improve the planning process' efficiency and support, the need to perform some changes in the information systems incurs, since there are many planning aspects that could be improved with the introduction of more functionalities in the company's IT resources.

6.1.2. Delivery Date Definition

The definition of a delivery date depends on the factory's capacity, evaluated by Plan2013 software, and the order execution time, which is calculated by *Planificação* system when the parameters for the creation of a PO are introduced. The availability of raw materials is not considered in the delivery date's definition, since raw materials are ordered by the Purchasing Department after the delivery date is defined. Although the most ordinary types of raw materials are kept at a minimum stock, ordering raw materials after due date is established can lead to significant delays, since suppliers may not be able to fulfill the RM request on time.

Currently, raw materials availability is not considered in the definition of client's due date by the Commercial Department. In order to overcome this problem, Commercial Department employees should have access to raw materials stock data that is available in *Primavera* ERP, since stock management is done in *Primavera*. In case the required raw materials were not in stock, the Commercial Department would communicate with the Purchasing Department in order to estimate their availability. Then, the delivery date would be established.

6.1.3. Internal Planning

Another problem related to delivery date definition has to do with the fact that currently the Commercial Department only establishes a Customer Due Date (CDD) in the PO. The current delivery date definition method is presented in Figure 49.

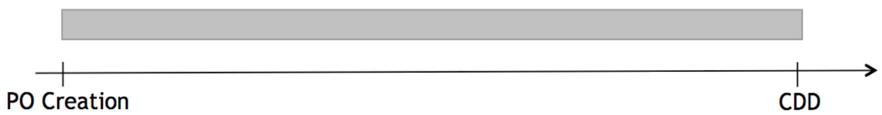

Figure 49 - Conceptual Representation of the Current Delivery Date Definition Method

In Figure 49 it is shown that there are only two dates involved in planning: the date when the PO was created and costumer due date (CDD). These dates are presented in the PO. An internal planning is not performed, which means that each department and section has no indication of when their particular work is due, since they only possess information concerning order's delivery date (CDD).

The introduction of internal planning would improve the departments' organization, since each department would have a very clear idea of when its own work was due, rather than when the product was to be delivered to the customer. A schematic representation of this planning concept is shown in Figure 50.

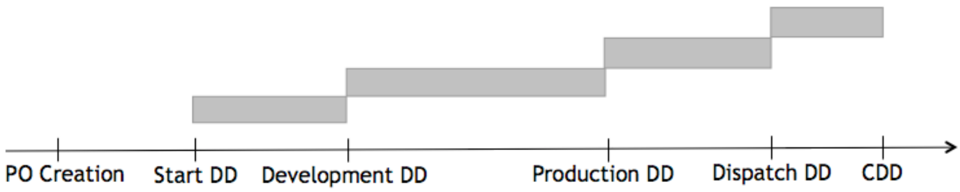

Figure 50 - Representation of the Internal Planning Concept

It is seen that after the PO is created, there is an established start date, when RM are ordered, as well as a Development due date, Production due date, Dispatch due date and finally, the Customer due date. This internal planning could be further decomposed, considering a due date for each department and section (Create Meter, Assemble and Mount; Reveal or Separate Plates; Cut; Print; Manufacture Flute; Laminate; Cut and Fold; Close; Dispatch). *Planificação* system would support the establishment of the due date for each intermediate section during the PO issue, based in medium values of work completion and the client's due date. Therefore, the physical PO document would have an extra column on the right where the due date for each section would be presented. Figure 51 depicts a conceptual model of a PO that includes internal planning.

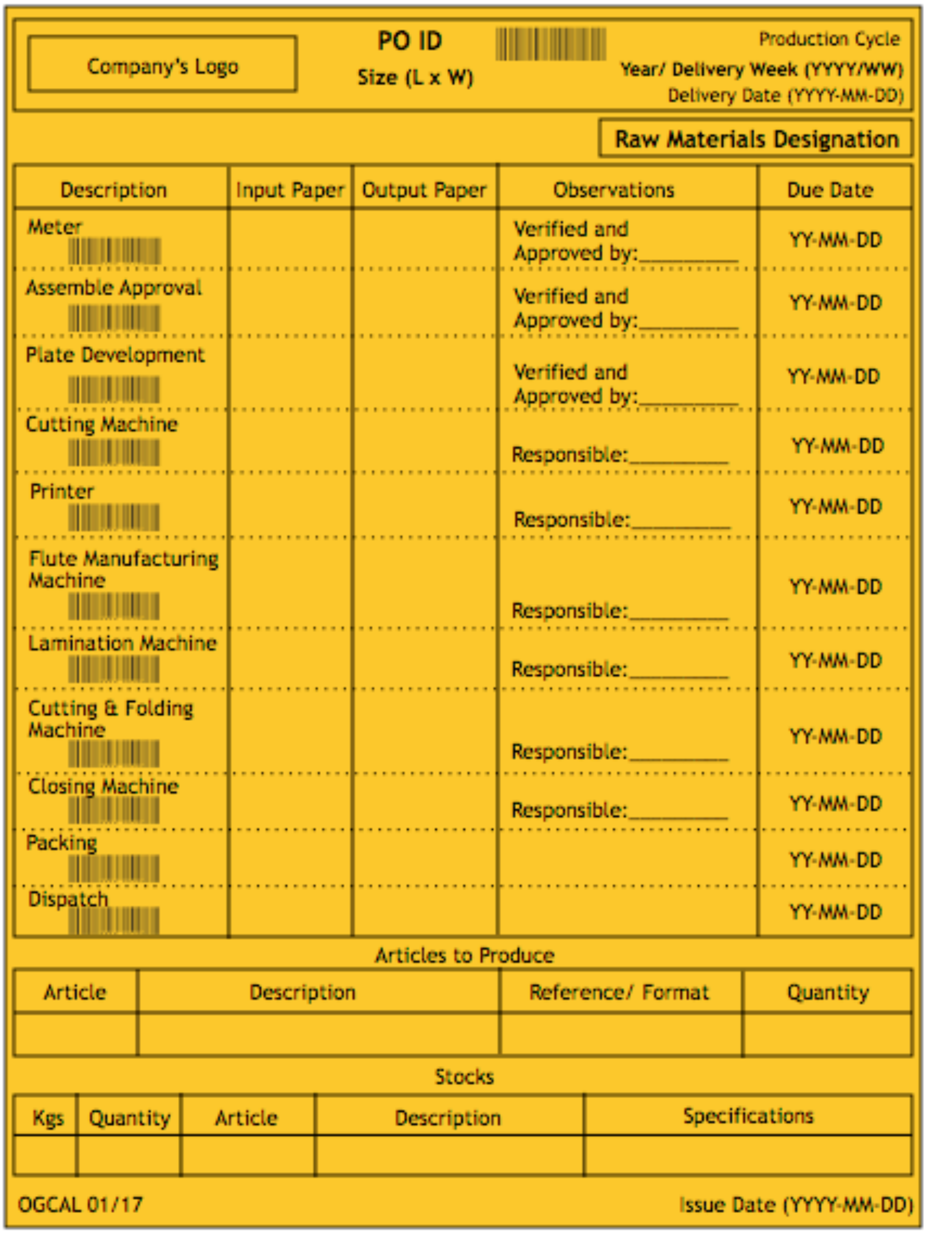

Figure 51 - Conceptual Model of a PO Including Internal Planning

The start of the product manufacturing should take place as late as possible, without exceeding the CDD. Early completion leads to excessive final product inventory and complicates the dispatch process, as products are disposed in the Finish Goods Warehouse as they finish production and may need to be rearranged in order to be shipped. Late completion, however, leads to client dissatisfaction and possible client loss. Therefore, if a proper internal planning is performed, the company will be following a Just-in-Time manufacturing approach, producing what is necessary, only when it is necessary.

6.1.4. Raw Materials Order

Another restraining aspect was identified in the Purchasing Department. As described in Chapter 4, after POs are issued by the Commercial Department, the Purchasing Department collects the POs' list from *Primavera* ERP. This collection occurs three times a week: on Monday, Wednesday and Friday at around 9pm.

In order to illustrate the problem, let's consider a PO that is due next week, issued by the Commercial Department on Monday at 10pm, which may be considered urgent due to its early CDD. As the Purchasing Department collects the PO list at 9pm, it will only take notice of the urgent request on Wednesday. In case the required raw materials are special, they need to be ordered from the supplier, which can take around one week average. This situation will lead to a significant order delay.

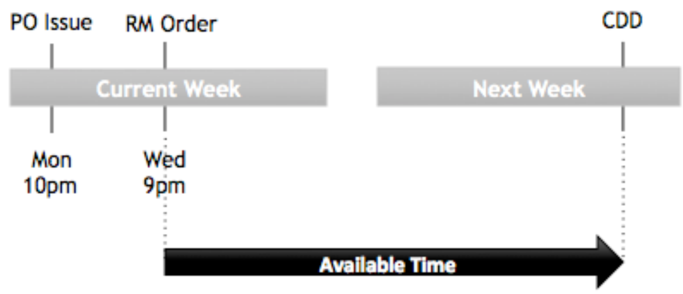

Figure 52 - Conceptual Representation of the Purchasing Department Problem

In this department, the PO list is collected three times a week. In order to surpass the detected problem, the list should be available every day. This way, the raw material necessities would be monitored and fulfilled more often. In order to implement this solution, changes in the *Planificação* system and *Primavera* ERP schedules would have to be conducted. *Planificação* should be scheduled to send the PO list to *Primavera* ERP every day rather than three times a week.

Also, a special raw materials detection mechanism should be implemented. Whenever an order that requires special raw materials was issued in *Planificação*, the system would emit an alert in *Primavera* ERP and communicate this requirement to Purchasing Department in real time. This way, it would be granted that raw materials would be requested to the supplier as soon as possible, which would decrease process lead-time.

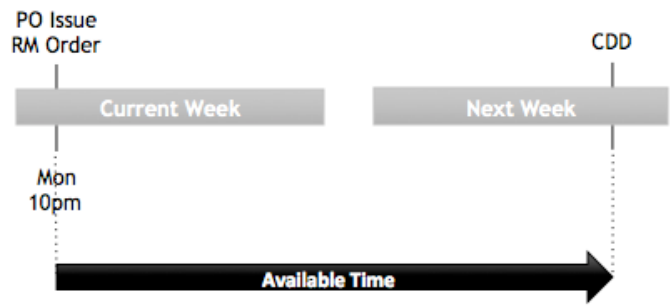

Figure 53 - Conceptual Representation of a Purchasing Department Solution

A similar mechanism could be developed to address urgent orders. Whenever an urgent order was placed, *Planificação* would also issue an alert in *Primavera* ERP to communicate the urgent need to fulfill that request. Given the average process lead-time of 14 days, all orders scheduled for delivery next week or in two weeks could be classified as urgent.

6.1.5. Order Sequencing

Currently, there is not a systematized optimization of the order in which production occurs. Although the company has experimented with production cycles, these practices are not strictly used due to the lack of organization and long lead times they may lead to. As production cycles dictate certain flute profiles and coil width combinations to be produced in odd or even weeks, they narrow the manufacturing plant flexibility, leading to longer lead times. Production cycles are responsible for the reduction of wasted paper in the flute manufacturing and lamination machines' set-up. However, paper waste and product lead time can be considered a trade-off, since that in order to reduce paper waste on set-up, longer lead times are originated. As the main goal of an organization is to create value to the customer, lead time reduction ends up being the strongest criteria from an optimizing perspective. An example of how production cycles may increase lead time is depicted in Figure 54.

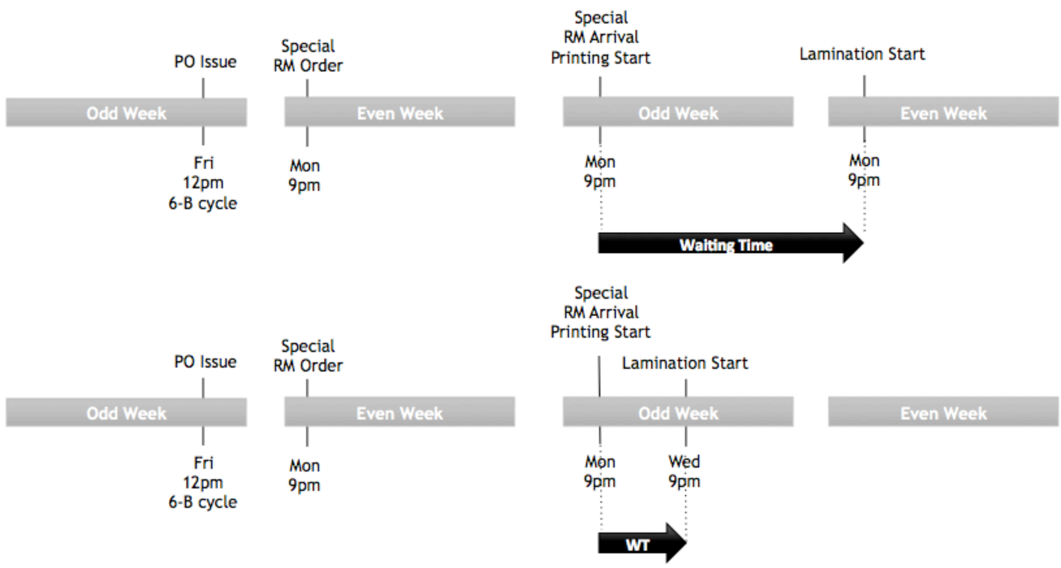

Figure 54 - Conceptual Representation of the Production Cycles Problem

In Figure 54 a PO for a 6-B cycle product is presented. Cycles 6-B are produced in Odd Weeks, as can be seen in Fig. Assuming that the PO was issued on Friday at 12pm, the Purchasing Department will only fulfill the special RM request on Monday, with RM arriving in the RM warehouse next week's Monday. Once RM is available, printing starts. However, as printing starts in an odd week, and according to this method lamination occurs exclusively in even weeks, there is a waiting time of one week between printing and lamination. This means that stock will accumulate between these two sections. In case production cycles were not considered, production would follow its natural flow, despite the aggravated waste of paper in set-up.

Although production cycles strict usage is not recommended, production cycles inspired an optimizing rule that is currently applied to the Lamination Section. This rule consists in having one flute manufacturing machine (17) producing F Flute and E Flute, while the other machine (19) produces exclusively B Flute and Double Flute. Even though this rule represents a good optimization practice, leading to set-up reductions, most of the time the used criteria to order production ends up being delivery date. This means that, for example, if at a certain moment there are only F Flute and E Flute PO's queued, a set-up is performed in machine 19 so that it will also produce F or E flute.

Manufacturing simulation results showed that machine utilization, which is the ratio of actual output to the potential output, ranges from approximately 50% to 65%. In this company's context, low machine utilization rate can be explained due to the need to perform machine adjustments between each order, as different orders may require specific adjustments. However, set-up may take variable amounts of time depending on if it is related to changes in sizing, changes in raw materials type or simply machine cleaning. Therefore, in the case-study company, order sequencing is a very complex problem because of the extremely high product differentiation, which leads to almost mandatory adjustments between each order manufacturing. In order to overcome this problem, further studies regarding optimization practices should be conducted. However, in order to conduct a thorough investigation on this subject, relating set-up times to different order types, more data would be required such as accurate set-up times, since currently they are not rigorously measured. Even thought manufacturing plant employees have a broad idea of set-up times, they are not officially measured. This leads to another improvement opportunity, which is further discussed in the next topic.

6.1.6. Machine Monitoring

During the conduction of studies in the company, it was noticed that machine set-up times and machine velocity were poorly documented. Although section chiefs of each manufacturing section often measure machine's production averages in order to serve capacity evaluation for planning purposes, set-up time measurement is not conducted, even though the section's employees have a general idea of those times and are able to provide estimations. The lack of dependable set-up time information represents an obstacle in order sequence optimization, since without reliable data it is very difficult to understand the influence of different types of set-up in different order types. In order to conduct a thorough study of order optimization, it would be required to possess a set of collected set-up time's data.

As manual registration tends to lead to inaccurate results and can be very time consuming, the company should consider the integration of monitoring devices on the machines.

6.1.7. Closing Section

There were some problems related to workforce identified in Closing Section. While conducting the manufacturing processes simulation, data concerning manufacturing labour was collected. It was noticed that while Printing, Lamination and Cutting and Folding Sections have around 12 labourers each, Closing Section has around 26 labourers, which is more than twice as much as every other section, for the same amount of production. The need for extra labour was analyzed and it was concluded that it is due to the presence of manual tasks in this section. Packages are closed in a gluing machine and then transported by a conveyor system, which needs two labourers placed at its ends so that they put the glued packages in boxes.

On the other hand, there are some package sizes that are not supported by the gluing machines. In this case, packages need to be glued individually by the means of manual processes. Another example is when packages require windows. Although there is a window-gluing machine in the Closing Section, it does not support many window formats. This also leads to the need to glue some packages windows individually and manually. Given the high number of units in each order, all types of manual work are a huge waste of workforce resources. These types of situations were observed on the manufacturing floor during the stay at the company.

Manual work in an industrial environment is very time consuming and therefore the acceptance of orders containing specials formats that are not supported by the machines should be considered thoroughly. Given the complexity of this section and the low degree of automation it currently employs, the company would benefit from a study focusing in its machines and labour force.

6.1.8. Production Visual Management

During the observation of the production process, it was noticed that currently there are not proper visual management tools implemented. Each manufacturing section has a computer where orders that are to be produced are shown under a list in *Planificação*. While a PO is being produced, it is placed on a desk next to the machine. POs that are in queue are placed on that desk or boxes attached to the machine's side. When orders are finished and ready to be collected by employees of the upstream section, they are placed in designated places, which mainly consist in boxes attached to a machine's side or the section chief's desk, as was described in Chapter 4. Therefore, if there is need to instantly know which POs are being produced, the ones that are in queue, concluded POs as well as late PO's, the current organization system does not provide a very immediate and effective visualization method. As an example, printing section (printing machines) current PO sites are shown in Figure 55 and 56.

Figure 55 - In Progress and To Be Produced PO's Site (Printing Machine)

In Figure 55, the desk next to the printing machine is presented. PO's that are stored in the transparent box behind the computer correspond to PO's that are in queue to be produced. The PO that is at the front, on the left, is the one that is currently being produced. The PO located on the right corresponds to the next PO in line to be produced.

Figure 56 - Finished POs (Printing Machine)

In Figure 56, the section chief's desk is presented. Finished POs are stored in those yellow boxes so that employees of the upstream section can collect them. PO's whose next productive step is Lamination are put in the top drawer and are ordered according to their width, following production cycles assumptions. PO's whose next step is Cutting and Folding are placed in the bottom drawer. Each drawer is identified with the respective upstream section, as can be seen in Fig.

In order to improve visual work management, there are two solutions that could be implemented, one regarding physical PO management and another aiming at computerized PO management.

Physical POs should be stored together. In the example shown above, we see that POs are stored in different locations according to their completion status. These storage locations are distributed though many different manufacturing plant places, which differ from section to section. Therefore, the need for systematization incurs. In order to surpass this problem, it would be recommended to group all orders in the same site at each manufacturing section, which would be located next to each section's control computer. PO's could be placed in boxes identified with order status. In case the PO could flow through two different manufacturing sections, the box would be divided and identified with its respective upstream section. There would be one box for PO's in queue, in progress and concluded. A conceptual example of a lean tool designed for this purpose is exhibited in Figure 57.

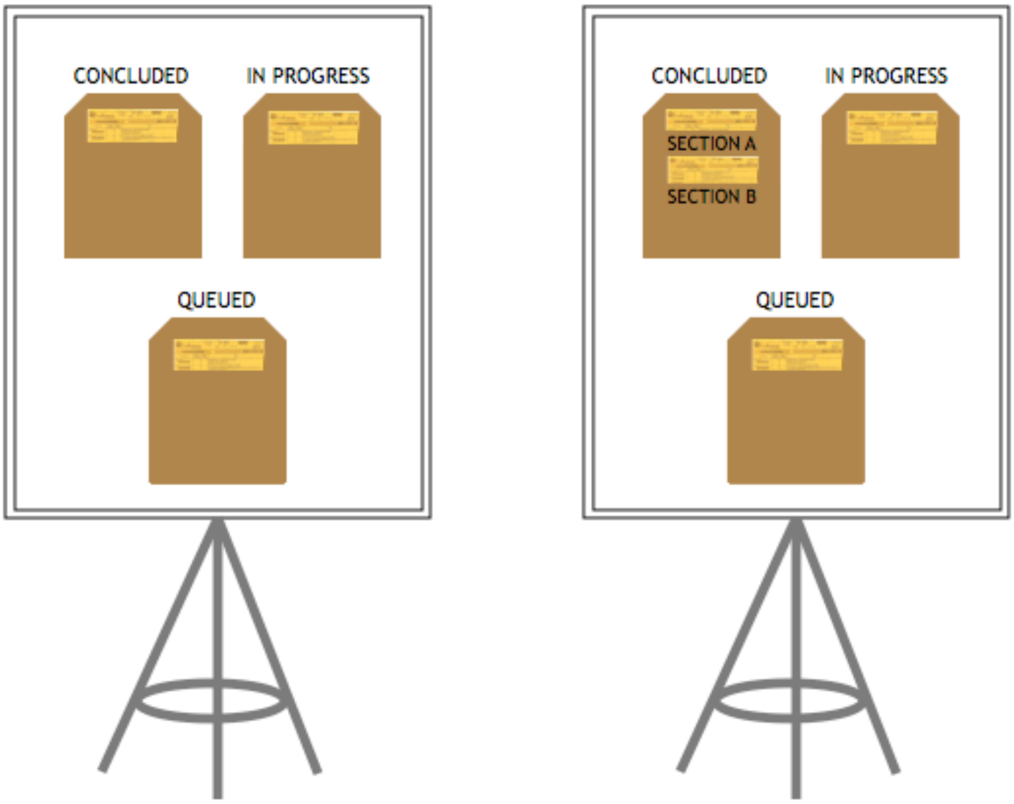

Figure 57 - Prototype of a Visual Management Tool for Physical PO's

In what concerns computerized OP's visual management, the introduction of a dashboard in each factory's section, which would group the PO's interactively into categories such as "in progress", "in queue", "concluded" and "late" would provide means for a better work organization and time management. The dashboard could be integrated with *Planificação* system. PPC Department employees would have access to information regarding all manufacturing sections, while each section employees would have access to information regarding their own section and downstream sections. A conceptual prototype of a dashboard for computerized visual management is presented in Figure 58.

Figure 58 - Conceptual Prototype of a Dashboard for Computerized Visual Management

Another visual management improvement opportunity would consist in attributing the product's family groups color code to the physical POs (Table). This would provide means for an easy and fast manufacturing operations identification. This way, all POs for product family G1 would be printed in orange; POs for product family G2 would be printed in yellow; POs for product family G3 would be printed in green; PO's for product family G4 would be printed in red; PO's for product family G5 would be printed in light orange; and PO's for product family G6 would be printed in blue. Prototypes for the colored POs are presented in Appendix 7.

As an example, when the PO arrived in the Pre-Printing Section, the section responsible would immediately know that this PO would require Plate Separation. The following logic applies to all types of families. The introduction of this color identification mechanism would also provide for a better work organization and control.

6.1.9. Cutting and Folding Section Bottleneck

The Manufacturing Simulation enabled the detection of two bottlenecks: one in the Cutting Machine and another in Cutting and Folding Section. The bottleneck detected in the Cutting Machine was not considered critical, since is may be explained by the excess of orders in the simulation week. As there was no time for the completion of all orders, there were two orders that where introduced in the system, from the raw material warehouse and kept at the Cutting Machine buffer, being held there until simulation end. Therefore no emphasis is provided to this bottleneck. However, the Cutting and Folding Section Bottleneck was considered critical. This means that input comes in faster than Cutting and Folding machines can use it to create output. Identifying and fixing bottlenecks is extremely important to a manufacturing company since bottlenecks may be the cause to a lot a problems such as wasted time, poor quality products, high stress in team member, ultimately leading to dissatisfied customers and lost revenue. Bottlenecks can be eliminated by the means of two classic approaches: increasing the efficiency of the bottleck step or decreasing input to the bottleneck step. Following a first approach, removing activities from the bottleneck process that could be outsourced to other human or machine resources could be a possible measure to implement. Also, assigning the most productive team members and technology, much as machinery, to the Cutting and Folding process could introduce improvements. Ultimately, adding capacity in the bottleck process could also contribute to problem elimination. Bottleneck process capacity could be reached by introducing additional machines. The other approach, decreasing input to the bottleneck step, ensures that no more than is ultimately manageable is produced. This eliminates the amount of work-in-progress inventory immediately before the step that is not working efficiently.

The aim of this study was simply to identify the manufacturing plant most critical section and provide some advise to ways in which this problem could be surpassed. Although some recommendations are made to the company, in order to choose an action strategy to eliminate this bottleneck, more studies would have to be conducted in order to evaluate the cost-benefit relation of the all possible solutions before implementation.

6.2. To-Be Model

In this section, the company's To-Be Model is presented. In order to characterize the To-Be-Model, Level 1 Customer Oriented Core Processes Model (Production Process), Level 1 Production Planning and Control Process Model and Future State VSM for G1 are depicted, as well as a description of the modified processes. The changes introduced in each of the referred models reflect the detected improvement opportunities described in the previous section.

6.2.1. Process Models

Figure 59 depicts Future Level 1 Customer Oriented Core Processes Model (Production Process).

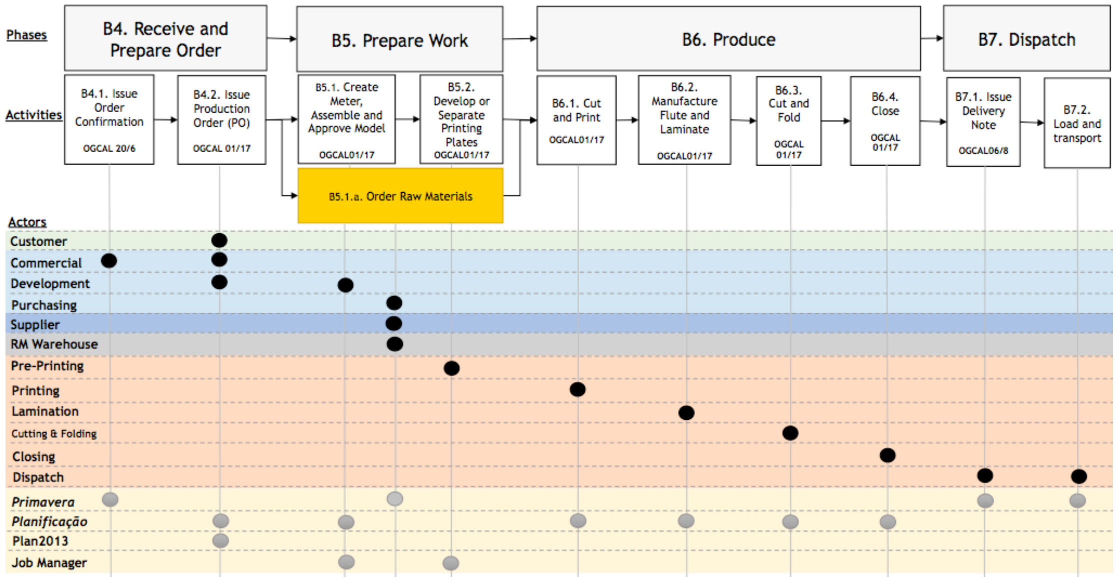

Figure 59 - Future Level 1 Customer Oriented Core Processes Model (Production Process)

In this representation, changed activities and actors are highlighted in bright yellow. It is seen that in this process, B5.1.a, Order Raw Materials, has suffered modifications. As was identified in the improvement opportunities section, in the future model the PO list is collected from *Primavera* ERP every day rather than on Mondays, Wednesdays and Fridays. Also, PO's that require special raw materials are treated differently since the Commercial Department detects special raw materials need upon order receivable, which is instantly communicated to the Purchasing Department so that they can fulfill the request.

In Figure 60, Future Level 1 Production Planning and Control Process Model is presented.

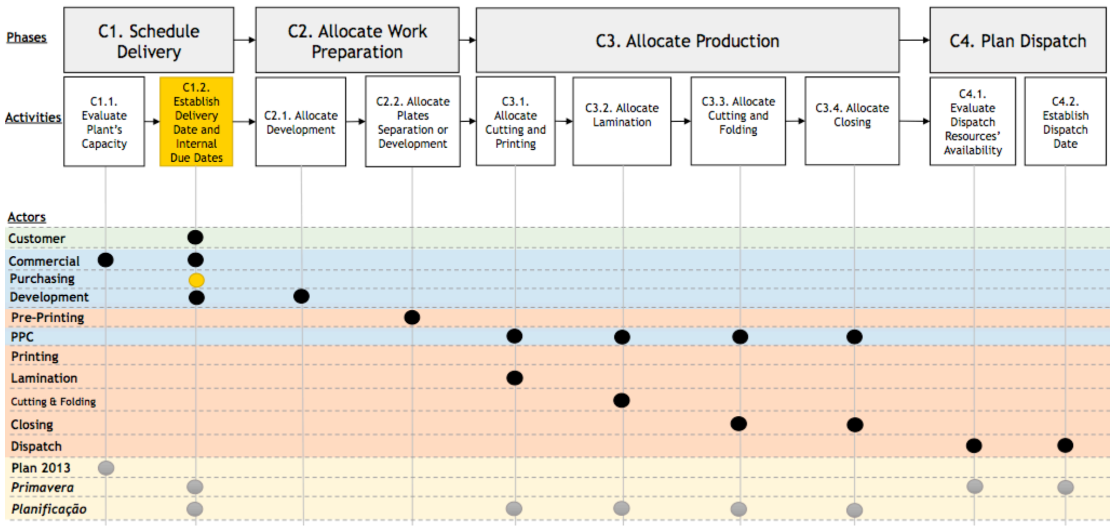

Figure 60 - Future Level 1 Production Planning and Control Process Model

This representation shows that C1.2 activity, Establish Delivery Date and Internal Due Dates, was changed. Changes in this activity's actors were also performed. The establishment of internal due dates was added, which means that after this modification internal planning, which did not exist in the previous model, will be conducted. According to the introduced alterations, stock levels will also be considered when establishing a customer delivery date.

In the company's As-Is-Model, customer delivery date is scheduled according to customer's preferences and available resources in the manufacturing plan. However, in the To-Be-Model, raw materials availability is also considered. C1.2 activity is further described by the means of a flow chart, which is shown in Figure 61.

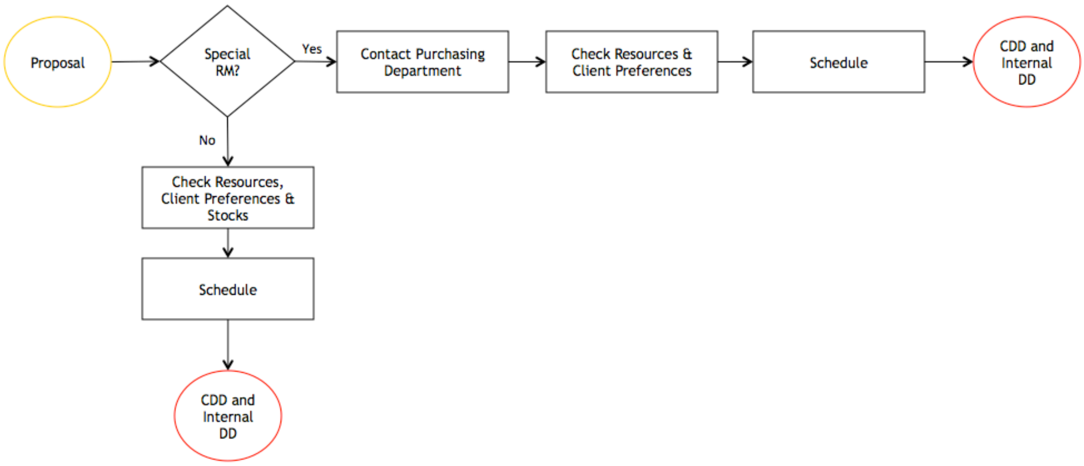

Figure 61 - Establish Delivery Date (CDD) and Internal Due Dates Activity Flow Chart

6.2.2. Value Stream Maps

In Figure 62, future VSM for G1 is presented.

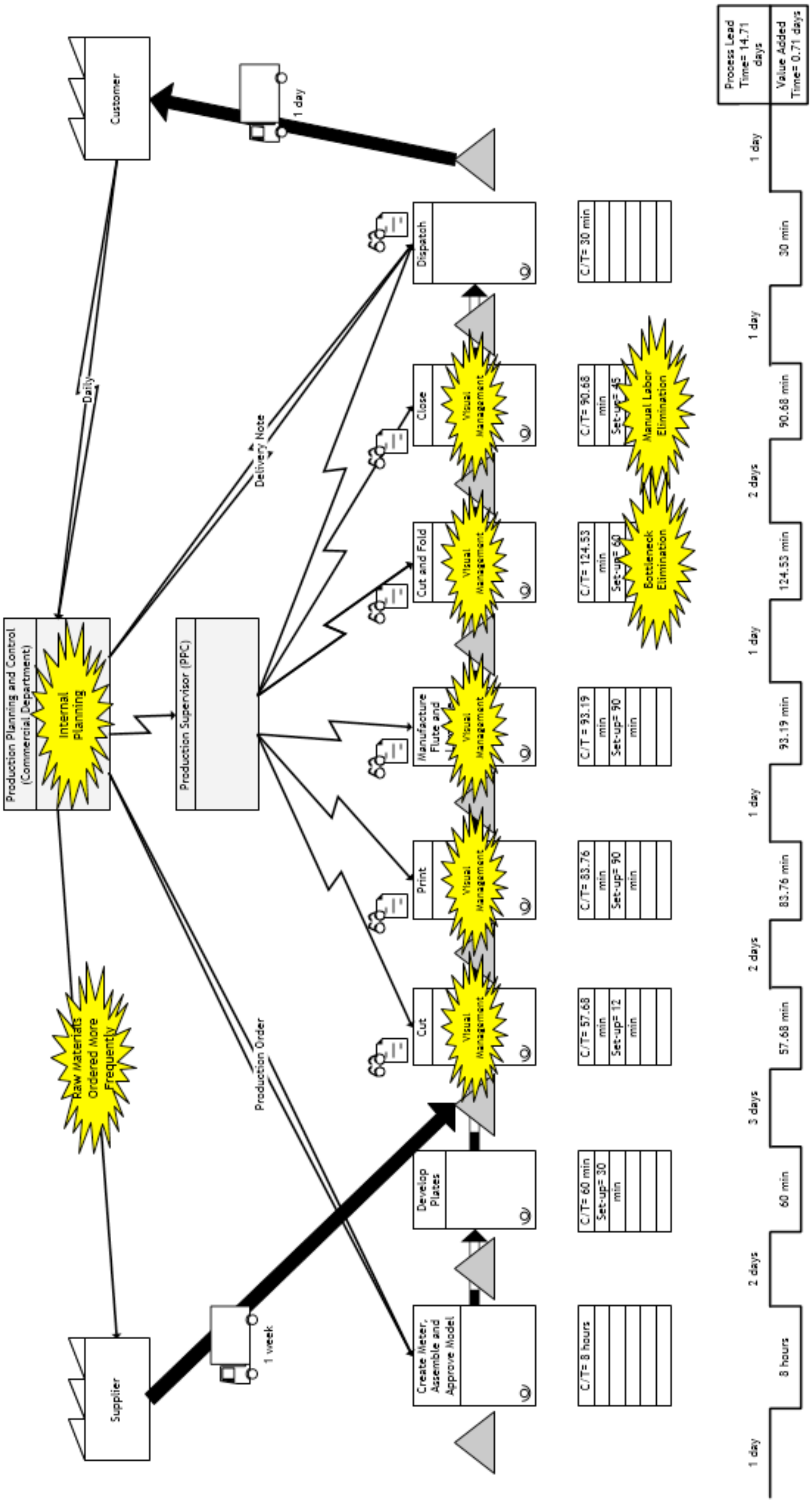

Figure 62 - Future Value Stream Map (G1)

In Figure 62 representation, kaisen bursts, which consist in events that target particular problems within a company, are shown in yellow. These events, when carried out by a cross-functional team, will result in dramatic changes for the company. Internal planning, more frequent RM order, visual management, manual labour elimination and bottleneck elimination were the main identified kaisen events that will help the company to improve while taking one further step into lean management.

In what concerns family product group G3, the identified kaisen events are the same as the ones identified for G1. Future state VSM for G3 is depicted in Figure 63.

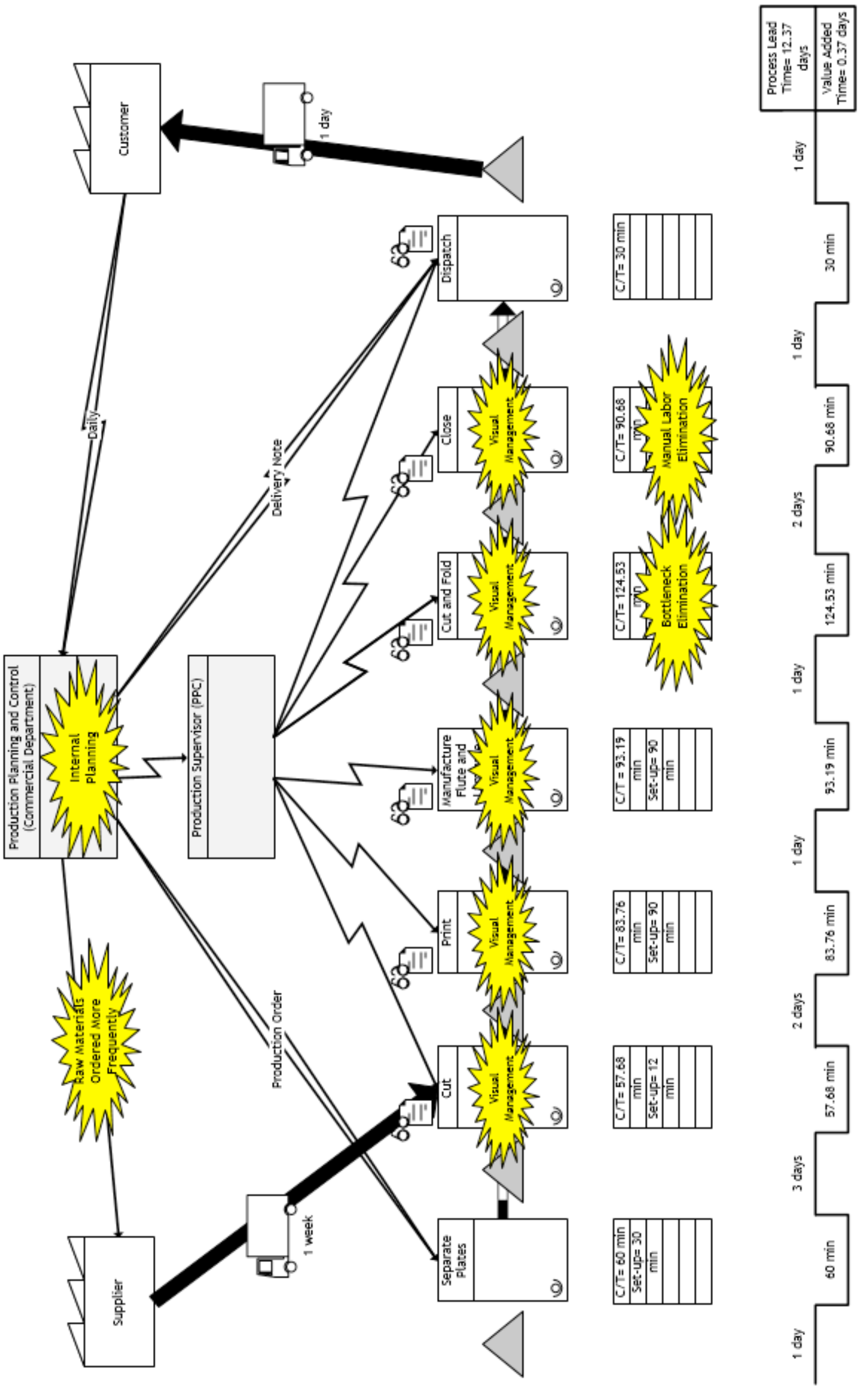

Figure 63 - Future Value Stream Map (G3)

Chapter 7

Conclusions

The structure of this concluding chapter is as follows. In Section 7.1., a general overview is presented by addressing problems and improvement opportunities to their respective solution proposals, posing the research questions and answers. Directions for futher research are discussed in Section 7.2, while Section 7.3 presents the author's concluding remarks.

7.1. General Overview

As a result of the company's As-Is Model built based on observation and data collection, as well as the conducted Manufacturing Simulation, problems and improvement opportunities for the case study company were identified and possible solutions for these problems were discussed. These solution proposals were developed in order to respond to the following detected problems:

1. The availability of raw materials is not considered when establishing a CDD.
2. When defining a CDD no internal planning is performed.
3. The raw materials order activity is conducted in specific days, rather that when necessary.
4. Concerning production, order sequencing is not optimized.
5. There are not any machine monitoring devices in the manufacturing plant.
6. There is excessive labor force and lack of automation in the closing section.
7. Manufacturing sections lack visual management tools.
8. There is a bottleneck in the Cutting and Folding Section.

The first acknowledged problem may incur in order delivery lateness, since when delivery date is established no indication of raw materials availability is available, since the Commercial Department does not have access to raw materials database. By providing access to RM related data and communication with the Purchasing Department, the establishment of CDD would be more accurate.

With respect to the second detected problem, the need to perform an internal planning when establishing a CDD was explained by emphasizing the lack of organization that incurs from the current lack of planning. The option considered to provide better internal organization consists in introducing planning support by the means of adding an internal planning functionality to the existing *Planificação* system.

In what concerns the third obstacle, the option considered to provide more frequent special raw materials request to suppliers would also be associated with the introduction of a special raw materials detection mechanism in *Primavera* system. This system should also be scheduled to collect PO's list every day rather that three times a week so that RM necessities could be fullfilled more regulary.

Regarding production order sequencing, it was concluded that the production cycles mechanism is not recommended. Due to the lack of accurate order manufacturing data, especially in what concerns machine set-up times, which are highly variable, it was not possible to study the influence of set-up times in diferent order types or identify patterns in set-up. Also, set-up time measurement by the author was not viable due to the extremely high product variation and project time limitations. This lead to another detected problem, concerned with the lack of counting devices in the machines. In order to enable the possibility of conducting thorough studies in this area, from whose the company would benefit, a suggested option would be conducting a market survey in order to find a counting solution that would fit the company's needs. Altough there are copious amounts of production manufacturing and scheduling software solutions available in the market, further studies regarding cost and benefit would have to be pursued in order to verify the viability of introducing one of these software solutions in the company.

With respect to the Closing Section problem, special size order acceptance is not recommended since it is not profitable due to the high amount of human resources it mobilizes in the Closing Section. Due to this section's lack of automation and high labor force in relation to all other manufacturing sections, an option to increase the degree of automation in this section would be to perform a machine update. This way, it is eminently recommended to focus on surveying the market for better technological solutions.

The bottleneck situation would be surpassed with the adoption of physical and computarized visual management tools in all the manufactuing sections. While the physical PO solution would have a low ease of implementation, since it consists in a physical dashboard with identified boxes to place POs, the *Planificação* solution aims at the development of an integrated visual management module.

Finally, the last problem, which is concerned with a bottleck in the Cutting and Folding Section, could be eliminated by the means of two bottleneck elimination approaches: increasing the efficiency of the bottleneck step or decreasing input to the bottleneck step. Even though some recommendations to overcome this problem were suggested, in order to choose an action plan more thorough studies, regarding solutions' cost-benefit relation would have to be conducted so that the company could make the best of the chosen solving approach.

7.2. Directions for Further Research

This chapter addresses a summary of the problems and respective solution proposals that were possible to detect based in the company's As-Is Model construction and analysis. Even though solutions were suggested, those solutions were not developed and implemented. Some of the proposed solutions could represent independent projects. However, several research aspects remain open and could be further explored. As such, a list of some of those investigation topics is exhibited, as well as projects that could be developed as means to implement the solutions proposed in this dissertation.

1. Focus on order sequencing optimization problem. Due to data, time and focus restrictions, it was not possible to fulfill the need to study the order sequencing optimization problem. As a continuation of this study, and after means for more accurate data acquisition are implemented, it would be relevant to conduct a study aiming at production management improvement following an alternative quantitative approach. Existing scheduling software could be adopted as a vehicle to determine optimal order sequence. Another study opportunity, although at a higher complexity level, would be to develop heuristic methods for this company's particular production scheduling problem.

2. Study of the Closing Section. As was exposed in Chapter 6, the Closing Section is the manufacturing plant's section that mobilizes the most human and machine resources. Even though the particular improvement of this section is out of this dissertation's scope, the need to further analyze this section's behaviour was detected as a result of the holistic study conducted. An alluring approach would be to conduct an investigation and respective investment analysis of technological solutions that could introduce more flexibility in this section and reduce labor force.

3. Another interesting project that could be handled in the future would be the development of a visual PO management module that would support better visual management and work monitoring in the manufacturing sections.

4. Analyze the hypothesis of performing a Commercial and Purchasing Departments aggregation. Since interaction between these two departments is crucial, an analysis of this change in the company's organizational structure could be conducted.

5. Develop a strategy for Cutting and Folding bottleneck elimination.

7.3. Concluding Remarks

The solutions found with the support of the company's As-Is Model and Manufacturing Simulation can provide significant improvements in the company's customer oriented processes, as well as in the planning and control process. Future implementation of these solutions will lead to product lead time decrease while contributing to the company's overall better process organization and monitoring. The set of changes that resulted from the holistic study approach will enable the company to take a further step into lean thinking. In addition, future research regarding order sequencing may reveal itself a very important contribution to a comprehensive improvement of production management.

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Appendix

Appendix 1

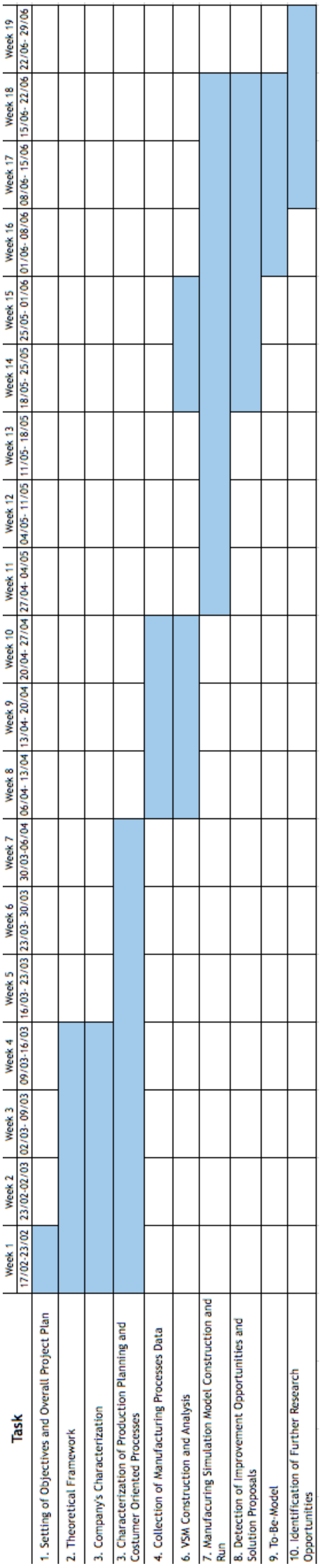
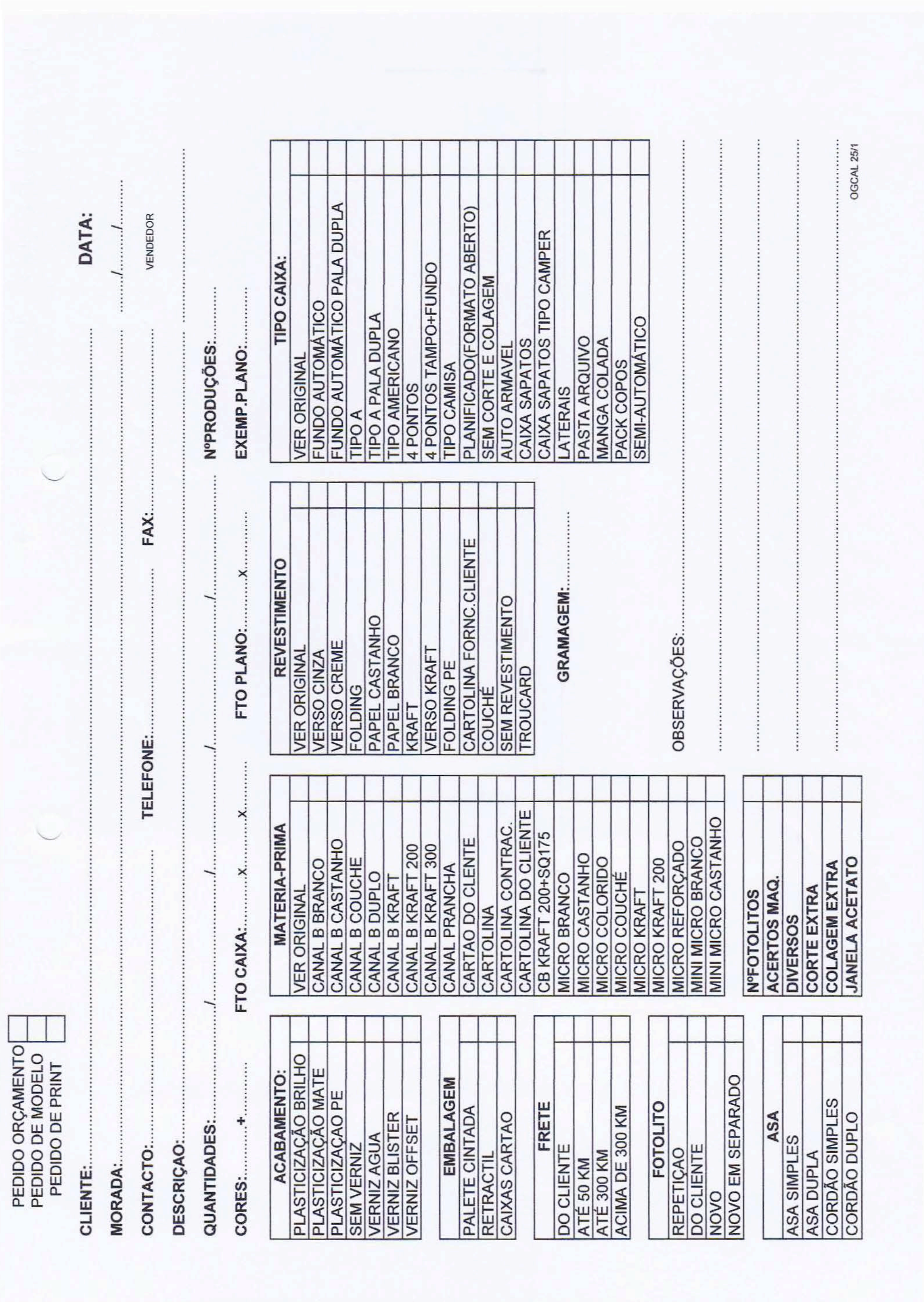


Figure 64 - Project Long Term Planning (Gantt Chart)

Appendix 2 – Company's Internal Documents



PEDIDO ORÇAMENTO
PEDIDO DE MODELO
PEDIDO DE PRINT

CLIENTE: .... DATA: ..../..../....

MORADA: ....

CONTACTO: .... TELEFONE: .... FAX: .... VENDEDOR

DESCRIÇAO: ....

QUANTIDADES: ..../..../..../..../.... NºPRODUÇÕES: ....

CORES: ....+.... FTO CAIXA: ....x....x.... FTO PLANO: ....x.... EXEMP.PLANO: ....

ACABAMENTO:	
PLASTICIZAÇÃO BRILHO	
PLASTICIZAÇÃO MATE	
PLASTICIZAÇAO PE	
SEM VERNIZ	
VERNIZ AGUA	
VERNIZ BLISTER	
VERNIZ OFFSET	

EMBALAGEM	
PALETE CINTADA	
RETRACTIL	
CAIXAS CARTAO	

FRETE	
DO CLIENTE	
ATÉ 50 KM	
ATÉ 300 KM	
ACIMA DE 300 KM	

FOTOLITO	
REPETIÇAO	
DO CLIENTE	
NOVO	
NOVO EM SEPARADO	

ASA	
ASA SIMPLES	
ASA DUPLA	
CORDÃO SIMPLES	
CORDÃO DUPLO	

MATERIA-PRIMA	
VER ORIGINAL	
CANAL B BRANCO	
CANAL B CASTANHO	
CANAL B COUCHE	
CANAL B DUPLO	
CANAL B KRAFT	
CANAL B KRAFT 200	
CANAL B KRAFT 300	
CANAL PRANCHA	
CARTAO DO CLIENTE	
CARTOLINA	
CARTOLINA CONTRAC.	
CARTOLINA DO CLIENTE	
CB KRAFT 200+SQ175	
MICRO BRANCO	
MICRO CASTANHO	
MICRO COLORIDO	
MICRO COUCHÉ	
MICRO KRAFT	
MICRO KRAFT 200	
MICRO REFORÇADO	
MINI MICRO BRANCO	
MINI MICRO CASTANHO	

NºFOTOLITOS	
ACERTOS MAQ.	
DIVERSOS	
CORTE EXTRA	
COLAGEM EXTRA	
JANELA ACETATO	

REVESTIMENTO	
VER ORIGINAL	
VERSO CINZA	
VERSO CREME	
FOLDING	
PAPEL CASTANHO	
PAPEL BRANCO	
KRAFT	
VERSO KRAFT	
FOLDING PE	
CARTOLINA FORNC.CLIENTE	
COUCHÉ	
SEM REVESTIMENTO	
TROUCARD	

GRAMAGEM: ....

TIPO CAIXA:	
VER ORIGINAL	
FUNDO AUTOMÁTICO	
FUNDO AUTOMÁTICO PALA DUPLA	
TIPO A	
TIPO A PALA DUPLA	
TIPO AMERICANO	
4 PONTOS	
4 PONTOS TAMPO+FUNDO	
TIPO CAMISA	
PLANIFICADO(FORMATO ABERTO)	
SEM CORTE E COLAGEM	
AUTO ARMAVEL	
CAIXA SAPATOS	
CAIXA SAPATOS TIPO CAMPER	
LATERAIS	
PASTA ARQUIVO	
MANGA COLADA	
PACK COPOS	
SEMI-AUTOMÁTICO	

OBSERVAÇÕES: ....

OGCAL 25/1

Figure 65 - Company's Internal Documents: OGCAL 25/1 (Request Form)

calheiros
embalagens

Pedido de Modelo,Print e Orçamento

Artigo **Ref.**
Cliente
Vend.
Empr. **Data Criação**

Cores: + c/

Tipo Caixa:

Fto. Caixa: xx

Mat. Prima:

Janela Acetato: **Não Microns**

Asa/Cordão: **Não**

Ultimo Calculo Orçamento:

Lâmina a Lâmina: x Exemplares: +

Observações

Modelo:.. **Data:** ..../............../..............

Print:.. **Data:** ..../............../..............

OGCAL 88/8 2009-10-29

Figure 66 - Company's Internal Documents: OGCAL 88/8 (Request Form)

ESTE PRINT TEM QUE SER DEVOLVIDO DEPOIS DE CONFERIDO E ASSINADO

CLIENTE: ....

DESCRIÇÃO:.. V/ REFª...........................

Nº CORES: .... N/ ARTIGO ....

RESP. PROJECTO.......................................DATA ..../ ..../ ....

APROVAÇÃO DO CLIENTE

A assinatura desta etiqueta indica que o presente layout está **APROVADO** e foi **CONFERIDO** (texto/"lettering", cores e localização dos elementos), sendo da v/ inteira responsabilidade verificar que o mesmo cumpre com os v/ requisitos.

O CLIENTE .... DATA ..../ ..../ ....

OGCAL 164/0

ESTA MAQUETA TEM QUE SER DEVOLVIDA DEPOIS DE TESTADA E ASSINADA

CLIENTE. ....

DESCRIÇÃO:.. V/ REFª...........................

FTO.: ..............X..............X............ N/ ARTIGO ....

MAT.PRIMA:.. REVEST.:...........................

RESP. PROJECTO.......................................DATA ..../ ..../ ....

CAIXAS C/ PICOTE ☐

APROVAÇÃO DO CLIENTE

A assinatura desta etiqueta indica que a presente maqueta está APROVADA e foi **TESTADA** em termos de estrutura, resistência e funcionalidade, sendo da v/ inteira responsabilidade verificar que a mesma cumpre com os requisitos ao fim a que se destina.

O CLIENTE .... DATA ..../ ..../ ....

OGCAL 159/1

Figure 67 - Company's Internal Documents: OGCAL 164/0 (Print) and OGCAL 159/1 (Model)

calheiros embalagens

Cálculo para Orçamento **6110**

Cores: 1 + 0 Plasticização PE

Cortante:

570 X 990 Plano: 60 X 102 Ex. 12 + 0 Acertos: 1 Perc Media:

C o r t e a o C o n t r á r i o

Seccao	Descricao	Papel Entrada	Papel Saida	Mult	Valor	Acerto	Prod.	Tempo Total
Total	13836.1059628849	51.266	0	1	13.836.11	0.00	0.00	0.00
Micro	CARTOLINA	50.556	0	1	0.00	0.00	0.00	0.00
Papel	CI400	51.266	12.550	1	7.404.41	0.00	0.00	0.00
020.01	Modelos	0	0	1	7.50	0.00	0.30	0.30
020.02	Esquadrias	0	0	1	12.50	0.00	0.50	0.50
020.03	Plotter Esquadrias	0	0	1	3.06	0.00	0.12	0.12
030.01	Montagem Electrónica	0	0	1	75.00	3.00	0.00	3.00
030.02	Montagem Aprovação	0	0	1	0.00	0.00	0.00	0.00
030.03	Prova Imposição	0	0	1	18.36	0.00	0.61	0.61
030.04	Prova cor	0	0	1	18.36	0.00	0.61	0.61
050.01	Chapas	0	0	1	7.00	0.00	0.20	0.20
5000.020.001	Tinta	51.266	0	1	282.37	0.00	0.00	0.00
0600.001.006	CHAPA ARTE IP 21 795x1050	0	0	1	10.50	0.00	0.00	0.00
050.10	KBA 74x105-4 Cores + Verniz	51.266	50.556	1	891.56	2.00	10.21	12.21
5000.010.004	Plasticização PE	50.556	0	1	4.022.16	0.00	0.00	0.00
[illegible]ante	Cortante	0	0	1	206.27	0.00	0.00	0.00
[illegible].02	Separação Cortantes	0	0	1	3.50	0.00	0.10	0.10
085.01	Preparação Cortantes	0	0	1	60.00	1.00	1.00	2.00
080.20	Bobst 72x102	50.556	50.000	1	540.05	1.00	14.43	15.43
CAIXA CARTÃO	PA007362	0	0	1	147.67	0.00	0.00	0.00
110.01	Embalagem	0	0	1	25.84	0.00	0.00	0.00
Frete	PA007362	0	0	1	100.00	0.00	0.00	0.00
Metros 3	PA007362	600.000	0	0	14.77	0.00	0.00	0.00

Artigos a Produzir

Artigo / Cliente	**Descricao** / Cliente	**Tipo de Caixa**	**RefCliente** / Formato	**Quantidade**
PA007362	**TAMPAS NO FTO. 247X188**	PL0001	**247X188**	**600,000**
1873 0 + 0	DIAS ARAÚJO & SOBERANO SANTOS, LDA.		247 X 188 X 0 X 0	MAX:600,000

Stocks

QTD	Unid.	Artigo	Descricao	Formato1	Formato2	Corte1	Corte2	Gramagem
12,550	KG	CI400120	V/ CINZA	120		60	102	400
0	UN	CAIXA CARTÃO	Caixa Cartão					

Observações:

Figure 68 - Company's Internal Documents: OGCAL 157/2 (Budget Calculation)

Contacto:
comercial@calheiros.pt

Ou
Conceição Gomes
+351 229 773 234
comercial@calheiros.pt

organização gráfica calheiros, sa
EMBALAGENS EM CARTOLINA • MINIMICRO • MICROCANELADO • CANAL B

SGS SGS SGS PME líder

Orçamento Nº 801807

Data: **2008-04-24**

Exmos. Srs.
Cliente nº 0069
ISAURA GUERRA - COM. E REP. DE EMBALAGENS
RUA LUIS DE CAMÕES, 24
2625-115 PÓVOA DE STA. IRIA

Exmos. Senhores.

Com os n/ cumprimentos temos o prazer de submeter à apreciação de V. Exªs. a proposta abaixo discriminada, a qual será executada conforme V/ ordens.

Artigo	Descrição	QTD.	Preço Un.
PA004159	TAB. BARBISCO P/24 UNIDADES TAMPA CARTOLINA V/ Refª BARBISCO no fto. 260x388x92 mm. do Tipo 4 PONTOS, em Micro Branco Revestido a V/ Cinza 230 Grs, litog. a 2 cores (Frente), c/ Verniz Brilhante, Embalado em CAIXA DE CARTÃO. Acessórios: 1 x PA004161 - TAMPA CARTOLINA. em 1 entrega(s).	5,000	0.50380
PA004161	TAMPA CARTOLINA V/ Refª TAMPA no fto. 560x250 mm. do Tipo PLANIFICADO, em Cartolina V/ Cinza 350 Grs	5,000	0.00000
PA004159	IDEM. em 1 entrega(s).	10,000	0.37880

APROVADO
Rubrica
Data 8 / 12 08

Documento processado por computador

Condições Pagame **A Combinar**

Prazo de Entrega: **A Combinar**

OBS: **VALORES SUJEITOS A 21% IVA - VÁLIDO POR 15 DIAS**

Esperando merecer a honra da v/ aprovação, o que antecipadamente agradecemos, subscrevemo-nos com elevada estima e consideração.

-Dada a natureza especifica desta industria, as encomendas estão sujeitas a um aumento ou diminuição das quantidades até 10%.

-Reservamos o direito de alterar os preços sempre que haja alteração nos custos da metéria-prima.

De V. Exªs.,

Atenciosamente

OGCAL 14/2 Pag.
Rua das Macieiras 220 • Apt. 4008 • 4445-502 Ermesinde • Tel.: (+351) 229 773 220 • Fax: (+351) 229 773 225 Contribuinte n.º IVA PT 500 207 976
Sociedade Anónima • Capital Social 2.330.000 Euros • Matriculado na C.R.C. de Valongo, com o n.º 500 207 976 • E-mail: grafica@calheiros.pt • www.calheiros.pt

Figure 69 - Company's Internal Documents: OGCAL 14/2 (Budget Presentation)

Departamento Comercial: Conceição Gomes (comercial@calheiros.pt)
Departamento da Qualidade: Cláudia Barros (claudia@calheiros.pt)
Departamento de Expedição: Susana Ferreira (susana@calheiros.pt)

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SGS SGS SGS PME lider

Exmo.(s) Sr.(s)
FLAMA - FÁB. DE LOUÇAS E ELECTRODOMÉSTICOS, S.A.
ZONA INDUSTRIAL
APARTADO 2041
3701-906 CESAR
PORTUGAL

Confirmação de Encomenda
Nº 1000450

Contribuinte	Cliente	Condição Pagamento	Data	Pag.
PT 500903352	0011	90 Dias	2010-03-30	1/1

Com os n/cumprimentos temos o prazer de confirmar a V. Sa(s)., a(s) alínea(s) discriminada(s) abaixo, que será executada conforme as V/ ordens:

Artigo	Qt.Enc.	Descrição	Pr. Unitário	Entrega Prevista
D5970H	3,500	CAIXAS FLAMA MAGNUS 439FL V/ Refª 6001.439.0001 no fto. 410x175x339 mm. do Tipo FUNDO AUTOMÁTICO COM FECHO, em Micro Castanho Revestido a V/ Cinza 220 Grs, litog. a 4 cores (Frente), c/ Verniz Anti-Fricção, Embalado em CAIXA DE CARTÃO. Acessórios: 1 x PA000015 - INTERIOR . em 1 entrega(s). Possivel variação da quantidade a entregar: +/- 10% V/ REQUISIÇÃO: A1000340	0.73000	**SEM 15**
PA000015	3,500	INTERIOR REFª 6001.439.0001 V/ Refª 6001.439.0001-INTERIOR no fto. 402x167x339 mm. do Tipo INTERIOR PLANIFICADO, em Micro Castanho Revestido a V/ Cinza 215 Grs V/ REQUISIÇÃO: A1000340	0.00000	**SEM 15**
E2229B	2,000	CAIXAS FLAMA 427FLREFª 6001.427.0001 V/ Refª 6001.427.0001 no fto. 300x100x530 mm. do TIPO A PALA DUPLA COM FECHO, em Micro Castanho Revestido a V/ Cinza 220 Grs, litog. a 4 cores (Frente), c/ Verniz Anti-Fricção, Embalado em CAIXA DE CARTÃO. em 1 entrega(s). Possivel variação da quantidade a entregar: +/- 10% V/ REQUISIÇÃO: A1000340	0.89870	**SEM 15**
		==> PRAZO ENTREGA POSSÍVEL: SEM 15		
		===> ENTREGA ÚNICA <===		

Documento Processado por Computador

Total Documento (EUR) **4,352.40**

Prazos de Entrega: Apresentação da prova - 8 dias úteis após todos os elementos em nosso poder.
Entrega da Encomenda - A confirmar após aprovação do modelo e prova pelo cliente.

Observações: VALORES SUJEITOS A IVA À TAXA EM VIGOR - VÁLIDO POR 15 DIAS

Os elementos físicos e informáticos entregues à Organização Gráfica Calheiros, serão destruidos no prazo de 3 meses se a sua devolução não for solicitada.

Qualquer reclamação deverá ser apresentada e justificada no prazo de 30 dias após a entrega da mercadoria.

Agradecendo desde já a V/ preferência,
subscrevemo-nos com elevada estima e consideração

De V. Sa(s).,
Atenciosamente,

OGCAL 20/6

- Dada a natureza especifica desta indústria, as encomendas estão sujeitas a um aumento ou diminuição das quantidades até à percentagem indicada no artigo.
- Reservamos o direito de alterar os preços sempre que haja alteração nos custos da matéria-prima.

CALHEIROS EMBALAGENS, S.A.
Rua das Macieiras, 220 • Apt. 4008 • 4445-502 Ermesinde • Tel.: (+351) 229 773 220 • Fax: (+351) 229 773 225 Contribuinte n.º IVA PT 500 207 976
Capital Social 2.330.000 Euros • Matriculada na C.R.C. de Valongo, com o n.º 500 207 976 • E-mail: grafica@calheiros.pt • www.calheiros.pt

Figure 70 - Company's Internal Documents: OGCAL 20/6 (Order Confirmation)

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Montagem AA13846

OP 19215

Plano: 133 X 80 Ex. 4 + 0

Ciclo: 8-A

2014/10
2014-03-07

Corte ao Contrário

Micro - CI210 + MB

Descricao	Papel Entrada	Papel Saida	OBS
Esquadrias	0	0	Cortante Novo - Tipos de Caixa:AA0001 Lamina: 1304 x 766 % 6.52 Verificado e aprovado por:____________
Montagem Aprovação	0	0	Fotolito Novo - Codigo Montagem: AA13846 => CLIENTE ENVIOU LINK P/FAZER O DOWNLOAD - EMAIL 06/02/14 AC Verificado e aprovado por:____________
Cortadeira Apollo	13,707	13,541	Lote da cartolina:____________ Fornecedor____________ QTD Prod.____________ Responsável:__________
Revelação Chapas	0	0	Queima e Lavagem de chapas SIM / NÃO Verificado e aprovado por:____________
KBA 102x142-4 Cores +	13,541	13,062	Verniz Água - Cores 4+0 Validação do arranque da produção/limpeza da linha:__________ Verificação de ______ em ______ Planos. QTD Prod.__________. Resp:__________
Onduladora Secção 070.	13,062	0	Usar Papeis: B125133 + F85133
Contra Colagem DDL c/ F	13,062	12,882	Humidade Registada:________ Responsavel:__________ Validação do arranque da produção/limpeza da linha:__________ Verificação de ______ em ______ Planos. QTD Prod.__________. Resp:__________
Bobst 102X142	12,882	12,703	Cortante nº 13846. Validação do arranque da produção/limpeza da linha:__________ Verificação de ______ em ______ Planos. QTD Prod.__________. Resp:__________
Janelas Nova	50,812	50,000	Acetato de 100 Microns - PA041406Validação do arranque da produção/limpeza da linha:__________ Verificação de ______ em ______ Caixas. QTD Prod.__________. Resp:__________ ==> Só aplicar a janela após boa secagem da contracolagem
Embalagem	0	0	PALETE C/ FILME ESTIRÁVEL às 3000 - PA041406
Expedicao	0	0	Tem artigos associados: PA041405

CÓPIA NÃO NEGOCIÁVEL
NONNEGOTIABLE COPY

Artigos a Produzir

Artigo / Cliente	Descricao / Cliente	RefCliente / Formato	Quantidade
PA041406	CAIXA GO AFRICA (TAMPO)	TAMPO	50,000
0202	CONFEITARIA CARLOS GONÇALVES, LDA.	375 X 249 X 67 X 0	MAX:55,000

Stocks

Kgs	QTD	Artigo	Descricao	Fto1	Fto2	Corte1	Corte2	GRM	Area
3,217	13,707	CI210133	V/ Cinza 210 Grs Bobines 133 Cm	133			80	210	H02
1,818	13,062	B125133	Branco 125 Grs bobines 132,5 Cm	133			80	125	E04
1,737	18,286	F85133	Fluting 85 Grs Bobines 133Cm	133			80	85	C10
605	50,812	1000.002.001	Acetato 100 Micros FTJanela 35x20	35	20			170	

OGCAL 01/17

2014-02-18

Figure 71 - Company's Internal Documents: OGCAL 01/17 (Production Order)

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SGS SGS SGS PME líder

Exmo.(s) Sr.(s)
CLOVER PORTUGAL, UNIPESSOAL, LDA.
RUA DO GALHANO, Nº 11

VARZIELA - ÁRVORE
4480-586 VILA DO CONDE

Triplicado

Guia Remessa GR 2014/1400825

Pág. 1/1

Chave AT: 882919954

V/Nº Contrib.	Desc. Cli.	Desc. Fin.	Condição Pagamento	Vencimento	Data	Cliente	Vend.
PT 507228340	0.00	0.00	90 Dias	2014-07-06	2014-04-07	1023	07

Artigo	Descrição	Quant.	Un	Lote	V/ Requisicao
PA006164	CAIXA (00) OFFICE DEPOT REFª 832289-100	1,100	UN	18815	HP140029
	VOLUMES 1X1100				
PA019755	CAIXA (0) Q-CONNECT (PLAISIO) REFª 832290-048	2,370	UN	19012	HP140118
PA019755	CAIXA (0) Q-CONNECT (PLAISIO) REFª 832290-048	450	UN	19012	HP140118
	VOLUMES 3X940				
PALETES	PALETES ENTREGUES	4	UN	1023	

Este documento não serve de fatura
cj2V-Processado por Programa Certificado n.º 0030/AT / GR 2014/1400825 / © PRIMAVERA BSS /

Carga - N/ Viatura (58-IX-80)
N/ Morada - 2014-04-07 / 08:15
Rua das Macieiras, 220

Ermesinde
4445-502 Ermesinde
PORTUGAL (Porto)

Descarga
V/ Morada
RUA DO GALHANO, Nº 11

VARZIELA - ÁRVORE
4480-586 VILA DO CONDE
PORTUGAL (Porto)

Certificamos, que o produto se encontra de acordo com a Especificação Técnica correspondente ao(s) Artigo(s) acima mencionado(s).

Nota: A mercadoria viaja por conta e risco do cliente. Só podemos aceitar reclamações no prazo de 8 dias a contar da data da guia de remessa.
Em caso de litígio, só os tribunais do Porto servirão para julgar.
Caso não possua a Especificação Técnica relativa a este(s) Artigo(s), Por favor contacte o Departamento da Qualidade/Ambiente/Segurança.

Tem um saldo de -122 paletes.
Tem um saldo de 0 tábuas 80x130 cm.
Tem um saldo de 0 tábuas 80x120 cm.
Tem um saldo de 0 tábuas 12x112 cm.

OGCAL 06/8

CALHEIROS EMBALAGENS, S.A.
Rua das Macieiras, 220 • Apt. 4008 • 4445-502 Ermesinde • Tel.: (+351) 229 773 220 • Fax: (+351) 229 773 225 Contribuinte n.º IVA PT 500 207 976
Capital Social 2.330.000 Euros • Matriculada na C.R.C. de Valongo, com o n.º 500 207 976 • E-mail: grafica@calheiros.pt • www.calheiros.pt

Figure 72 - Company's Internal Documents: OGCAL 08/8 (Delivery Note)

Appendix 3 – Manufacturing Processes Data

Note: All presented data is based in PPC Department documents' analysis.

1 sheet =	3	packages(average)

Buffer 1

Real Buffer Capacity (Buffer 1)	70400	sheets	
Converted Buffer Capacity	704	sheets	
Lenght 1	2,7	Lenght 2	1,2
Width 1	1	Width 2	0,5
Scaling factor	800		
Area cm2	2640		
Area m2	26,4		
Coil area m2	2,25		
Max height m	6		
Plan's average lenght m	1		
Paper coil's average lenght m	1000		
Number of coils	70,4		

Manufacuring Processes Data

Cutting

Average 1	11058	packages/PO	
Average 2	3686	sheets/PO	
Average C/T (PPC Data)	6935	sheets/hour	
Conversion Factor	100		
Time to produce a sheet	0,009	min	
Time to produce a PO	57,678	min	VSM Data (C/T)
Time to produce a sheet after conversion factor	0,86518	min	Delmia Quest Data
Rejection Rate	1,32%		
Real Buffer Capacity (Buffer 2)	86400	sheets	
Converted Buffer Capacity	864	sheets	
Lenght	0,8	cm	
Width	2,7	cm	
Area cm2	1728	cm2	

Area m2	17,28 m2		
Number of sheets/pallet	5000		
Pallet area	1 m2		

Printing

Average 1	11058 packages/PO		
Average 2	3686 sheets/PO		
Average C/T (PPC Data)	2379 sheets/hour		
Time to produce a sheet	0,025 min		
Time to produce a PO	92,963 min		VSM Data (C/T)
Time to produce a sheet after conversion factor	2,52207 min		Delmia Quest Data
Rejection Rate	1.00%		
Real Buffer Capacity (Buffer 3)	84000 sheets		
Converted Buffer Capacity	840 sheets		
Lenght 1	3	Lenght 2	3
Width 1	0,4	Width 2	0,3
Area cm2	1680 cm2		
Area m2	16,8 m2		
Number of sheets/pallet	5000		
Pallet area	1 m2		

Lamination

Average 1	11058 packages/PO	
Average 2	3686 sheets/PO	
Average C/T (PPC Data)	2373,33333 sheets/hour	
Time to produce a sheet	0,025 min	
Time to produce a PO	93,185 min	VSM Data (C/T)
Time to produce a sheet after conversion factor	2,52809 min	Delmia Quest Data
Rejection Rate	1,53%	
Real Buffer Capacity (Buffer 4)	100800 sheets	
Converted Buffer Capacity	1008 sheets	

Lenght 1	1,6	Lenght 2	1,5
Width 1	1,5	Width 2	1,4
Area cm2	3600	cm2	
Area m2	36	m2	
Number of sheets/pallet	2800		
Pallet area	1	m2	

Cutting and Folding		
Average 1	11058 packages/PO	
Average 2	3686 sheets/PO	
Average C/T (PPC Data)	1776 packages/hour	
Time to produce a package	0,034 min	
Time to produce a PO	124,527 min	VSM Data (C/T)
Time to produce a package after conversion factor	3,37838 min	Delmia Quest Data
Rejection Rate	1,55%	
Real Buffer Capacity (Buffer 5)	121856 packages	
Converted Buffer Capacity	1218,56 packages	
Lenght 1	3,2 cm	
Width 1	1,7 cm	
Area cm2	4352 cm2	
Area m2	43,52 m2	
Number of packages/pallet	2800	
Pallet area	1 m2	

Closing		
Average 1	11058 packages/PO	
Average 2	3686 sheets/PO	
Average C/T (PPC Data)	4877,2 packages/hour	
Time to produce a package	0,012 min	
Time to produce a PO (Gluing Machine)	45,346 min	
Time to produce a PO (Closing Section)	90,691 min	VSM Data (C/T)
Time to produce a package after conversion factor	7,38128 min	Delmia Quest Data
Rejection Rate	1,78%	

Real Buffer Capacity (Buffer 6)	67200	packages
Converted Buffer Capacity	672	packages
Lenght 1	3	cm
Width 1	1	cm
Area cm2	2400	cm2
Area m2	24	m2
Number of packages/pallet	2800	
Pallet area	1	m2

Conveyors Average Velocity	
80	m/min
1,33	m/s

Appendix 4 – Machine's List

Section	Process	Machine
Printing	Cut	Apollo Cutter
	Print	KBA 102x142 – 4 Colors
		KBA 102x142 – 4 Colors + Polish
		KBA 120x160 – 5 Colors + Polish
Lamination	Manufacture Flute + Laminate	DDL with Filp-Flop (17)
		Double DDL (19)
Cutting and Folding	Cut and Fold	Bobst 72x102 (21)
		Bobst 102x142 (23)
		Bobst 110x160 (24)
Closing	Glue	Vega 750 (25)
		Vega 1000 (26)
		Vega 1100 (27)
		Vega 1440 (28)
		Vega 2000 (29)
		Vega 2000 + ADF (32)

Table 17 – Machine's List

Appendix 5 - Company's Manufacturing Plant Blueprint

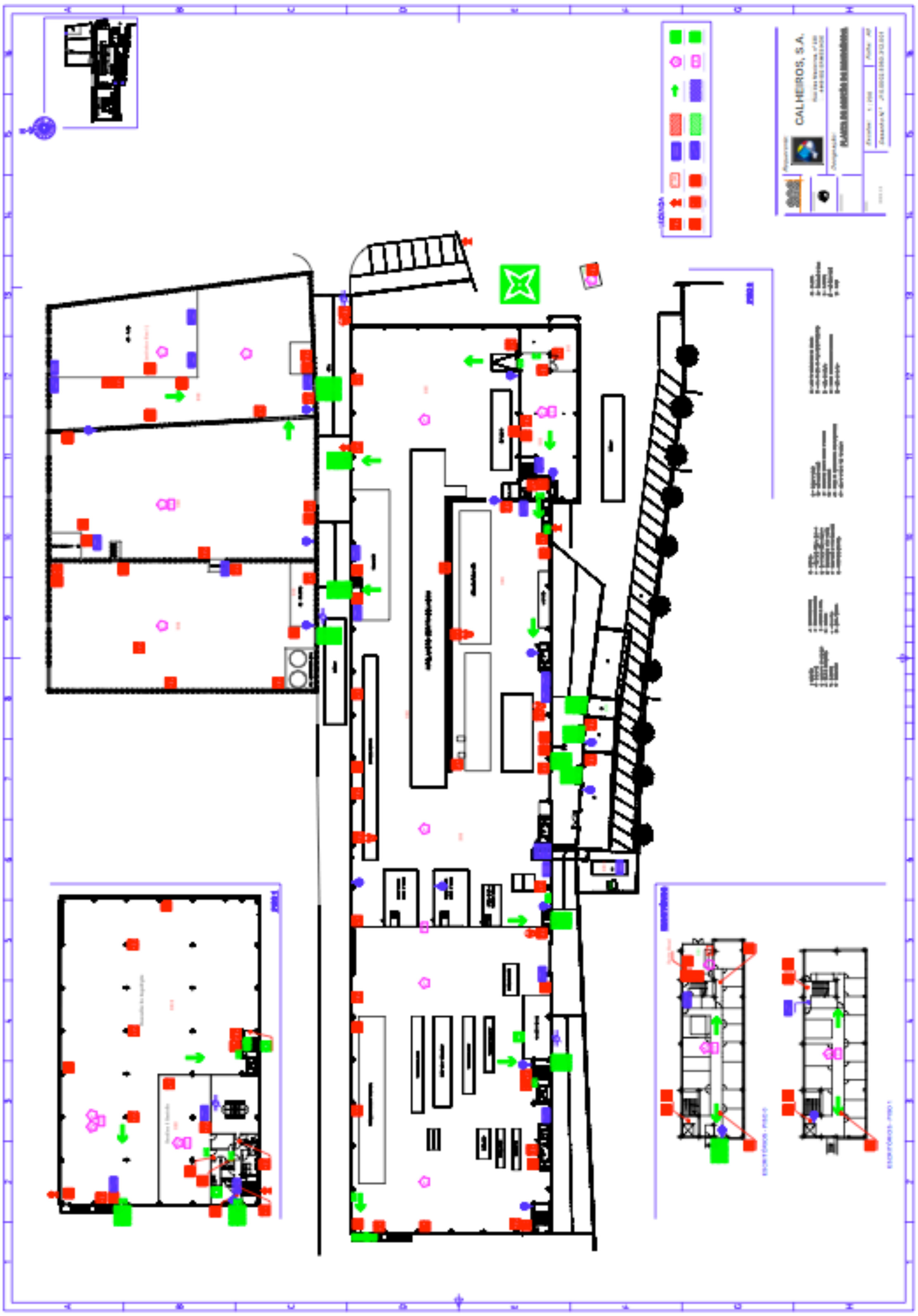

Figure 73 - Company's Manufacturing Plant Blueprint

Appendix 6 – Delmia Quest Source Data

```
# File Based Part Creation relative
# PartClassName          Creation Time   Lot Size
# Encomenda 1
Prod1                            21600                    200
# Encomenda 2
Prod2                            7200                     200
# Encomenda 3
Prod3                            14400                    200
# Encomenda 4
Prod4                            14400                    200
# Encomenda 5
Prod5                            14400                    200
# Encomenda 6
Prod6                            39600                    60
# Encomenda 7
Prod7                            3600                     30
# Encomenda 8
Prod8                            10800                    30
# Encomenda 9
Prod9                            14400                    30
# Encomenda 10
Prod10                           14400                    70
# Encomenda 11
Prod11                           7200                     40
# Encomenda 12
Prod12                           32400                    50
# Encomenda 13
Prod13                           10800                    5
# Encomenda 14
Prod14                           3600                     200
# Encomenda 15
Prod15                           14400                    200
# Encomenda 16
Prod16                           7200                     200
# Encomenda 17
Prod17                           7200                     200
# Encomenda 18
Prod18                           7200                     200
# Encomenda 19
Prod19                           36000                    60
# Encomenda 20
Prod20                           14400                    30
# Encomenda 21
Prod21                           7200                     30
# Encomenda 22
Prod22                           10800                    30
# Encomenda 23
Prod23                           14400                    70
# Encomenda 24
Prod24                           39600                    40
# Encomenda 25
Prod25                           18000                    50
# Encomenda 26
Prod26                           14400                    5
END_OF_SCHEDULE
```

Figure 74 - Delmia Quest Source Data

Day	Parts	Creation Time	
		Hour of the Day	Simulation Seconds
Day 1	Prod1	06h	21600
	Prod2	08h	7200
	Prod3	12h	14400
	Prod4	16h	14400
	Prod5	20h	14400
Day 2	Prod6	07h	39600
	Prod7	08h	3600
	Prod8	11h	10800
	Prod9	15h	14400
	Prod10	19h	14400
	Prod11	21h	7200
Day 3	Prod12	06h	32400
	Prod13	09h	10800
	Prod14	10h	3600
	Prod15	14h	14400
	Prod16	16h	7200
	Prod17	18h	7200
	Prod18	20h	7200
Day 4	Prod19	06h	36000
	Prod20	10h	14400
	Prod21	12h	7200
	Prod22	15h	10800
	Prod23	19h	14400
Day 5	Prod24	06h	39600
	Prod25	11h	18000
	Prod26	17h	14400

Table 18 - Delmia Quest Creation Time Data

Appendix 7 - Production Order Future Model

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Montagem AA13846 | **OP 19215** | Plano: 133 X 80 Ex. 4 + 0 | Ciclo: 8-A 2014/10 2014-03-07

Corte ao Contrário — **Micro - CI210 + MB**

Descricao	Papel Entrada	Papel Saida	OBS
Esquadrias	0	0	Cortante Novo - Tipos de Caixa:AA0001 Lamina: 1304 x 766 % 6.52 Verificado e aprovado por:_______________
Montagem Aprovação	0	0	Fotolito Novo - Codigo Montagem: AA13846 => CLIENTE ENVIOU LINK P/FAZER O DOWNLOAD - EMAIL 06/02/14 AC Verificado e aprovado por:_______________
Cortadeira Apollo	13,707	13,541	Lote da cartolina:_______________ Fornecedor_______________ QTD Prod._______________ Responsável:_________
Revelação Chapas	0	0	Queima e Lavagem de chapas SIM / NÃO Verificado e aprovado por:_______________
KBA 102x142-4 Cores + '	13,541	13,062	Verniz Água - Cores 4+0 Validação do arranque da produção/limpeza da linha:___________ Verificação de _______ em _______ Planos. QTD Prod.__________. Resp:___________
Onduladora Secção 070.	13,062	0	Usar Papeis: B125133 + F85133
Contra Colagem DDL c/ F	13,062	12,882	Humidade Registada:________ Responsavel:___________ Validação do arranque da produção/limpeza da linha:___________ Verificação de _______ em _______ Planos. QTD Prod.__________. Resp:___________
Bobst 102X142	12,882	12,703	Cortante nº 13846. Validação do arranque da produção/limpeza da linha:___________ Verificação de _______ em _______ Planos. QTD Prod.__________. Resp:___________
Janelas Nova	50,812	50,000	Acetato de 100 Microns - PA041406Validação do arranque da produção/limpeza da linha:___________ Verificação de _______ em _______ Caixas. QTD Prod.__________. Resp:___________ ==> Só aplicar a janela após boa secagem da contracolagem
Er[illegible]lagem	0	0	PALETE C/ FILME ESTIRÁVEL às 3000 - PA041406
Expedicao	0	0	Tem artigos associados: PA041405

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Artigos a Produzir

Artigo / Cliente	Descricao / Cliente	RefCliente / Formato	Quantidade
PA041406	CAIXA GO AFRICA (TAMPO)	TAMPO	50,000
0202	CONFEITARIA CARLOS GONÇALVES, LDA.	375 X 249 X 67 X 0	MAX:55,000

Stocks

Kgs	QTD	Artigo	Descricao	Fto1	Fto2	Corte1	Corte2	GRM	Area
3,217	13,707	CI210133	V/ Cinza 210 Grs Bobines 133 Cm	133			80	210	H02
1,818	13,062	B125133	Branco 125 Grs bobines 132,5 Cm	133			80	125	E04
1,737	18,286	F85133	Fluting 85 Grs Bobines 133Cm	133			80	85	C10
605	50,812	1000.002.001	Acetato 100 Micros FTJanela 35x20	35	20			170	

OGCAL 01/17 — 2014-02-18

Figure 75 - Future Production Order (G1)

calheiros embalagens

Montagem AA13846

OP 19215

Plano: 133 X 80 Ex. 4 + 0

Ciclo: 8-A

2014/10

2014-03-07

Corte ao Contrário

Micro - CI210 + MB

Descricao	Papel Entrada	Papel Saida	OBS
Esquadrias	0	0	Cortante Novo - Tipos de Caixa:AA0001 Lamina: 1304 x 766 % 6.52 Verificado e aprovado por:__________
Montagem Aprovação	0	0	Fotolito Novo - Codigo Montagem: AA13846 => CLIENTE ENVIOU LINK P/FAZER O DOWNLOAD - EMAIL 06/02/14 AC Verificado e aprovado por:__________
Cortadeira Apollo	13,707	13,541	Lote da cartolina:__________ Fornecedor__________ QTD Prod.__________ Responsável:________
Revelação Chapas	0	0	Queima e Lavagem de chapas SIM / NÃO Verificado e aprovado por:__________
KBA 102x142-4 Cores +	13,541	13,062	Verniz Água - Cores 4+0 Validação do arranque da produção/limpeza da linha:__________ Verificação de ______ em ______ Planos. QTD Prod.__________. Resp:__________
Onduladora Secção 070.	13,062	0	Usar Papeis: B125133 + F85133
Contra Colagem DDL c/ I	13,062	12,882	Humidade Registada:______ Responsavel:__________ Validação do arranque da produção/limpeza da linha:__________ Verificação de ______ em ______ Planos. QTD Prod.__________. Resp:__________
Bobst 102X142	12,882	12,703	Cortante nº 13846. Validação do arranque da produção/limpeza da linha:__________ Verificação de ______ em ______ Planos. QTD Prod.__________. Resp:__________
Janelas Nova	50,812	50,000	Acetato de 100 Microns - PA041406Validação do arranque da produção/limpeza da linha:__________ Verificação de ______ em ______ Caixas. QTD Prod.__________. Resp:__________ ==> Só aplicar a janela após boa secagem da contracolagem
Embalagem	0	0	PALETE C/ FILME ESTIRÁVEL às 3000 - PA041406
Expedicao	0	0	Tem artigos associados: PA041405

CÓPIA NÃO NEGOCIÁVEL
NON NEGOTIABLE COPY

Artigos a Produzir

Artigo / Cliente	Descricao / Cliente	RefCliente / Formato	Quantidade
PA041406	CAIXA GO AFRICA (TAMPO)	TAMPO	50,000
0202	CONFEITARIA CARLOS GONÇALVES, LDA.	375 X 249 X 67 X 0	MAX:55,000

CÓPIA NÃO NEGOCIÁVEL
NON NEGOTIABLE COPY

Stocks

Kgs	QTD	Artigo	Descricao	Fto1	Fto2	Corte1	Corte2	GRM	Area
3,217	13,707	CI210133	V/ Cinza 210 Grs Bobines 133 Cm	133			80	210	H02
1,818	13,062	B125133	Branco 125 Grs bobines 132,5 Cm	133			80	125	E04
1,737	18,286	F85133	Fluting 85 Grs Bobines 133Cm	133			80	85	C10
605	50,812	1000.002.001	Acetato 100 Micros FTJanela 35x20	35	20			170	

OGCAL 01/17

2014-02-18

Figure 76 - Future Production Order (G2)

calheiros embalagens

Montagem AA13846

OP 19215

Plano: 133 X 80 Ex. 4 + 0

Ciclo: 8-A

2014/10

2014-03-07

Corte ao Contrário

Micro - CI210 + MB

Descricao	Papel Entrada	Papel Saida	OBS
Esquadrias	0	0	Cortante Novo - Tipos de Caixa:AA0001 Lamina: 1304 x 766 % 6.52 Verificado e aprovado por:____________
Montagem Aprovação	0	0	Fotolito Novo - Codigo Montagem: AA13846 => CLIENTE ENVIOU LINK P/FAZER O DOWNLOAD - EMAIL 06/02/14 AC Verificado e aprovado por:____________
Cortadeira Apollo	13,707	13,541	Lote da cartolina:____________ Fornecedor____________ QTD Prod.____________ Responsável:________
Revelação Chapas	0	0	Queima e Lavagem de chapas SIM / NÃO Verificado e aprovado por:____________
KBA 102x142-4 Cores +	13,541	13,062	Verniz Água - Cores 4+0 Validação do arranque da produção/limpeza da linha:________ Verificação de ______ em ______ Planos. QTD Prod.________. Resp:________
Onduladora Secção 070.	13,062	0	Usar Papeis: B125133 + F85133
Contra Colagem DDL c/	13,062	12,882	Humidade Registada:______ Responsavel:________ Validação do arranque da produção/limpeza da linha:________ Verificação de ______ em ______ Planos. QTD Prod.________. Resp:________
Bobst 102X142	12,882	12,703	Cortante nº 13846. Validação do arranque da produção/limpeza da linha:________ Verificação de ______ em ______ Planos. QTD Prod.________. Resp:________
Janelas Nova	50,812	50,000	Acetato de 100 Microns - PA041406Validação do arranque da produção/limpeza da linha:________ Verificação de ______ em ______ Caixas. QTD Prod.________. Resp:________ ==> Só aplicar a janela após boa secagem da contracolagem
Embalagem	0	0	PALETE C/ FILME ESTIRÁVEL às 3000 - PA041406
Expedicao	0	0	Tem artigos associados: PA041405

CÓPIA NÃO NEGOCIÁVEL
NON NEGOTIABLE COPY

Artigos a Produzir

Artigo / Cliente	Descricao / Cliente	RefCliente / Formato	Quantidade
PA041406	CAIXA GO AFRICA (TAMPO)	TAMPO	50,000
0202	CONFEITARIA CARLOS GONÇALVES, LDA.	375 X 249 X 67 X 0	MAX:55,000

Stocks

Kgs	QTD	Artigo	Descricao	Fto1	Fto2	Corte1	Corte2	GRM	Area
3,217	13,707	CI210133	V/ Cinza 210 Grs Bobines 133 Cm	133			80	210	H02
1,818	13,062	B125133	Branco 125 Grs bobines 132,5 Cm	133			80	125	E04
1,737	18,286	F85133	Fluting 85 Grs Bobines 133Cm	133			80	85	C10
605	50,812	1000.002.001	Acetato 100 Micros FTJanela 35x20	35	20			170	

OGCAL 01/17

2014-02-18

Figure 77 - Future Production Order (G3)

calheiros embalagens

Montagem AA13846	OP 19215	Ciclo: 8-A
	Plano: 133 X 80 Ex. 4 + 0	2014/10 2014-03-07

Corte ao Contrário | **Micro - CI210 + MB**

Descricao	Papel Entrada	Papel Saida	OBS
Esquadrias	0	0	Cortante Novo - Tipos de Caixa:AA0001 Lamina: 1304 x 766 % 6.52 Verificado e aprovado por:________
Montagem Aprovação	0	0	Fotolito Novo - Codigo Montagem: AA13846 => CLIENTE ENVIOU LINK P/FAZER O DOWNLOAD - EMAIL 06/02/14 AC Verificado e aprovado por:________
Cortadeira Apollo	13,707	13,541	Lote da cartolina:________ Fornecedor________ QTD Prod.________ Responsável:________
Revelação Chapas	0	0	Queima e Lavagem de chapas SIM / NÃO Verificado e aprovado por:________
KBA 102x142-4 Cores +	13,541	13,062	Verniz Água - Cores 4+0 Validação do arranque da produção/limpeza da linha:________ Verificação de ________ em ________ Planos. QTD Prod.________. Resp:________
Onduladora Secção 070.	13,062	0	Usar Papeis: B125133 + F85133
Contra Colagem DDL c/ I	13,062	12,882	Humidade Registada:________ Responsavel:________ Validação do arranque da produção/limpeza da linha:________ Verificação de ________ em ________ Planos. QTD Prod.________. Resp:________
Bobst 102X142	12,882	12,703	Cortante nº 13846. Validação do arranque da produção/limpeza da linha:________ Verificação de ________ em ________ Planos. QTD Prod.________. Resp:________
Janelas Nova	50,812	50,000	Acetato de 100 Microns - PA041406Validação do arranque da produção/limpeza da linha:________ Verificação de ________ em ________ Caixas. QTD Prod.________. Resp:________ ==> Só aplicar a janela após boa secagem da contracolagem
Embalagem	0	0	PALETE C/ FILME ESTIRÁVEL às 3000 - PA041406
Expedicao	0	0	Tem artigos associados: PA041405

Artigos a Produzir

Artigo / Cliente	Descricao / Cliente	RefCliente / Formato	Quantidade
PA041406	CAIXA GO AFRICA (TAMPO)	TAMPO	50,000
0202	CONFEITARIA CARLOS GONÇALVES, LDA.	375 X 249 X 67 X 0	MAX:55,000

Stocks

Kgs	QTD	Artigo	Descricao	Fto1	Fto2	Corte1	Corte2	GRM	Area
3,217	13,707	CI210133	V/ Cinza 210 Grs Bobines 133 Cm	133			80	210	H02
1,818	13,062	B125133	Branco 125 Grs bobines 132,5 Cm	133			80	125	E04
1,737	18,286	F85133	Fluting 85 Grs Bobines 133Cm	133			80	85	C10
605	50,812	1000.002.001	Acetato 100 Micros FTJanela 35x20	35	20			170	

OGCAL 01/17 2014-02-18

Figure 78 - Future Production Order (G4)

calheiros embalagens

Montagem AA13846

OP 19215

Plano: 133 X 80 Ex. 4 + 0

Ciclo: 8-A

2014/10

2014-03-07

Corte ao Contrário — **Micro - CI210 + MB**

Descricao	Papel Entrada	Papel Saida	OBS
Esquadrias	0	0	Cortante Novo - Tipos de Caixa:AA0001 Lamina: 1304 x 766 % 6.52 Verificado e aprovado por:______________
Montagem Aprovação	0	0	Fotolito Novo - Codigo Montagem: AA13846 => CLIENTE ENVIOU LINK P/FAZER O DOWNLOAD - EMAIL 06/02/14 AC Verificado e aprovado por:______________
Cortadeira Apollo	13,707	13,541	Lote da cartolina:______________ Fornecedor______________ QTD Prod.______________ Responsável:__________
Revelação Chapas	0	0	Queima e Lavagem de chapas SIM / NÃO Verificado e aprovado por:______________
KBA 102x142-4 Cores + '	13,541	13,062	Verniz Água - Cores 4+0 Validação do arranque da produção/limpeza da linha:____________ Verificação de _______ em _______ Planos. QTD Prod.____________. Resp:____________
Onduladora Secção 070.	13,062	0	Usar Papeis: B125133 + F85133
Contra Colagem DDL c/ F	13,062	12,882	Humidade Registada:____ Responsavel:____________ Validação do arranque da produção/limpeza da linha:____________ Verificação de _______ em _______ Planos. QTD Prod.____________. Resp:____________
Bobst 102X142	12,882	12,703	Cortante nº 13846. Validação do arranque da produção/limpeza da linha:____________ Verificação de _______ em _______ Planos. QTD Prod.____________. Resp:____________
Janelas Nova	50,812	50,000	Acetato de 100 Microns - PA041406Validação do arranque da produção/limpeza da linha:____________ Verificação de _______ em _______ Caixas. QTD Prod.____________. Resp:____________ ==> Só aplicar a janela após boa secagem da contracolagem
Er lagem	0	0	PALETE C/ FILME ESTIRÁVEL às 3000 - PA041406
Expedicao	0	0	Tem artigos associados: PA041405

Artigos a Produzir

Artigo / Cliente	Descricao / Cliente	RefCliente / Formato	Quantidade
PA041406	CAIXA GO AFRICA (TAMPO)	TAMPO	50,000
0202	CONFEITARIA CARLOS GONÇALVES, LDA.	375 X 249 X 67 X 0	MAX:55,000

Stocks

Kgs	QTD	Artigo	Descricao	Fto1	Fto2	Corte1	Corte2	GRM	Area
3,217	13,707	CI210133	V/ Cinza 210 Grs Bobines 133 Cm	133			80	210	H02
1,818	13,062	B125133	Branco 125 Grs bobines 132,5 Cm	133			80	125	E04
1,737	18,286	F85133	Fluting 85 Grs Bobines 133Cm	133			80	85	C10
605	50,812	1000.002.001	Acetato 100 Micros FTJanela 35x20	35	20			170	

OGCAL 01/17 2014-02-18

Figure 79 - Future Production Order (G5)

calheiros embalagens

Montagem AA13846

OP 19215

Plano: 133 X 80 Ex. 4 + 0

Ciclo: 8-A

2014/10

2014-03-07

Corte ao Contrário

Micro - CI210 + MB

Descricao	Papel Entrada	Papel Saida	OBS
Esquadrias	0	0	Cortante Novo - Tipos de Caixa:AA0001 Lamina: 1304 x 766 % 6.52 Verificado e aprovado por:_______________
Montagem Aprovação	0	0	Fotolito Novo - Codigo Montagem: AA13846 => CLIENTE ENVIOU LINK P/FAZER O DOWNLOAD - EMAIL 06/02/14 AC Verificado e aprovado por:_______________
Cortadeira Apollo	13,707	13,541	Lote da cartolina:_______________ Fornecedor_______________ QTD Prod._______________ Responsável:___________
Revelação Chapas	0	0	Queima e Lavagem de chapas SIM / NÃO Verificado e aprovado por:_______________
KBA 102x142-4 Cores +	13,541	13,062	Verniz Água - Cores 4+0 Validação do arranque da produção/limpeza da linha:____________ Verificação de _______ em _______ Planos. QTD Prod.____________. Resp:____________
Onduladora Secção 070.	13,062	0	Usar Papeis: B125133 + F85133
Contra Colagem DDL c/ I	13,062	12,882	Humidade Registada:_______ Responsavel:____________ Validação do arranque da produção/limpeza da linha:____________ Verificação de _______ em _______ Planos. QTD Prod.____________. Resp:____________
Bobst 102X142	12,882	12,703	Cortante nº 13846. Validação do arranque da produção/limpeza da linha:____________ Verificação de _______ em _______ Planos. QTD Prod.____________. Resp:____________
Janelas Nova	50,812	50,000	Acetato de 100 Microns - PA041406Validação do arranque da produção/limpeza da linha:____________ Verificação de _______ em _______ Caixas. QTD Prod.____________. Resp:____________ ==> Só aplicar a janela após boa secagem da contracolagem
Embalagem	0	0	PALETE C/ FILME ESTIRÁVEL às 3000 - PA041406
Expedicao	0	0	Tem artigos associados: PA041405

Artigos a Produzir

Artigo / Cliente	Descricao / Cliente	RefCliente / Formato	Quantidade
PA041406	CAIXA GO AFRICA (TAMPO)	TAMPO	50,000
0202	CONFEITARIA CARLOS GONÇALVES, LDA.	375 X 249 X 67 X 0	MAX:55,000

Stocks

Kgs	QTD	Artigo	Descricao	Fto1	Fto2	Corte1	Corte2	GRM	Area
3,217	13,707	CI210133	V/ Cinza 210 Grs Bobines 133 Cm	133			80	210	H02
1,818	13,062	B125133	Branco 125 Grs bobines 132,5 Cm	133			80	125	E04
1,737	18,286	F85133	Fluting 85 Grs Bobines 133Cm	133			80	85	C10
605	50,812	1000.002.001	Acetato 100 Micros FTJanela 35x20	35	20			170	

OGCAL 01/17

2014-02-18

Figure 80 - Future Production Order (G6)